

## **A Study on Emissions from Waste Incineration in Europe: A Framework for the Waste Treatment Sector of Bangladesh**

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### **Abstract**

*The incineration of municipal waste involves the generation of climate-relevant emissions. These are mainly emissions of CO<sub>2</sub> (carbon dioxide) as well as N<sub>2</sub>O (nitrous oxide), NO<sub>x</sub> (oxides of nitrogen) NH<sub>3</sub> (ammonia) and organic C, measured as total carbon. CH<sub>4</sub> (methane) is not generated in waste incineration during normal operation. It only arises in particular, exceptional, cases and to a small extent (from waste remaining in the waste bunker), so that in quantitative terms CH<sub>4</sub> is not to be regarded as climate-relevant. CO<sub>2</sub> constitutes the chief climate-relevant emission of waste incineration and is considerably higher, by not less than 102, than the other emissions.*

*Formulas (1) and (2) are to be used for the purpose of compiling an inventory of greenhouse gas emissions, taking the following into account:*

*The incineration of 1 Mg of municipal waste in MSW incinerators is associated with the production/release of about 0.7 to 1.2 Mg of carbon dioxide (CO<sub>2</sub> output). The proportion of carbon of biogenic origin is usually in the range of 33 to 50 percent. The climate-relevant CO<sub>2</sub> emissions from waste incineration are determined by the proportion of waste whose carbon compounds are assumed to be of fossil origin. The allocation to fossil or biogenic carbon has a crucial influence on the calculated amounts of climate-relevant CO<sub>2</sub> emissions.*

*Annex 1 contains a description of a method to calculate the energy credit for the use of waste as a substitute for fossil fuel (MSW incineration plants with energy recovery). Formulas (3) and (4) are to be used for the purpose of a comparative evaluation of the climate-relevant emissions from waste incineration in relation to those of other types of energy production. A factor that has a decisive influence on the calculated amounts of climate-relevant emissions from waste incineration*

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*plants with energy utilization is the credit allowed or allowable due to the substitution of energy from fossil fuels. The latter in turn is influenced by the energy carriers used as a basis to calculate the emission factor of the power plant mix.*

*An energy transformation efficiency equal to or greater than about 25 percent results in an allowable average substituted net energy potential that renders the emission of waste incineration plants (calculated as CO<sub>2</sub> equivalents) climate-neutral due to the emission credits from the power plant mix.*

**Keywords:** emissions, waste, incineration, calculation methodology, waste treatment in Europe, MSW (Municipal Solid Waste) incineration processes.

### **The status of waste management in Bangladesh**

Methods of waste disposal have not changed in Bangladesh in over ten thousand years (BCAS, 2001). Earlier, people used to pile it and then burn it, or just bury it in some out-of-the-way place and forget about it. But today, there is too much garbage and not enough place left to throw it away. For example, Dhaka, the capital city of Bangladesh, is one of the fastest growing metropolises of the world, with an annual average growth rate of 6.6 per cent. Within the Dhaka City Corporation (DCC) limits itself, the present population is estimated at 10 million in an area of 344 sq. km (Bangladesh Bureau of statistics (BBS), 2009). The population of Dhaka, a mega city with an area of 1353 sq. kms, is estimated to be around 14 million. The population within DCC's limits generates about 4,500 metric tons of municipal solid waste per day (DCC, 2008). DCC is responsible for the management of this enormous amount of solid waste. With limited manpower and logistical resources, DCC can collect only 42 percent of the total solid waste generated every day, while the rest lies on roadsides, near open drains, and in the low-lying areas of the city. The efficiency of waste collection of the municipalities and the local governments is more or less the same in both the large and small cities of Bangladesh. Recently, the Government and some other private organizations are working on waste management and reuse as a profitable business as well as saving the ecological system of the country. This article is a study on emissions from waste incineration in Europe as well as a study material for the waste treatment sector of Bangladesh.

## **1 Nature, Magnitude and Distribution of Source**

### **1.1 Waste incineration**

The role of waste incineration differs in the countries of the world. While in the industrialized countries in Europe as well as in Japan, the USA and Canada the proportion of waste burned in waste incineration plants can be

very high (up to 100 percent), in most developing countries land filling is the more common waste management practice.

#### 1.1.1 Status of waste incineration in the various EU member states

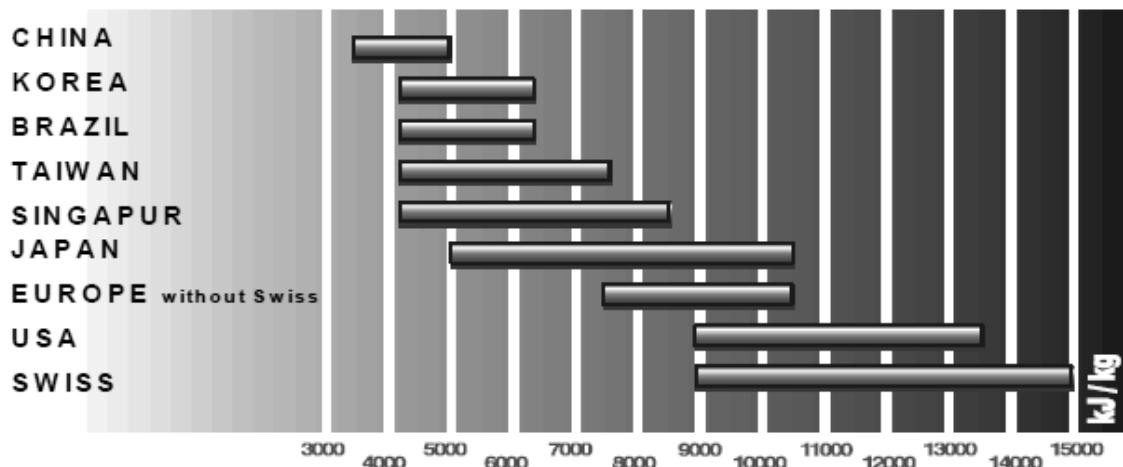
The role of municipal waste incineration in European countries varies from country to country. The compilation presented below (Table 1) shows the amounts of municipal waste incinerated in waste incineration plants of countries in Western Europe. It has been taken from an EU report on waste incineration which has been prepared for the European Commission by the Netherlands-based TNO, with 1993 as the reference year. The figures for Germany, Portugal, Luxembourg and Austria have been updated to reflect the status in 1998.

