CHAPTER 6

WASTE

6. WASTE

6.1 Overview

Disposal and treatment of industrial and municipal wastes can produce emissions of most of the important greenhouse gases (GHG). Solid wastes can be disposed of through landfilling, recycling, incineration or waste-to-energy. This chapter will deal with emissions resulting from landfilling of solid waste, treatment of liquid wastes and waste incineration. Greenhouse gas emissions from waste-to-energy, where waste material is used directly as fuel or converted into a fuel, should be calculated and reported under the Energy Chapter.

The most important gas produced in this source category is methane (CH_4). Approximately 5-20 per cent (IPCC, 1992) of annual global anthropogenic CH_4 produced and released into the atmosphere is a by-product of the anaerobic decomposition of waste. Two major sources of this type of CH_4 production are solid waste disposal to land and wastewater treatment. In each case, methanogenic bacteria break down organic matter in the waste to produce CH_4.

In previous editions of the *IPCC Guidelines* (1995), solid waste disposal sites were characterised as "open dumps" or "sanitary landfills," both of which can produce CH_4 if the waste deposited in them contains organic matter (IPCC, 1995). Open dumps were defined as shallow, open piles, generally only loosely compacted, and with no provision for control of any pollutants generated, where scavenging by animals and humans can remove much of the biodegradable wastes. Sanitary landfills, in contrast, were defined as sites specifically designed to receive wastes, which may manage these waste with practices such as compacting, use of liners, daily cover, and a final cap. Recognising that the distinction between landfills and open dumps is not always clear, the *Revised 1996 IPCC Guidelines* (this chapter) instead characterises all sites at which solid waste is deposited to land as "solid waste disposal sites" (SWDSs).

In addition to CH_4, solid waste disposal sites can also produce substantial amounts of CO_2 and non-methane volatile organic compounds (NMVOCs). Decomposition of organic material derived from biomass sources (e.g., crops, forests) which are regrown on an annual basis is the primary source of CO_2 released from waste. Hence, these CO_2 emissions are not treated as net emissions from waste in the IPCC Methodology. If biomass raw materials are not being sustainably produced, the net CO_2 release should be calculated and reported under the Agriculture and Land-Use Change and Forestry Chapters.

The process of wastewater treatment produces NMVOCs as well as CH_4 (CORINAIR, 1994). These emissions are not currently addressed in the *Revised Guidelines*. Wastewater treatment is also a source of N_2O, and a methodology for estimating N_2O emissions is included in this Chapter for human sewage. (Chapter 4 of these *Revised Guidelines* addresses N_2O emissions from agriculture, using a life-cycle emissions approach.)

Waste incineration, like all combustion, can produce CO_2, CH_4, CO, NO_x, N_2O and NMVOCs. No detailed methodologies are provided here for this source category. Instead, the section on waste incineration later in this chapter provides references to methods available for some of the gases. For CH_4 and N_2O it is only possible to report preliminary estimates and research results at this time. Further studies are needed to give more information about GHG emissions from this source category. For additional information, refer to the discussion of emissions from combustion in Chapter 1.

The sections in this chapter dealing with land disposal of solid waste and wastewater treatment give background information on the source, describe a methodology to estimate CH_4 and N_2O emissions, and discuss uncertainties associated with estimating emissions. This is consistent with the priorities under the IPCC Methodology programme. National experts are encouraged to report any other relevant emissions for which data are available, along with documentation of methods used. This will greatly assist in the development of more complete methods for future editions of *IPCC Guidelines*. For information on estimation procedures and emissions factors for other GHGs which are currently not provided in this chapter, experts should consult extensive existing literature developed by other emissions inventory programmes. Some key examples are:

- Default Emissions Factor Handbook (CORINAIR, 1994);
- Joint Atmospheric Emission Inventory Guidebook (1st edition) (EMEP/CORINAIR, 1996);
- US EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (US EPA, 1995);
- Criteria Pollutant Emission Factors for the 1985 NAPAP Emissions Inventory (Stockton and Stelling, 1987);
- Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines (US EPA, 1991; Doorn and Barlaz, 1995);
- Greenhouse Gases from Wastewater Treatment: Collection and Review of Country Specific Data and Preliminary Emission Models (Doorn and Eklund, 1995).

6.2 Methane Emissions from Solid Waste Disposal Sites

6.2.1 Introduction

The gases produced in solid waste disposal sites, particularly CH_4, can be a local environmental hazard if precautions are not taken to prevent uncontrolled emissions or migration into surrounding land. Landfill gas is known to be produced both in managed "landfill" and "open dump" sites. Both are considered here as solid waste disposal sites (SWDSs). Gas can migrate from SWDSs either laterally or by venting to atmosphere, causing vegetation damage and unpleasant odours at low concentrations, while at concentrations of 5-15 per cent in air, the gas may form explosive mixtures.