<b>Country</b>	<b>Incineration capacity per country Mg • 10<sup>6</sup> /y</b>	<b>share of incineration</b>	<b>No of MSW incinerators</b>
Austria	0.513	20%	3
Belgium	2.24	35%	24
Denmark	2.31	75%	30
Finland	0.07	4%	1
France	11.33	45%	225
Greece	0	-	0
Germany	14	32%	59
Ireland	0	-	0
Italy	1.9	7%	28
Luxembourg	0.125	95%	1
Netherlands	3.15	27%	10
Norway	0.5	n.d.	18
Portugal	0.5	n.d.	2
Spain	0.74	5%	14
Sweden	1.86	40%	21
Switzerland	2.84	100%	30
UK	3.67	2%	31
West-Europe total	45.748	-	497
EU total	42.408	-	449

The compilation presented below (figure 1) shows that the calorific values of mixed municipal solid waste in other countries differ very much and range from 3,500 to 15,000 kJ/kg.

Figure 1 - Compilation of calorific values from MSW in different countries

**Calorific values of municipal solid waste in other Countries**



Source: Martin GmbH, München company brochure "Thermische Behandlung und energetische Verwertung von Abfall", page 5, 1997

1.1.2 MSW incineration in Europe (example Germany)

The thermal treatment of solid municipal waste mostly takes place in plants equipped with grate firing systems, in individual cases, in pyrolysis, gasification or fluidized bed plants or in plants using a combination of these process stages. Residual municipal waste (domestic refuse, commercial waste similar to domestic refuse, bulky waste, road sweepings, market waste, etc.) is delivered to grate furnaces as a heterogeneous mixture of wastes. Combustible components account for a content of about 40-60 wt. percentage. Since the municipal waste incinerated is a heterogeneous mixture of wastes, in terms of sources of CO<sub>2</sub>, a distinction is drawn between carbon of biogenic and carbon of fossil origin. The calorific value of mixed waste ranges from 7,500 to 11,000 kJ/kg. The waste's carbon content is generally in the range of 28 - 40 wt. percent (averages, related to dry matter).

Treatment in incineration plants is an output-controlled process (geared, as a rule, to steam output). The combustion temperature of the gases in the combustion chamber as measured for at least two seconds after the last injection of combustion air is usually at least 850°C. The oxygen necessary for incineration is supplied via ambient air, as primary, secondary and/or tertiary air. The volume of air supplied to the incinerator is between 3,000 and 4,500 m<sup>3</sup> (dry) per Mg of waste. This gives a waste gas volume of 3,500 - 5,500 m<sup>3</sup> (dry) per Mg of waste.

At almost all municipal waste incineration plants, the heat produced during incineration is utilized for steam generation. Upon reaching the

end of the steam generator, the temperature of the waste gas has been reduced to

200°C. The steam produced in municipal waste incinerators exhibits pressures between 14 and 120 bar and temperatures between 196 and 525°C. Common steam parameters are 40 bar and 400°C. A high heat utilization efficiency can only be achieved if incineration is controlled so that the produced amounts of steam can be made available continuously for direct supply of heat and electricity to an industrial plant or for use in a heating station or cogeneration plant.

### 1. 1.3 Hazardous waste incineration in Europe (example Germany)

Hazardous waste is treated almost exclusively by incineration. Incineration must be understood here as an element of comprehensive logistics for the treatment of those wastes which due to their harmful nature have to be managed separately from municipal waste. Hazardous waste is waste requiring particular supervision, which by its nature, condition or amount poses a particular hazard to health, air and/or water or is particularly explosive, or may contain or bring forth pathogens of communicable diseases. Since hazardous waste is generated for the most part in industrial production, notably the chemical industry, it is also referred to as industrial waste or industrial residue.

Hazardous wastes occur, for example, as residues from petrochemical distillation processes, as undesirable by-products of syntheses processes of the basic organic chemical industry and the pharmaceutical industry as well as in the recovery and disposal of contaminated or post-expiration-date products such as solvents, paints or waste oil. In addition, environmental protection measures such as regulations prohibiting PCBs, CFCs or halons may generate streams of hazardous waste. The waste going to incineration is usually a mixture of waste types which may differ in composition and be present in solid, semi-liquid or liquid form. Its chemical description differs from that of municipal waste. As hazardous wastes are of varying consistency, the rotary kiln is widely used as a universally applicable incineration process. Only in exceptional cases are hazardous wastes incinerated in a conventional combustion chamber, a muffle-type furnace or other type of incineration system. The rotary kiln operates according to the parallel-flow principle, in which the material being incinerated and the combustion gas are transported in the same direction, from the cold to the hot side. With combustion temperatures between 800 and 1200°C, the residence time of solids in the rotary kiln is up to 1 hour while for the combustion gases it is only a few seconds. The waste gas generated during the combustion process is fed to an after

burning chamber, in which the minimum temperature of between 850 and 1200°C is maintained for a residence time of at least 2 seconds. The waste gas volume from this process is generally assumed to be about 7,000 m<sup>3</sup> (dry) per Mg of waste.

At nearly all hazardous-waste or residues incineration plants, the heat produced during incineration is utilized for steam generation downstream from the afterburner. Upon reaching the end of the steam generator, the temperature of the waste gas has been reduced to 200-300°C. The steam from hazardous-waste incineration exhibits pressures between 17 and 30 bar and temperatures between 250 and 300°C.

#### 1.1.4 Mono-incineration of sewage sludge in Europe (example Germany)

The system mainly used for the incineration of sewage sludge is fluidized-bed combustion. Most plants are stationary fluidized-bed furnaces, but there are also multiple-hearth furnaces and multiple-hearth fluidized-bed furnaces in use. Fluidized-bed furnaces for the incineration of sewage sludge are usually operated at combustion temperatures in the range of 850°C and 900°C. The waste gas volume from this process is generally assumed to be about 8,000 m<sup>3</sup> (dry) per Mg. of sewage sludge (dry matter). Modern plants are equipped with a steam generator downstream from incineration, producing wet steam with a pressure of 10 bar and a temperature of 180°C. Most plants use the produced steam to meet in-plant requirements (e.g. for sludge drying).

The sewage sludge delivered to the incineration plants in de-watered and/or partially dried condition usually has a water content of 50-70 percent. The calorific value of de-watered sludge averages 3,500 kJ/kg in the case of raw sludge (25 percent dry matter) and 2,500 kJ/kg in the case of digested sludge (25 percent dry matter). The content of mineral and inorganic components in sludge can be as high as 30 percent. The carbon content of sludge is generally about 30 percent.

#### 1.1.5 Co-incineration in Europe

In the future, the use of waste in plants other than waste incineration plants will be gaining in importance as a waste management option. The object of co-incinerating high-calorific waste as substitute fuel (so-called waste for energy recovery) in production (e.g. cement works, brick manufacture, blast furnace), power plants (e.g. use of sewage sludge in coal-fired power plants) and industrial boilers is the substitution of regular fuel (coal, fuel oil, etc.) and to reduce energy costs.

The climate-relevant emissions of a waste incineration plant are made up of a proportion to be allocated to the waste's contribution to the thermal output and that of the remaining regular fuel. Therefore, a proportions calculation has to be carried out to determine the proportion

of those climate-relevant emissions which result from the co-incineration of the waste.

#### 1.1.6 Other kinds of waste incineration

In most European countries, the use of incineration plants for medical waste or as crematoria is for the combustion capacity and the climate-relevant emission of flue gas stream not so relevant. For that reason this kind of incineration will not be considered in this paper.

(From a waste management perspective, merely dividing the total CO<sub>2</sub> load produced by a waste incineration plant into carbon compounds of biogenic and a carbon compound of fossil origin is too simple a view. It fails to take into account that waste of biogenic origin. It includes a fossil component from the product life-cycle. That component stems from manufacture and transport (e.g. of textiles, paper and cardboard, composites, wooden furniture ⇒ bulky waste) and needs to be allocated and charged to the product/waste fraction as climate-relevant. When reporting emissions according to the Revised 1996 IPCC Guidelines for National Greenhouse Gas for National Inventories (IPCC Guidelines) however, these emissions are included in the energy sector and should therefore not be included in the waste emission.)

## 2 Methodological Issues

### 2.1 Proposed methodology to calculate the emissions from waste incineration

(The values of the calculation shall be standardized on the following conditions: dry gas, 11 percent O<sub>2</sub>, 273 K, 1013 hPa).

Equation 1 calculates the emissions from waste incineration plants:

<p><b>EQUATION 1</b></p> $\text{Emissions } i \text{ [Mg]} = \text{emission concentration } i \text{ [Mg} \bullet 10^{-9}/\text{m}^3]$ <ul style="list-style-type: none"><li>• exhaust gas volume (dry) [m<sup>3</sup>/Mg waste]</li><li>• amount of incinerated waste [Mg waste]</li></ul>
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Where:

Emission *i* in [Mg emission]

*i* ≅ CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, NO<sub>x</sub>, CO, TOC, NH<sub>3</sub>

emission concentration *i* [Mg • 10<sup>-9</sup>/ m<sup>3</sup>] of the climate-relevant emission according to chapter 2.2

*i* ≅ CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, NO<sub>x</sub>, CO, TOC, NH<sub>3</sub>

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exhaust gas volume (dry) [ $\text{m}^3/\text{Mg}$  waste] of the incineration plant according to chapter 2.4 amount of incinerated waste [ $\text{Mg}$  waste] of a country per year.

Equation 2 calculates the emissions in  $\text{CO}_2$ -equivalent:

**EQUATION 2**

$$\text{Emissions in CO}_2\text{-equivalent } i \text{ [Mg CO}_2\text{]} = \text{Emission } i \text{ [Mg emission]} \bullet \text{GWP [Mg CO}_2\text{/Mg emission]}$$

Where:

Emissions in  $\text{CO}_2$ -equivalent  $i$  [ $\text{Mg CO}_2$ ]

Emission  $i$  [ $\text{Mg}$  emission] of Formula (1)

$i \cong \text{CO}_2, \text{N}_2\text{O}, \text{CH}_4, \text{NO}_x, \text{CO}, \text{TOC}, \text{NH}_3$

global warming potential GWP in [ $\text{Mg CO}_2/\text{Mg}$  emission] according to chapter 2.3

## 2. 2 Choice of emission factor and activity data

### Carbon Dioxide $\text{CO}_2$

The incineration of 1 Mg of municipal waste in MSW incinerators is associated with the production/release of about 0.7 to 1.2 Mg of carbon dioxide  $\text{CO}_2$ . Although this carbon dioxide is directly released into the atmosphere and thus makes a real contribution to the greenhouse effect, only the climate-relevant  $\text{CO}_2$  emissions from fossil sources are considered for the purposes of a global analysis. Since the municipal waste incinerated is a heterogeneous mixture of wastes, in terms of sources of  $\text{CO}_2$  a distinction is drawn between carbon of biogenic and carbon of fossil origin. In the literature, the proportion of  $\text{CO}_2$  assumed to be of fossil origin (e.g. plastics) and consequently to be considered as climate-relevant, is given as 33 to 50 percent.

Assuming that carbon dioxide emissions from MSW incineration average 1 Mg per Mg of waste, then of these  $\text{CO}_2$  emissions 0.33 (0.50) Mg are of fossil and 0.67 (0.50) Mg are of biogenic origin. In subsequent calculations, the proportion of climate-relevant  $\text{CO}_2$  is figured out as an average value of 0.415 Mg of  $\text{CO}_2$  per Mg of waste. The measured  $\text{CO}_2$  output content of the exhaust gas (dry) in MSW incineration plants is round about 10 Vol. percent multiply with  $5,500 \text{ m}^3$  exhaust gas volume (dry) per Mg waste multiply with  $1.9768 \text{ kg}/\text{m}^3$  density of  $\text{CO}_2$  result in  $1087 \text{ kg CO}_2$  per Mg waste. The content of C in  $\text{CO}_2$  is round about 27.3 percent resulting in  $297 \text{ kg C}$  per Mg waste.

Another way to develop the estimate of climate-relevant  $\text{CO}_2$  emission from the input, was to estimate the amount of non-biogenic carbon in the waste. Usually, three waste categories contain non-biogenic carbon:



plastics, textiles, and a combined category for rubber and leather (U.S. EPA 1997). But it is a problem to determine the real content of carbon in the heterogeneous MSW, because it is variable from day to day. The waste's carbon content of German MSW is generally in the range of 28 - 40 wt .percent (averages, related to dry matter) or 280 - 400 kg C per Mg waste.