More recently, increasing attention has focused on the role of CH_4 in global atmospheric change. Methane from SWDSs contributes a significant proportion of annual global CH_4 emissions, although the estimation is subject to a great deal of uncertainty. Estimates of global CH_4 emissions from SWDSs range from less than 20 to 70 Tg/yr (Bingemer and Crutzen, 1987, US EPA, 1994), or about 5 per cent to 20 per cent of the total estimated emissions of 375 Tg/yr (IPCC, 1996) from anthropogenic sources globally.

This section will describe the processes that result in gas generation from SWDSs and the factors which affect the amount of CH_4 produced. It will then describe two methodologies for estimating CH_4 emissions from SWDSs. One of these methods is a default base method which all countries can use to estimate CH_4 emissions from different types of SWDSs. It is recommended that countries which have adequate data also estimate their emissions using the second method presented. Finally, this section discusses sources of uncertainty associated with any estimates of CH_4 emissions from SWDSs, in particular the availability and quality of data required.

6.2.2 Gas Generation from Solid Waste Disposal Sites

Organic waste in SWDSs is broken down by bacterial action in a series of stages that result in the formation of CH_4 and CO_2 (termed biogas or landfill gas) and further bacterial biomass. In the initial phase of degradation, organic matter is broken down to small soluble molecules including a variety of sugars. These are broken down further to hydrogen, CO_2, and a range of carboxylic acids. These acids are then converted to acetic acid which, together with hydrogen and CO_2, forms the major substrate for growth of methanogenic bacteria.

Landfill gas consists of approximately 50 per cent CO_2 and 50 per cent CH_4 by volume. However, the percentage of CO_2 in landfill gas may be smaller because of decomposition of substrates with a high hydrogen/oxygen ratio (e.g., fats, hemicellulose) and because some of the CO_2 dissolves in water within the site.

SWDSs are by nature heterogeneous. Microbiological investigations into site characteristics have shown that there are considerable differences between different SWDSs and even different regions within the same SWDS (Westlake, 1990). This makes it very difficult to extrapolate from observations on single SWDSs to predictions of global CH_4 emissions. Nevertheless, a better understanding of the factors thought to most significantly influence the generation of CH_4 from land disposal of solid waste can reduce the uncertainty associated with emissions estimates.

6.2.3 Factors Influencing Methane Generation in Solid Waste Disposal Sites

This section will provide a brief summary of the most significant factors affecting CH_4 generation.

Waste disposal practices

Waste disposal practices of concern for CH_4 emissions vary in the degree of control of the placement of waste and management of the site. In general, waste disposal on land will result in CH_4 production if the waste contains organic matter. Managed disposal (controlled placement of waste), in particular, tends to encourage development and maintenance of anaerobic activity.

Waste composition

The composition of waste is one of the main factors influencing both the amount and the extent of CH_4 production within SWDSs. Municipal solid waste (MSW) typically contains significant quantities of degradable organic matter. Different countries and regions are known to have MSW with widely differing compositions.

Physical factors

Moisture content is an important physical factor influencing landfill gas production. Moisture is essential for bacterial growth and metabolism, as well as for transport of nutrients and bacteria within the SWDS. The moisture content of a SWDS depends on the initial moisture content of the waste, the extent of infiltration from surface and groundwater sources, and the amount of water produced during the decomposition processes.

Temperature, pH, and nutrient availability will affect the growth rate of the bacteria. Under anaerobic conditions, landfill temperatures are generally between 25-40°C. These temperatures can be maintained within the SWDS regardless of the ambient surface temperatures. Outside of these temperatures, CH_4 production is reduced. Optimal pH for CH_4 production is around neutral (pH 7.0). Important nutrients for efficient bacterial growth include sulphur, phosphorus, sodium and calcium. The significance of these physical factors to CH_4 generation can be demonstrated within controlled laboratory conditions.

6.2.4 Methodologies to Estimate Methane Emissions from Solid Waste Disposal Sites

A number of methods have been used to estimate CH_4 emissions from solid waste disposal sites. These methods vary widely, not only in the assumptions that they make, but also in their complexity, and in the amount of data they require. This chapter will deal only with those methods that can be applied to whole regions or countries. There are some very complex models that are concerned with movement of CH_4 and other gases through individual disposal sites; however these models cannot be applied to site populations and therefore will not be considered further here.

The methods described below include the theoretical gas yield methodology, of which the default methodology is one variation, and a first order kinetics methodology.

Theoretical gas yield methodology

This is the simplest method for calculating CH_4 emissions from SWDSs. It is based on a mass balance approach, and does not incorporate any time factors into the methodology. Rather, this methodology assumes that all potential CH_4 is released from waste in the year that the waste is disposed of. Although this is not what actually occurs, it gives a reasonable estimate of the current year's emissions if the amount and composition of the waste disposed of has been relatively constant over the previous several years. If, however, there have been significant changes in the rate of waste disposal, this simple method will likely not provide a good estimate of current emissions.

Default methodology

The default methodology is a mass balance approach that involves estimating the degradable organic carbon (DOC) content of the solid waste, i.e., the organic carbon that is accessible to biochemical decomposition, and using this estimate to calculate the amount of CH_4 that can be generated by the waste. This is the approach taken by Bingemer and Crutzen (1987), who divided the world into four economic regions (the United States, Canada and Australia; other OECD countries; the Former USSR and Eastern and Central Europe; developing countries), and applied different DOC values to the waste generated within each of these regions. It is the most widely accessible, easy-to-apply methodology for calculating country-specific emissions of CH_4 from SWDSs. It requires the least amount of data to perform the calculations, and it can be modified and refined as the amount of data available for each country increases. This approach was provided as the default methodology in the *IPCC Guidelines* (IPCC, 1995).

The revised default methodology provided here modifies the *IPCC Guidelines* (IPCC, 1995) in three important ways:

- Rather than distinguishing between "landfills" and "open dumps," the methodology uses a continuum of solid waste disposal sites, characterised by the degree of waste management and depth.
- Default DOC values are provided for different waste streams so that countries can calculate the DOC content of their waste rather than relying on single default values.
- Emphasising the fact that this methodology estimates CH_4 generation rather than emission, and that oxidation often occurs in the upper layers of the waste mass and in site cover material, a CH_4 oxidation factor (OX) is included in the equation (currently equal to 0, pending the availability of further data).

The determination of annual CH_4 emissions for each country or region can be calculated from Equation 1:

EQUATION 1

Methane emissions (Gg/yr)

$$= (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1-OX)$$

where:

MSW_T = total MSW generated (Gg/yr)

MSW_F = fraction of MSW disposed to solid waste disposal sites

MCF = methane correction factor (fraction)

DOC = degradable organic carbon (fraction)

DOC_F = fraction DOC dissimilated

F = fraction of CH_4 in landfill gas (default is 0.5)

R = recovered CH_4 (Gg/yr)

OX = oxidation factor (fraction - default is 0)

Total MSW (MSW_T) can be calculated from Population (thousand persons) x Annual MSW generation rate (Gg/thousand persons/yr). Per capita MSW generation rates are provided for many countries and regions in Table 6-1. The components of MSW may vary from country to country. These differences can play an important role in the resulting emissions estimate, as each waste stream may have a different DOC content and hence a different CH_4 generation potential. In general, countries should include the following waste streams in their estimate of total MSW generated:

1. household waste;
2. yard/garden waste; and
3. commercial/market waste.

In some countries, significant quantities of organic industrial solid waste are generated. The default values in Table 6-1 should not include industrial waste or construction and demolition material. If a significant quantity of organic industrial solid waste is generated and disposed of in solid waste disposal sites, this waste should be included in the MSW generation rates and reflected in the corresponding DOC value chosen (see below under Degradable Organic Carbon).

In countries where no organised waste collection or disposal takes place in rural areas, the population considered should include only the urban population. The default values in Table 6-1 for developing countries and countries with economies-in-transition do not include rural area information.

TABLE 6-1
COUNTRY WASTE GENERATION, COMPOSITION, AND DISPOSAL DATA

Region/Country	MSW Generation Rate (kg/cap/day)	Fraction of MSW disposed to SWDS	Fraction of DOC of MSW	MSW disposal Rate (kg/cap/day)
North America			0.18-0.21	
USA[a]	2.0	0.62		1.24
Canada[b]	1.81	0.75		1.35
Oceania				
Australia[c]	1.26	1.00	0.15	1.26
New Zealand[l]	1.33	1.0	0.19	1.33
UK/Western Europe/Scandinavia			0.08-0.19	
UK[m]	1.9	0.9	0.10	1.7
Ireland[b]	0.85	1.00		0.85
Austria[d]	0.92	0.40		0.36
Belgium[b]	1.10	0.43		0.47
Denmark[b]	1.26	0.20		0.25
Finland[b]	1.70	0.77		1.3
France[b]	1.29	0.46		0.60
Germany[b]	0.99	0.66		0.65
Greece[b]	0.85	0.93		0.79
Italy[e]	0.94	0.88		0.83
Luxembourg[b]	1.34	0.35		0.47
Netherlands[f]	1.58	0.67	0.14	1.06
Norway[b]	1.40	0.75		1.05
Portugal[b]	0.90	0.86		0.78
Spain[b]	0.99	0.85		0.83
Sweden[b]	1.01	0.44		0.44
Switzerland[b]	1.10	0.23		0.25
Eastern Europe				
Poland[g]			0.15	0.54
Russia[h]	0.93	0.94	0.17	0.87