Calculation example (Germany MSW incinerated  $14 \bullet 10^6$  Mg waste/year):

Equation 1:

Total Emission  $\text{CO}_2 = 0.415 \text{ Mg CO}_2 / \text{Mg waste} \bullet 14 \bullet 10^6 \text{ Mg waste/year}$

Total Emission  $\text{CO}_2 = 5.81 \bullet 10^6 \text{ Mg/year}$

Equation 2:

Total emission  $\text{CO}_2 = 5.81 \bullet 10^6 \text{ Mg CO}_2 / \text{year}$

For the incineration of sewage sludge in fluidized-bed plants, an emission of 1 Mg of  $\text{CO}_2$  per Mg of incinerated sludge (dry matter) is assumed.

### **Nitrous Oxide $\text{N}_2\text{O}$**

As well as the above nitrogen oxide compounds  $\text{NO}$  and  $\text{NO}_2$ , nitrous oxide  $\text{N}_2\text{O}$  is of relevance from a climate perspective. Emission levels of 1 to 12  $\text{mg/m}^3$  have been determined in individual measurements at MSW incineration plants, with an average of 1-2  $\text{mg/m}^3$ . From hazardous waste incineration plants the emission levels of 30 to 32  $\text{mg/m}^3$  have been determined in individual measurements.

$\text{NO}_2$  emission levels (individual measurements) are markedly higher in the incineration of sewage sludge in fluidized-bed plants. An average of 100  $\text{mg N}_2\text{O/m}^3$  was used for the calculations presented here.

### **Calculation example**

Equation 1:

Total Emission  $\text{N}_2\text{O} = 2 \text{ mg/m}^3 \bullet 5,500 \text{ Nm}^3 / \text{Mg waste} \bullet 14 \bullet 10^6 \text{ Mg waste/year}$

Total Emission  $\text{N}_2\text{O} = 154 \text{ Mg/year}$

Equation 2:

Total emission  $\text{CO}_2\text{-equivalent} = 154 \text{ Mg N}_2\text{O/y} \bullet 310 \text{ Mg CO}_2 / \text{Mg N}_2\text{O}$

Total emission  $\text{CO}_2\text{-equivalent N}_2\text{O} = 0.04774 \bullet 10^6 \text{ Mg CO}_2 / \text{year}$

### **Methane $\text{CH}_4$**

It can be assumed that under the oxidative combustion prevailing in waste incineration in MSW incinerators, methane is not present in the waste gas

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and consequently is not emitted. Although methane emissions may form in the waste bunker, the under pressure in the waste bunker causes them to be transported with the bunker air to the combustion chamber as primary air, to be converted there.

### **Calculation example**

Equation 1:

Total Emission CH<sub>4</sub> = 0

Equation 2:

Total emission CO<sub>2</sub>-equivalent CH<sub>4</sub> = 0

## **2.2.1 Other climate-relevant emissions from M S W incineration (NOT relevant for IPCC methodology)**

### **Carbon Monoxide CO**

During the incineration of municipal waste in MSW incinerators carbon monoxide is formed as the product of incomplete combustion. CO is an indicator substance for the combustion process and an important quality criterion for the level of combustion of the gases. As a rule, CO is measured continuously in the plants. Average CO emissions, as daily means, are below 50 mg/ m<sup>3</sup>. Plants reflecting BAT (Best Available Techniques) have daily means in the range of <10 mg/ m<sup>3</sup>.

### **Calculation example**

Equation 1:

Total Emission CO=50 mg/m<sup>3</sup> • 5,500 Nm<sup>3</sup>/Mg waste • 14 • 10<sup>6</sup> Mg waste/year

Total Emission CO=3.85 • 10<sup>3</sup> Mg/year

Equation 2:

Total emission CO<sub>2</sub>-equivalent=3.85 • 10<sup>3</sup> Mg CO/y • 3 Mg CO<sub>2</sub> /Mg CO

Total emission CO<sub>2</sub>-equivalent CO=0.01155 • 10<sup>6</sup> Mg CO<sub>2</sub> /year

### **Nitrogen Oxides NO<sub>x</sub>**

In the incineration of municipal waste in MSW incinerators nitrogen oxides NO<sub>x</sub> (NO, NO<sub>2</sub>) arise, which are formed essentially from the nitrogen contained in the waste, from the combustion process itself and from spontaneous reaction (so-called prompt NO<sub>x</sub>). As a rule, nitrogen oxide concentrations in waste gas are measured continuously at these plants. If no measures were performed at MSW incinerators for nitrogen removal, the emissions would be between 350 and 400 mg/m<sup>3</sup>. An emission level of 200 mg/m<sup>3</sup> can safely be attained if selective waste gas treatment measures are carried out (SNCR, SCR). Plants reflecting BAT (best available techniques) attain emission levels in the range of 100 to

150 mg NO<sub>x</sub>/m<sup>3</sup> when using SNCR technology and <70 mg NO<sub>x</sub>/m<sup>3</sup> when using SCR technology.

Hazardous waste incineration plants reflecting BAT attain emission levels in the range of 40 to 50 mg NO<sub>x</sub>/m<sup>3</sup> when using SCR technology.

### Calculation example

Equation 1:

Total Emission NO<sub>x</sub>=0.2 • 10<sup>3</sup> mg/m<sup>3</sup> • 5,500 Nm<sup>3</sup> /Mg waste • 14 • 10<sup>6</sup> Mg waste/year

Total Emission NO<sub>x</sub> =15.4 • 10<sup>3</sup> Mg/year

Equation 2:

Total emission CO<sub>2</sub>-equivalent=15.4 • 10<sup>3</sup> Mg NO<sub>x</sub>/y • 8 Mg CO<sub>2</sub>/Mg NO<sub>x</sub>

Total emission CO<sub>2</sub>-equivalent NO<sub>x</sub> =0.123 • 10<sup>6</sup> Mg CO<sub>2</sub> /year

### Ammonia NH<sub>3</sub>

In MSW combustion, emissions of ammonia NH<sub>3</sub> arise in particular from the use of ammonia (and also ammonia water) as an additive in waste gas treatment measures for nitrogen removal (SNCR, SCR). As a rule, emissions (determined in individual measurements) are in the range of 1-10 mg/m<sup>3</sup>; the average is assumed to be 4 mg NH<sub>3</sub>/m<sup>3</sup>.

### Calculation example

Equation 1:

Total Emission NH<sub>3</sub> =4 mg/m<sup>3</sup> • 5,500 Nm<sup>3</sup>/Mg waste • 14 • 10<sup>6</sup> Mg waste/year

Total Emission NH<sub>3</sub> =308 Mg/year

Equation 2:

Total emission CO<sub>2</sub>-equivalent NH<sub>3</sub>=n.d.

### Non-Methane Volatile Organic Compounds ( NMVOCs)

Organic compounds (organic C) in the waste gas of MSW incineration plants are measured continuously as sum parameter Total Carbon. This parameter constitutes an indicator of the level of combustion achieved in an incineration process. The emissions are subject to a limit of 10 mg/ m<sup>3</sup>, but BAT plants attain, as a rule, emission levels of 1 mg/ m<sup>3</sup>.

### Calculation example TOC

Equation 1:

Total Emission TOC= 5 mg/ m<sup>3</sup> • 5,500 N m<sup>3</sup> /Mg waste • 14 • 10<sup>6</sup> Mg waste/year

Total Emission TOC= 385 Mg/year

Equation 2:

$$\text{Total emission CO}_2\text{-equivalent} = 385 \text{ Mg TOC/y} \bullet 11 \text{ Mg CO}_2 / \text{Mg TOC}$$

$$\text{Total emission CO}_2\text{-equivalent TOC} = 0.004235 \bullet 10^6 \text{ Mg CO}_2 / \text{year}$$

### 2. 3 Estimation of the specific emissions of a Power Plant Mix Per Kwh Net (Related to total Electricity Consumption) and the Global Warming Potential (Gwp)

The specific emissions data, in mg/kWh, refer to the total amount of electricity produced in all public power plants, based on a power plant mix consisting of fossil-fuelled power plants (gas, oil, coal), nuclear power plants and power plants operated with renewable energy sources (hydro, wind, solar). They are used to make a global estimate at country level (in the present case, Germany) of the specific climate-relevant emissions from the power plant sector. For local-level analyses, instead of the electricity-related power plant mix more specific emission factors (related to the energy carrier actually being replaced) should be used in the calculations to determine the substitution effect of energy produced in waste incineration (Table 2).

**TABLE 2 EMISSION FACTORS FOR POWER PLANT MIX**

<b>Emission</b>	<b>Emission factor (power plant mix) [mg/kWh]</b>	<b>GWP (100 years) [kg CO<sub>2</sub>/kg emission]</b>
CO <sub>2</sub>	690,000	1
N <sub>2</sub> O	32	310
CO	235	3
NM VOC	13	11
NH <sub>3</sub>	7	not defined
NO <sub>x</sub>	660	8
CH <sub>4</sub>	13	21

### 2.4 exhaust gas volumes in waste incineration

Waste incineration plants have different exhaust gas volumes. This depends on the kind of the process and the composition of waste. Table 3 shows the usual exhaust gas volumes in MSW incineration plants, hazardous waste incineration plants and mono-sewage sludge incineration plants.

**TABLE 3 DIFFERENT EXHAUST GAS VOLUMES IN WASTE INCINERATION PLANTS**

	<b>Exhaust gas volume (dry)</b>
Municipal solid waste incineration	5,500 m <sup>3</sup> /Mg waste
Hazardous waste incineration	7,000 m <sup>3</sup> /Mg waste
Mono sewage sludge incineration	8,000 m <sup>3</sup> /Mg sewage sludge dry matter

### **3 Reporting and Documentation**

Transparency will be improved if all countries report estimates for their waste incineration activities separately, and indicate whether they use Tier 1, Tier 2, or Tier 3 methods.

### **4 Inventory Qa/Qc**

#### **4.1 Internal inventory Q A /Q C systems**

Quality of the data used to calculate climate-relevant emissions:

Tier 1 Emissions data for the waste gas parameters  $\text{NO}_x$ , CO, Total Organic Carbon are determined by continuous measurements in the waste incineration plants, monitored by the competent licensing authorities and published on a yearly basis.

Municipal solid waste is heterogeneous (a composite of many waste components). A determination of the climate-relevant chemical substances contained in the waste input, cannot be specifically stated, due to the fact that MSW analysis can only make individual conclusion and not general statements (due to their permanent changing as non-homogenous composition). The method proposed here for estimation of the climate-relevant total emissions is therefore based on exhaust gas measurements. These output measurements can be more exactly defined as the waste input analysis.

Tier 2 Emissions data for the waste gas parameter  $\text{CO}_2$  are calculated on the basis of waste analyses, and emissions data for  $\text{NH}_3$  and  $\text{N}_2\text{O}$  are determined by individual measurements.

Tier 3 The specific emissions factors, related to electricity consumption, for climate-relevant emissions of the power plant mix have been calculated on the basis of energy statistics and annual reports of the energy industry.

The specific waste gas volumes generated in the various treatment processes have been calculated from the operators' data on waste gas volume and the associated waste throughputs. Uncertainty is involved in determining the proportion of climate-relevant  $\text{CO}_2$  from waste incineration for the purpose of calculating total climate-relevant  $\text{CO}_2$  emissions, since the range of variation in the proportion of  $\text{CO}_2$  from waste of biogenic origin leaves ample scope for subjective judgment. One has to largely draw upon literature data from analyses for the carbon content in waste, its distribution among the various waste fractions, associated assumptions with respect to waste composition, and estimates based thereon.

The results of the calculation in Annex 1 shows, that the determination of the energy actually substituted in a country by waste incineration is likewise subject to a great deal of uncertainty. Energy-related data (calorific value of the waste, utilization of waste-derived energy) and possible efficiencies vary widely. They are determined by the site conditions and the geographical location, and have a considerable influence on the energy credits to be deducted from the total emissions determined.

The comparison of the total emissions calculated according to formulas (1) and (3) allows a criterion to be obtained for the assessment of modern waste incineration with and without energy use which takes into account the substituted primary energy potential.

Using the climate-relevant CO<sub>2</sub> equivalents calculated according to formulas (2) and (4), the climate-relevant emissions of waste incineration plants can be added up as CO<sub>2</sub> equivalents to enable an overall assessment.

CO<sub>2</sub> constitutes the chief climate-relevant emission of waste incineration and is considerably higher, by not less than 10<sup>2</sup>, than the other emissions.

An energy transformation efficiency equal to or greater than about 25 percent results in an allowable average substituted net energy potential that renders the emission of waste incineration plants (calculated as CO<sub>2</sub> equivalents) climate-neutral due to the emission credits from the power plant mix.