TABLE 6-1 (CONTINUED)
COUNTRY WASTE GENERATION, COMPOSITION, AND DISPOSAL DATA

Region/Country	MSW Generation Rate (kg/cap/day)	Fraction of MSW disposed to SWDS	Fraction of DOC of MSW	MSW disposal Rate (kg/cap/day)
Asia				
Japan[b]	1.12	0.38		0.43
India[i]	0.33	0.6	0.18	0.2
China[j]			0.09	0.84
Indonesia[j]			0.17	0.51
Central America				
Guatemala[j]			0.13	0.46
South America				
Brazil[j]			0.12	1.47
Peru[j]			0.15	0.98
Chile[j]			0.18	0.59
Africa				
Egypt[j]			0.21	0.40
Nigeria[j]			0.11	0.40
South Africa[k]		1.00		

Note: The values in Table 6-1 represent the best data available to the Expert Group. Note that all values may not reflect identical assumptions regarding MSW composition (and hence corresponding DOC values). Where updated national data are available corresponding to the definitions used here, they should be used for comparison instead of the values given in Table 6-1.

[a] US EPA, 1995

[b] OECD, 1995

[c] Tom Beer, CSIRO, 1996

[d] Carolin Ziegler, University of Vienna, 1996

[e] Domenico Gaudioso, ENEA Italy, 1995

[f] Hans Oonk, TNO Environment & Energy Research, The Netherlands, 1995

[g] Piotr Manczarski, Warsaw University, Poland, 1995

[h] Alexander Lifshits, Geopolis Consulting, Moscow, 1995

[i] A.D. Bhide, NEERI, India, 1995

[j] Cal Recovery Inc., California, USA - based on experience in country.

[k] Les Venter, Solid Waste Dept., Johannesburg, South Africa, 1995

[l] E. Gray, New Zealand Ministry of Environment, 1996

[m] UK DoE, 1995

The Fraction MSW Disposed to Solid Waste Disposal Sites (MSW_F) and Methane Correction Factor (MCF) reflect the way in which MSW is managed and the effect of management practices on CH_4 generation. The methodology requires countries to provide data or estimates of the quantity of waste that is disposed of to each of three categories of solid waste disposal sites (Table 6-2).

TABLE 6-2
SWDS CLASSIFICATION AND METHANE CORRECTION FACTORS

Type of site	Methane correction factor (MCF) default values
Managed	1.0
Unmanaged - deep (≥5m waste)	0.8
Unmanaged - shallow (<5m waste)	0.4
Default value - uncategorised SWDSs	0.6

1. **Managed solid waste disposal sites.** These must have controlled placement of waste (i.e., waste directed to specific deposition areas and a degree of control of scavenging and a degree of control of fires) and will include at least one of the following:
    - cover material;
    - mechanical compacting; or
    - levelling of the waste.
2. **Unmanaged-deep solid waste disposal sites.** All SWDSs not meeting the criteria of managed SWDSs and which have depths of greater than or equal to 5 metres.
3. **Unmanaged-shallow solid waste disposal sites.** All SWDSs not meeting the criteria of managed SWDSs and which have depths of less than 5 metres.

A methane correction factor (MCF) is assigned to each of these categories, as shown in Table 6-2. The MCF reflects the lower methane-generating potential of unmanaged sites. The classification recognises that some developing countries or countries with economies-in-transition may have a small number of well-managed waste disposal sites, with the majority of sites less well-managed or unmanaged, often shallow and with lower methane-generating potential. A default value is provided for countries where the quantity of waste disposed to each SWDS is not known. A country's classification of its waste sites into managed or unmanaged may change over a number of years as national waste management policies are implemented.

Degradable Organic Carbon (DOC) content is based on the composition of waste, and can be calculated from a weighted average of the carbon content of various components of the waste stream. Country/region default data for DOC, where available, are presented in Table 6-1 (in general, these values are for wet waste). It is highly recommended, however, for countries where the composition of the fractions in the waste stream are known, that these be combined with a knowledge of the carbon content of these various fractions to produce a country-specific value for DOC. It is critical that the DOC value corresponds to the waste generation/disposal rate on which the CH_4 estimate is based. For example, a country that includes industrial waste in its MSW estimate should ensure that the DOC value used reflects this component of the waste stream.

To assist countries to calculate the DOC of waste streams, a set of default DOC values for different waste types is given in Table 6-3. Note that these values are for wet (or fresh) waste.

TABLE 6-3
DEFAULT DOC VALUES FOR MAJOR WASTE STREAMS

Waste Stream		Per cent DOC (by weight)
A.	Paper and textiles	40
B.	Garden and park waste, and other (non-food) organic putrescibles	17
C.	Food waste	15
D.	Wood and straw waste[a]	30

[a] excluding lignin C

Source: Bingemer and Crutzen, 1987.

Using the values in Table 6-3, the DOC content of a country's waste could be calculated as shown in Equation 2.

EQUATION 2

$$\text{Per cent DOC (by weight)} = 0.4\ (A) + 0.17\ (B) + 0.15\ (C) + 0.30\ (D)$$

where:

A = per cent MSW that is paper and textiles

B = per cent MSW that is garden waste, park waste or other non-food organic putrescibles

C = per cent MSW that is food waste

D = per cent MSW that is wood or straw

Fraction dissimilated DOC (DOC_F) is the portion of DOC that is converted to landfill gas. To date, estimates of how much carbon may be dissimilated have relied on a theoretical model that varies only with the temperature in the anaerobic zone of a landfill: $0.014T + 0.28$, where T = temperature (Tabasaran, 1981). If one assumes that the temperature in the anaerobic zone of a SWDS remains constant at about 35°C, regardless of ambient temperature (Bingemer and Crutzen, 1987), this method yields a figure of 0.77 dissimilated DOC. This value is currently under review.

Recovered CH_4 (R) is the amount of CH_4 that is captured for flaring or use. No default values are provided for the quantity of CH_4 recovered, as this value is country-specific. See Section 6.2.6 below for more information.

Oxidation Factor (OX) accounts for the CH_4 that is oxidised in the upper layers of the waste mass and in cover material, where oxygen is present. Because the default methodology relies on an estimate of CH_4 generation, it is important to recognise the oxidation may reduce the quantity of CH_4 generated that is ultimately emitted. A number of researchers are investigating and quantifying the effects of CH_4 oxidation in waste disposal sites. However, as yet there is no internationally accepted factor that can be applied to account for CH_4 oxidation. The CH_4 oxidation factor in the equation has therefore been set equal to 0, pending the availability of new data. A better understanding of the factors influencing CH_4 oxidation, and more accurate quantification of it, may allow for a revised oxidation factor (or default values) in future editions of the *IPCC Guidelines*. It is important that the oxidation factor be applied after subtraction of CH_4 recovered, as this CH_4 is generally pulled from well below the surface of the SWDS, before oxidation can occur.

It is proposed that the default methodology, based on the theoretical gas yield methodology developed by Bingemer and Crutzen (1987), remain as the methodology that can be used by all countries to calculate CH_4 emissions from their SWDSs. The Workbook provides a detailed step-by-step version of this methodology.

Theoretical first order kinetics methodologies

More complex methods for estimating CH_4 emissions from SWDSs acknowledge the fact that CH_4 is emitted over a long period of time rather than instantaneously. A kinetic approach therefore needs to take into account the various factors which influence the rate and extent of CH_4 generation and release from SWDSs. A number of countries have applied this or similar modelling approaches to their own situation (Aitchison et al., 1996; UK, DOE, 1993; Van Amstel et al., 1993; Environment Canada, 1992).

First Order Decay Model

A first order decay model (Equation 3) can be used to model the rate of CH_4 generation over time. This approach has been used extensively to model landfill gas generation rate curves for individual landfills. It can also be used to model gas generation for a set of SWDSs to develop country emissions estimates or can be applied in a more general way to entire regions.

EQUATION 3

$$Q = L_O \, R \, (e^{-kc} - e^{-kt})$$

where:

Q = methane generated in current year (m^3/yr)

L_0 = methane generation potential (m^3/Mg of refuse)

R = average annual waste acceptance rate during active life (Mg/yr)

k = methane generation rate constant (1/yr)

c = time since SWDS closure (yr)

t = time since SWDS opened (yr)

Methane generation potential (L_o). The methane generation potential depends upon the composition of the waste. Values for L_o can vary widely, and are difficult to estimate accurately for a particular SWDS or set of SWDSs. L_o values may range from less than 100 to over 200 m^3/Mg.

Quantity of waste landfilled (R). This is the average annual waste acceptance rate during the SWDS's active life.

Methane generation rate constant (k). This value is based on the environment in which the SWDS is located. Higher k values are associated with greater moisture in the

SWDSs and other factors discussed in Section 6.2.3 above. Values for k may range from less than 0.005 per year to 0.4 per year (LANDTEC, 1994; US EPA 1991).

Time since SWDS closure (c). This is the length of time in years, not including the year of closure, since the SWDS stopped accepting waste.

Time since initial refuse replacement (t). This is the length of time in years since the SWDS began to accept waste.