## **5 Conclusions**

The incineration of municipal waste involves the generation of climate-relevant emissions. These are mainly emissions of CO<sub>2</sub>, but also of N<sub>2</sub>O, NO<sub>x</sub>, NH<sub>3</sub>, and organic C, measured as total carbon. CH<sub>4</sub> is not generated in waste incineration during normal operation. It only arises in particular, exceptional, cases and to a small extent (from waste remaining in the waste bunker), so that in quantitative terms CH<sub>4</sub> is not to be regarded as climate-relevant.

In waste incineration plants, CO<sub>2</sub> constitutes the chief climate-relevant emission and is considerably higher, by not less than 10<sup>2</sup>, than the other climate-relevant emissions.

In Germany the incineration of 1 Mg of municipal waste in MSW incinerators is associated with the production/release of about 0.7 to 1.2 Mg of carbon dioxide (CO<sub>2</sub> output). The proportion of carbon of biogenic origin is usually in the range of 33 to 50 percent. The climate-relevant CO<sub>2</sub> emissions from waste incineration are determined by the proportion

of waste whose carbon compounds are assumed to be of fossil origin. The allocation to fossil or biogenic carbon has a crucial influence on the calculated amounts of climate-relevant CO<sub>2</sub> emissions.

In Germany, every waste incineration plant is equipped with facilities to utilize energy. A factor that has a decisive influence on the calculated amounts of climate-relevant emissions from waste incineration plants with energy utilization is the credit allowed or allowable due to the substitution of energy from fossil fuels. The latter in turn is influenced by the energy carriers used as a basis to calculate the emission factor of the power plant mix.

An energy transformation efficiency equal to or greater than about 25 percent results in an allowable average substituted net energy potential that renders the emission of waste incineration plants (calculated as CO<sub>2</sub> equivalents) climate-neutral due to the emission credits from the power plant mix.

## References

- Energy from waste plants 1994, General/Technical Information, ISWA Working group on thermal treatment of waste, December 1994, ISWA General Secretariat DK-1069 Copenhagen K, Denmark, reporter for Germany: Dr. D.O. Reimann, Bamberg, Pages 39-52
- EU Report: Economic Evaluation of the Draft Incineration Directive, A report produced for the European Commission DGXI, Contract No. B4 3040/95/001047/MAR/B1, December 1996, ETSU
- Reimann, D.O., Hämmerli, H.: "Verbrennungstechnik für Abfälle in Theorie und Praxis", Schriftenreihe Umweltschutz, Bamberg 1995, Ed.: Dr. D.O. Reimann, Rheinstr. 6, D-96052 Bamberg
- Wallmann, R.: "Ökologische Bewertung der mechanisch-biologischen Restabfallbehandlung und der Müllverbrennung auf Basis von Energie- und Schadgasbilanzen", Schriftenreihe des Arbeitskreises für die Nutzbarmachung von Siedlungsabfällen (ANS) e.V., ISBN 3-924618-37-2, Vol. 38, April 1999, D-40822 Mettmann
- Emissions from waste incineration: Mr. Bernt Johnke (Germany), Robert Hoppaus (IPCC/OECD/IEA), Eugene Lee (US), Bill Irving (USEPA), T. Martinsen (IPCC/OECD/IEA), and K. Mareckova (IPCC/OECD/IEA), pages 455-468.

## **Annex 1 Method for Calculation of Energy Credit for use of Msw as A Substitute for fossil fuels**

Description of a method to calculate the energy credit for the use of waste as a substitute for fossil fuel (MSW incineration plants with energy recovery)

A 1.1 Formulas to calculate the energy credit for the use of waste as a substitute for fossil fuel (MSW incineration plants with energy recovery)

Equations 3 and 4 are to be used for the purpose of a comparative evaluation of the climate-relevant emissions from waste incineration in relation to those of other types of energy production. A factor that has a decisive influence on the calculated amounts of climate-relevant emissions from waste incineration plants with energy utilisation is the credit allowed or allowable due to the substitution of energy from fossil fuels. The latter in turn is influenced by the energy carriers used as a basis to calculate the emission factor of the power plant mix.

Equation 3 corrects the total emissions from Equation 1 for the use of waste as substitute fuel (for incineration plants with energy recovery):

<p><b>EQUATION 3</b></p> $\text{Total emission } i_{\text{cor}} [\text{Mg emission}] = \text{total emission } i [\text{Mg emission}] - \text{usable/used energy [kWh]} \\ \bullet \text{ emission factor (power plant mix) [Mg emission} \bullet 10^{-9}/\text{kWh}]$
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Where

Total emission  $i_{\text{cor}}$  in [Mg emission] for incineration plants with energy recovery

$i \cong \text{CO}_2, \text{N}_2\text{O}, \text{NO}_x, \text{CO}, \text{TOC}, \text{CH}_4, \text{NH}_3, \text{etc.}$  total emission  $i$  [Mg emission] of Formula (1)

$i \cong \text{CO}_2, \text{N}_2\text{O}, \text{NO}_x, \text{CO}, \text{TOC}, \text{CH}_4, \text{NH}_3, \text{etc.}$

usable/used energy [kWh] different for every country according to A 1.2 and A 1.3 in this annex.

emission factor (power plant mix) [Mg emission  $\bullet 10^{-9}/\text{kWh}$ ] for the climate-relevant emissions of substituted energy from fossil fuel according to chapter 2.3

Equation 4 adds the calculated correct climate-relevant total emission as CO<sub>2</sub>-equivalent (for incineration plants with energy recovery):



**EQUATION 4**

$$\text{Total emission CO}_2\text{-equivalent } i_{\text{cor}} [\text{Mg CO}_2] = \text{total emission } i_{\text{cor}} [\text{Mg emission}] \bullet \text{GWP} [\text{Mg CO}_2/\text{Mg emission}]$$

Where

Total emission CO<sub>2</sub>-equivalent  $i_{\text{cor}}$  [Mg CO<sub>2</sub>]

total emission  $i_{\text{cor}}$  [Mg emission] from Formula (3)

global warming potential (GWP) [Mg CO<sub>2</sub>/Mg emission] according to chapter 2.3

**Calculation example CO<sub>2</sub> :**

Equation 3:

$$\text{Total Emission CO}_2 \text{ cor} = 5.81 \bullet 10^6 \text{ Mg /year} - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 690,000 \text{ mg CO}_2 /\text{kWh}$$

$$\text{Total Emission CO}_2 \text{ cor} = 5.81 \bullet 10^6 \text{ Mg CO}_2 /\text{year} - 6.0375 \bullet 10^6 \text{ Mg CO}_2 /\text{year (energy credit)}$$

$$\text{Total Emission CO}_2 \text{ cor} = -0.2275 \bullet 10^6 \text{ Mg CO}_2 /\text{year}$$