Countries with sufficient data on annual waste disposal to SWDSs are encouraged to apply the derivative of the first order decay model (Equation 4), to provide a comparison to the default methodology as well as to test the feasibility of including this approach in future inventories guidelines.

To allow for variances in annual acceptance rates, the derivative of Equation 3 with respect to t can be used to estimate CH_4 generation from waste landfilled in a single year (R_x). In this equation, the variable t is replaced with T-x, which represents the number of years the waste has been in the SWDS. The resulting equation thus becomes:

EQUATION 4

$$Q_{T,x} = k \, R_x \, L_O \, e^{-k(T-x)}$$

where:

$Q_{T,x}$ = the amount of methane generated in the current year (T) by the waste R_x

x = the year of waste input

R_x = the amount of waste disposed in year x (Mg)

T = current year

In order to estimate the current emissions from waste placed in all years, Equation 4 can be solved for all values of R_x and the results summed (see Equation 5).

EQUATION 5

$$Q_T = \Sigma Q_{T,x}$$

for x = initial year to T

6.2.5 Sources of Uncertainty

There are two areas of uncertainty in the estimate of CH_4 emissions from solid waste disposal sites: (1) the uncertainty attributable to the method; and (2) data uncertainty.

Uncertainty attributable to the method. As discussed previously, the default methodology assumes that waste disposal into solid waste disposal sites is relatively constant and that the CH_4 generated by the waste is released in the same year the waste is deposited. However, if waste disposal into solid waste disposal sites is increasing over time, then the default method will overestimate CH_4 emissions. For example, it can be shown that if waste disposal into solid waste disposal sites is increasing at about 2 per cent per year over a 20- to 30-year period, then the default method will overestimate emissions by about 20-25 per cent. This is the principal type of uncertainty attributable to the default methodology itself. The amount of waste disposed of is therefore a sensitive parameter in this default methodology.

Data uncertainty. This source of uncertainty is simply the uncertainty attributable to each of the data inputs. In the case of the default methodology, this includes the uncertainty in the estimates for each of the factors used in Equation 1 (e.g., total MSW generated, fraction of MSW disposed to solid waste disposal sites). Although the uncertainty in any single one of these factors may be relatively large, if the sources of uncertainty for one factor are not related to the uncertainty for the other factors, then the uncertainty of the overall CH_4 emissions estimate can remain relatively low. For example, if the values for each of the factors used in Equation 1 are assumed to have an uncertainty of ± 10 per cent, then the overall uncertainty in the CH_4 emissions estimate will be about ± 20 per cent. If the uncertainty for each factor increases by ± 20 per cent, then the overall uncertainty in the CH_4 emissions estimate increases to ± 40-50 per cent.

The following key uncertainties related to the data are discussed further below:

- The quantity and composition of landfilled waste;
- The quantity of CH_4 that is actually *generated* from the waste in the SWDS;
- The quantity of CH_4 that is actually *emitted* to the atmosphere.

Waste quantity and composition: The quality of CH_4 emissions estimates is directly related to the quality and availability of the waste management data used to derive these estimates. However, an accurate knowledge of the quantity and composition of wastes already in place may not be available. For most countries, limitations on funds available will prevent extensive investigations of old and smaller sites. It is therefore more cost-effective to concentrate efforts on improving the quality of data being collected on existing landfilling operations, including total waste quantity as well as more detailed site-specific data.

Quantity of methane generated: The degradable organic carbon (DOC) content of waste is an essential component in all calculations of CH_4 generated, and small variations in the assumed values for DOC can result in large variations in the overall estimate of CH_4 emissions. Different countries have widely differing MSW compositions and therefore DOC content. Both the rate and the extent of degradation of the various waste fractions need to be taken into account where data are available. Waste management practices also have significant effects on CH_4 generation, for example the method of landfilling and the water management practices. Future changes in waste management practices may change the composition of waste to SWDSs considerably, resulting in different CH_4 emissions levels.

Quantity of methane generated that is emitted to the atmosphere: The main uncertainty influencing the quantity of CH_4 emitted is the degree of oxidation that occurs as the gas diffuses through the landfill cover material. The presence, thickness, and other characteristics of SWDS cover materials can play a large role in determining the quantity of CH_4 ultimately emitted from a site.

6.2.6 Flaring and Gas Recovery Schemes

Flaring and gas recovery schemes successfully reduce CH_4 emissions from SWDSs. Any national inventory of CH_4 emissions from SWDSs must therefore take into account the reductions achieved by these practices.

For sites recovering CH_4 for energy use, the quantity of gas utilised is generally well documented. Estimates of the extent of flaring are more difficult to achieve with accuracy, and generally have to be estimated from a knowledge of the state of SWDS management within the country. If data on gas flaring are not readily available for a country, the following steps might be useful in development of this information:

1. Creation of an inventory of gas flares purchased in the country for use with landfill gas, including year purchased, estimated useful life, and flow rates.
2. Use of this inventory to estimate quantity of landfill gas flared each year.

6.2.7 Conclusion

A default methodology is presented here that allows simple calculation of CH_4 emissions from SWDSs by all countries. Countries are encouraged to use more sophisticated methods that incorporate country-specific data, if available. In particular, countries with sufficient data are encouraged to apply the first order decay model presented in Section 6.2.4 above, and compare the results to the basic default approach. If such data are not available, countries are encouraged to collect data for future application of a first order methodology. The additional information required includes: i) the CH_4 generation potential of the waste; ii) the rate at which CH_4 is generated from the waste each year; iii) the year of waste input; and iv) the amount of waste disposed of to SWDSs each year.

6.3 Methane Emissions from Wastewater Handling

6.3.1 Introduction

Methane production from wastewater handling (WWH) under anaerobic conditions is estimated to range from 30 to 40 teragrams per year (Tg/yr). This represents 8 to 11 per cent of total global anthropogenic CH_4 emissions estimated at 375 Tg/yr. Industrial WWH sources are estimated to be the major contributor to WWH emissions, accounting for 26 to 40 Tg/yr. Domestic and commercial WWH is estimated to emit approximately 2 Tg/yr (IPCC, 1995; US EPA 1994).

Wastewater can produce CH_4 if it is handled anaerobically. Anaerobic methods are used to handle wastewater from municipal sewage and from food processing and other industrial facilities, particularly in developing countries. In contrast, developed countries typically use aerobic processes for municipal wastewater treatment or anaerobic processes in enclosed systems where CH_4 is recovered and utilised.

This section provides the default methodology for estimating CH_4 emissions from WWH.

6.3.2 Background

Handling of wastewater and its residual solids by-product (sludge) under anaerobic conditions results in CH_4 production. The extent of CH_4 production depends primarily on the following factors:

A) Wastewater Characteristics

The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are the BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand). Under the same conditions, wastewater with higher COD (or BOD) concentrations will generally yield more CH_4 than wastewater with lower COD (or BOD) concentrations.

B) Handling Systems

Handling systems vary in the environment that they provide for CH_4 production. Systems that provide anaerobic environments will generally produce CH_4 whereas systems that provide aerobic environments will normally produce little or no methane.

For example, the depth of a lagoon treatment system is a critical factor in CH_4 production. Shallow lagoons, less than 1 metre in depth, generally provide aerobic conditions and little CH_4 is likely to be produced. Lagoons deeper than about 2-3 metres will generally provide anaerobic environments and significant methane production is expected.

C) Temperature

With increases in temperature, the rate of CH_4 production increases. This is especially important in uncontrolled systems and in warm climates. CH_4 production typically requires a temperature higher than 15°C. Fermentation and thus CH_4 production is negligible at temperatures below 15°C, at which point the lagoon serves principally as a sedimentation tank (Gloyna, 1971). Below 15°C significant amounts of CH_4 will be produced only in instances where sedimentation and extended sludge retention occur.

Other factors that influence CH_4 generation in wastewater are retention time, degree of wastewater treatment, and other site specific characteristics.

D) BOD vs. COD

The BOD (Biochemical Oxygen Demand) concentration indicates only the amount of carbon that is aerobically biodegradable. The standard measurement for BOD is a 5-day test[1], denoted as BOD_5. The time period used in the BOD indicates whether only easily biodegradable materials or more resistant compounds are taken into account. COD (Chemical Oxygen Demand) measures the total material available for oxidation (both biodegradable and non-biodegradable). Since the BOD is an aerobic parameter, it may be less appropriate for determining the organic components in anaerobic environments. Also, both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater. Although BOD is the more

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[1] A seven day test, denoted as BOD_7, is used in some countries instead of BOD_5. The conversion between BOD_5 and BOD_7 is dependent on the characteristics of the wastewater. Experts within individual countries should be consulted to obtain appropriate conversion coefficients.

frequently reported parameter, reported COD/BOD ratios can be used to determine the COD if the BOD is known.[2]

6.3.3 Methodology for Wastewater Handling

Wastewater handling systems involve processes that transfer wastewater from its source to a disposal site. In most developed countries, wastewater treatment systems are used to chemically or biologically stabilise the wastewater before disposal. In many developing countries however, wastewater receives little or no formal treatment and is simply handled by transporting untreated wastewater to a disposal site.

Formal wastewater treatment methods can be classified as primary, secondary, and tertiary treatment. In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation by micro-organisms. These may include aerobic and anaerobic stabilisation ponds, trickling filters, and activated sludge processes. Tertiary treatment processes are used to further purify the wastewater of contaminants and pathogens. This is achieved using one or a combination of processes, including maturation/polishing ponds, advanced filtration, carbon adsorption, ion exchange, and disinfection.