Equation 4:

$$\text{Total emission CO}_2 \text{ cor} = -0.2275 \bullet 10^6 \text{ Mg CO}_2 /\text{year}$$

**Calculation example NO<sub>x</sub> :**

Equation 3:

$$\text{Total Emission NO}_x \text{ cor} = 15.4 \bullet 10^3 \text{ Mg/year} - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 660 \text{ mg NO}_x/\text{kWh}$$

$$\text{Total Emission NO}_x \text{ cor} = 15.4 \bullet 10^3 \text{ Mg /year} - 5.775 \bullet 10^3 \text{ Mg/year (energy credit)}$$

$$\text{Total Emission NO}_x \text{ cor} = 9.625 \bullet 10^3 \text{ Mg NO}_x/\text{year}$$

Equation 4:

$$\text{Total emission CO}_2\text{-equivalent NO}_x \text{ cor} = 9.625 \bullet 10^3 \text{ Mg NO}_x/\text{year} \bullet 8 \text{ Mg CO}_2 /\text{Mg NO}_x$$

$$\text{Total emission CO}_2\text{-equivalent NO}_x \text{ cor} = 0.077 \bullet 10^6 \text{ Mg CO}_2 /\text{year}$$

**Calculation example N<sub>2</sub>O :**

Equation 3:

$$\text{Total Emission N}_2\text{O cor} = 154 \text{ Mg /year} - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 32 \text{ mg N}_2\text{O} /\text{kWh}$$

$$\text{Total Emission N}_2\text{O cor} = 154 \text{ Mg /year} - 280 \text{ Mg /year (energy credit)}$$

$$\text{Total Emission N}_2\text{O cor} = -126 \text{ Mg/year}$$

Equation 4:

$$\text{Total emission CO}_2\text{-equivalent N}_2\text{O cor} = -126 \text{ Mg N}_2\text{O} /\text{year} \bullet 310 \text{ Mg CO}_2 /\text{Mg N}_2\text{O}$$

$$\text{Total emission CO}_2\text{-equivalent N}_2\text{O cor} = -0.03906 \bullet 10^6 \text{ Mg CO}_2 /\text{year}$$

**Calculation example CO :**

Equation 3:

$$\text{Total Emission CO}_{\text{cor}} = 3.85 \bullet 10^3 \text{ Mg/year} - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 235 \text{ mg CO/kWh}$$

$$\text{Total Emission CO}_{\text{cor}} = 3.85 \bullet 10^3 \text{ Mg/year} - 2.05 \bullet 10^3 \text{ Mg/year (energy credit)}$$

$$\text{Total Emission CO}_{\text{cor}} = 1.8 \bullet 10^3 \text{ Mg/year}$$

Equation 4:

$$\text{Total emission CO}_2\text{-equivalent CO}_{\text{cor}} = 1.8 \bullet 10^3 \text{ Mg CO/year} \bullet 8 \text{ Mg CO}_2 / \text{Mg CO}$$

$$\text{Total emission CO}_2\text{-equivalent CO}_{\text{cor}} = 0.0054 \bullet 10^6 \text{ Mg CO}_2 / \text{year}$$

**Calculation example TOC:**

Formula (3)

$$\text{Total Emission TOC}_{\text{cor}} = 385 \text{ Mg /year} - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 13 \text{ mg TOC/kWh}$$

$$\text{Total Emission TOC}_{\text{cor}} = 385 \text{ Mg /year} - 113.75 \text{ Mg /year (energy credit)}$$

$$\text{Total Emission TOC}_{\text{cor}} = 271.25 \text{ Mg/year}$$

Formula (4)

$$\text{Total emission CO}_2\text{-equivalent TOC}_{\text{cor}} = 271.25 \text{ Mg TOC/year} \bullet 8 \text{ Mg CO}_2 / \text{Mg TOC}$$

$$\text{Total emission CO}_2\text{-equivalent TOC}_{\text{cor}} = 0.002983 \bullet 10^6 \text{ Mg CO}_2 / \text{year}$$

**Calculation example NH<sub>3</sub> :**

Equation 3:

$$\text{Total Emission NH}_3_{\text{cor}} = 308 \text{ Mg /year} - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 7 \text{ mg NH}_3/\text{kWh}$$

$$\text{Total Emission NH}_3_{\text{cor}} = 308 \text{ Mg /year} - 61.25 \text{ Mg /year (energy credit)}$$

$$\text{Total Emission NH}_3_{\text{cor}} = 246.75 \text{ Mg/year}$$

Formula 4:

$$\text{Total emission CO}_2\text{-equivalent NH}_3_{\text{cor}} = \text{n.d.}$$

**Calculation example CH<sub>4</sub> :**

Equation 3:

$$\text{Total Emission CH}_4 = 0 - 8.75 \bullet 10^9 \text{ kWh/year} \bullet 13 \text{ mg CH}_4/\text{kWh}$$

$$\text{Total Emission CH}_4 = 0 - 113 \text{ Mg/year}$$

$$\text{Total Emission CH}_4_{\text{cor}} = - 113 \text{ Mg/year}$$

Equation 4:

$$\text{Total emission CO}_2\text{-equivalent CH}_4_{\text{cor}} = - 113 \text{ Mg CH}_4/\text{year} \bullet 21 \text{ Mg CO}_2 / \text{Mg CH}_4$$

$$\text{Total emission CO}_2\text{-equivalent CH}_4_{\text{cor}} = - 0.002373 \bullet 10^6 \text{ Mg CO}_2 / \text{year}$$

**A1.2 Energy utilization efficiency of (energy supplied by) different MSW incineration plants**

In general, about 300 to 600 kWh of electricity can be produced in a MSW incineration plant from 1 Mg of municipal waste, depending on plant size, steam parameters and steam utilization efficiency. In the case of the co-generation of electricity and heat, about 1,250 kWh of heat per Mg of waste can be produced in addition and supplied to external users, depending on the incineration plant's site-dependent heat supply opportunities as well as the geographical location of the country and the (long-distance) heat utilization periods usual for that country (e.g. in Germany, 1,300-1,500 hrs/year out of a possible 8,760 hrs/year). Given ideal site conditions with favorable opportunities for utilization and supply in the form of steam, electricity and hot water or exclusively steam, the transformation/recovery efficiency of an incineration plant operating at base load can be increased to a maximum of 75-83 percent of the energy input (calorific value). In this energetically favorable case, about 2 MWh, as energy mix (electricity and heat), per Mg of waste can be produced and supplied to external users.

Actual energy transformation efficiencies are shown in the Table 4 below, ranging from a site with minimum supply of energy (electricity only) to sites with normal or optimized power/heat co-generation or exclusively supplying heat. This broad range of variation among existing plants illustrates that the energy transformation efficiency as well as the proportion of energy actually supplied by waste incinerators to substitute for fossil energy sources, as estimated on the basis of it, and the resultant emissions, are of major importance to the calculation of climate-relevant emissions.

**TABLE 4 ENERGY TRANSFORMATION/RECOVERY EFFICIENCIES (W) OF THE GROSS ENERGY INPUT OF MSW INCINERATORS**

	<b>minimum energy recovery</b>	<b>normal energy recovery</b>	<b>optimised energy recovery</b>	<b>optimised energy recovery</b>
W thermal (%)	<1	11	15 - 55	70-83
W electrical (%)	13	14	20	0
W total (%)	13	25	35 - 75	70-83

### A1.3 Status of Waste Incineration and Energy Use in Germany

A study on emissions from waste incineration in Europe

In Germany an amount of approx.  $14 \bullet 10^6$  Mg/a of residual waste is subjected to thermal treatment (status: 1999). For waste incineration plants in Germany, a theoretical gross energy content in municipal waste, in kJ/a, can be specified by multiplying an assumed average calorific value of about  $9 \bullet 10^6$  kJ per Mg of waste, roughly reflecting as a rule the calorific value of low-quality lignite, by the amount of waste incinerated annually. From this, the energy made available by waste incineration can be calculated as a function of the assumed energy transformation and utilization efficiency (the average from all plants in Germany is in the range of 20 to 35 percent) to derive conclusions as to the relevance of waste-derived energy for the substitution of climate-relevant emissions from fossil energy sources. The waste incineration plant's own energy (electricity, etc.) requirements (e.g. for waste gas treatment) are considered to be external energy which in the ideal case would be met through in-plant electricity production.

Taking Germany as an example, the credit for energy from waste incineration is calculated as follows:

Amount of residual waste subjected to thermal treatment: approx.  $14 \bullet 10^6$  Mg/a,

multiplied by an average calorific value of approx.  $9 \bullet 10^6$  kJ/Mg waste

gives  $126 \bullet 10^{12}$  kJ, or  $126 \bullet 10^6$  GJ/a;

divided by 3.6 GJ/MWh gives  $35 \bullet 10^6$  MWh/a.

Of this amount, an average of  $35 \bullet 10^6$  MWh/a  $\bullet$  0.25 total energy transformation efficiency is utilized, which brings the average allowable substituted net energy potential to  $8.75 \bullet 10^6$  MWh/a (normal energy recovery).

Based on 1992 operating data taken from the ISWA's data compilation "Energy from Waste Plants 1994", the energy supplied to external users in the form of heat and electricity by waste incineration plants in Germany (incineration capacity  $7.3 \bullet 10^6$  Mg/a) can be calculated at approx.  $4.8 \bullet 10^6$  MWh/a.

If the total emission of the non-biogenic CO<sub>2</sub> is estimate with 0.414 Mg CO<sub>2</sub> per Mg waste and the average total energy transformation efficiency of all waste incineration plants with energy recovery were optimized to reach a value equal to or greater than about 0.25, the allowable substituted net energy potential would increase to  $8.75 \bullet 10^6$  MWh/a (normal energy recovery), leading to neutrality in climate-relevant emissions from waste incineration due to the emission credits from the power plant mix.

**A 1.4 Comparison example of the climate-relevant total emission from MSW Incineration in Germany with or without energy recovery Results of the amount of calculation from Equations 1, 2, 3, and 4 - Table 5**

CO<sub>2</sub> constitutes the chief climate-relevant emission of waste incineration and is considerably higher, by not less than 10<sup>2</sup>, than the other emissions.

**TABLE 5 SW INCINERATION IN GERMANY (THROUGHPUT 14 • 10<sup>6</sup> MG/YEAR)**

Emission	W = 0	W = 25%	W = 0	W = 25%
	Total Emission (1) [Mg/year]	Total Emission (3) [Mg/year]	Total Emission (2) [Mg CO <sub>2</sub> /year]	Total Emission (4) [Mg CO <sub>2</sub> /year]
CO <sub>2</sub>	5.81 • 10 <sup>6</sup>	- 0.2275 • 10 <sup>6</sup>	5.81 • 10 <sup>6</sup>	- 0.2275 • 10 <sup>6</sup>
NO <sub>x</sub>	0.0154 • 10 <sup>6</sup>	0.009625 • 10 <sup>6</sup>	0.123 • 10 <sup>6</sup>	0.077 • 10 <sup>6</sup>
N <sub>2</sub> O	0.000154 • 10 <sup>6</sup>	0.000126 • 10 <sup>6</sup>	0.0477 • 10 <sup>6</sup>	- 0.039 • 10 <sup>6</sup>
CO	0.00385 • 10 <sup>6</sup>	0.0018 • 10 <sup>6</sup>	0.0115 • 10 <sup>6</sup>	0.0054 • 10 <sup>6</sup>
TOC	0.000385 • 10 <sup>6</sup>	0.00027125 • 10 <sup>6</sup>	0.0042 • 10 <sup>6</sup>	0.0029 • 10 <sup>6</sup>
NH <sub>3</sub>	0.000308 • 10 <sup>6</sup>	0.00024675 • 10 <sup>6</sup>	not defined	Not defined
CH <sub>4</sub>	0	0.000113 • 10 <sup>6</sup>	0	- 0.00237 • 10 <sup>6</sup>
Amount of total emission as CO <sub>2</sub> equivalent from MSW Incineration			5.99 • 10 <sup>6</sup> Mg CO <sub>2</sub> per year	-0.18 • 10 <sup>6</sup> Mg CO <sub>2</sub> per year

An energy transformation efficiency equal to or greater than about 25 percent results in an allowable average substituted net energy potential that renders the emission of waste incineration plants (calculated as CO<sub>2</sub> equivalents) climate-neutral due to the emission credits from the power plant mix.