Sludge is produced in both the primary and secondary stages of treatment. Sludge that is produced in primary treatment consists of solids that are removed from the wastewater. Sludge produced in secondary treatment is a result of biological growth in the biomass, as well as the collection of small particles (Lexmond and Zeeman, 1995). This sludge must be treated further before it can be safely disposed of. Methods of sludge treatment include aerobic and anaerobic stabilisation (digestion), conditioning, centrifugation, composting, and drying. *Anaerobic* stabilisation will produce CH_4.

6.3.4 Wastewater Handling Methods in Developed and Developing Countries

Wastewater handling methods differ between developed and developing countries. The most common methods of wastewater handling in developed countries are *aerobic* wastewater treatment plants and lagoons (Lexmond and Zeeman, 1995). To avoid high discharge fees, many large industrial facilities pretreat their wastewater before releasing it into the sewage system. There is also an increasing trend towards anaerobic treatment systems, which can be cheaper and produce less sludge than aerobic systems.

The degree of wastewater treatment is variable in most developing countries. Most industrial wastewater is discharged directly into local bodies of water, and only a few major industries have comprehensive in-plant treatment facilities. Less than half of municipal wastewater produced is collected in a sewage system. Collected wastewater is usually discharged into unmanaged lagoons or waterways; in coastal cities it is discharged directly into the ocean. In many cases, the domestic wastewater handling facilities are pit

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[2] Lexmond and Zeeman estimated a minimum value of the wastewater COD/BOD ratio to be 1.70 (Lexmond and Zeeman 1995). The COD/BOD ratio may vary significantly depending upon the characteristics of the wastewater. This is especially true for industrial wastewater which may include inorganic oxidisable materials. Some countries report BOD_7 (or other) values rather than BOD_5 values. In this case, domestic wastewater experts should be consulted to convert the available BOD data into the BOD_5 form.

latrines. Table 6-4 presents the main wastewater handling methods in developed and developing countries.

Wastewater streams

Wastewater originates from a variety of domestic and industrial sources. Domestic wastewater streams include wastewater from toilets, bathrooms, kitchens, and in some cases, urban run-off. Industry classifies sources of wastewater into different industrial sectors (Lexmond and Zeeman, 1995), for example:

- Food and Beverages
- Paper and Pulp
- Textile
- Petrochemical
- Fertiliser
- Iron and Steel
- Non-Ferrous Metals
- Miscellaneous

Assessment of CH_4 production potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater, and the propensity of the industry to treat their wastewater in anaerobic lagoons. Using these criteria, Doorn and Eklund (1995) prioritised industrial wastewater sources with high CH_4 gas production potential. These are characterised as follows:

- Paper and Pulp manufacture
- Slaughterhouses
- Alcohol, Beer, Starch
- Organic Chemicals
- Others (vegetable oil production, textiles, rubber, petroleum refineries, fruits and vegetables)

Both the paper and pulp industry and the meat and poultry processing industries produce large volumes of wastewater that contain high levels of degradable organics. Additionally, both industries utilise large facilities that often have their own wastewater handling systems. The meat and poultry processing facilities commonly employ anaerobic lagoons to treat their wastewater, while the paper and pulp industry is known to use lagoons.

The non-animal food and beverage industries collectively produce considerable amounts of waste water with significant BOD levels.

TABLE 6-4
METHODS OF WASTEWATER HANDLING

Handling Method	Exceptions to Expected CH_4 Production
Mostly aerobic disposal and handling methods (little or no CH_4 production)	
Developing countries	
• Open Pits/Latrines	• Pits/latrines may produce methane when temperature and retention time are favourable
• Aerobic shallow ponds	• Aerobic shallow ponds over 3 metres deep may produce methane
• River Discharge	• Stagnant, oxygen-deficient rivers may allow for anaerobic decomposition
Developed countries	
• Sewer systems with aerobic treatment	• Poorly designed or managed aerobic treatment systems produce methane
Mostly anaerobic disposal and handling methods (high CH_4 production)	
Developing countries	
• Anaerobic deep ponds • Sewer systems with anaerobic treatment	• Poorly designed or managed anaerobic systems may allow for aeration and reduced methane production
Developed and developing countries	
• Septic Tanks	• Frequent solids removal reduces methane production
Anaerobic Methods with Methane Recovery (mainly for sludge handling)	
Primarily developed countries	

6.3.5 Methodology for Estimating Emissions from Wastewater Handling

Methane emissions from wastewater handling should be calculated for two different wastewater and resulting sludge types:

1 Domestic Wastewater.

2 Industrial Wastewater.

3 Domestic Sludge.

4 Industrial Sludge.

For each category, the method for estimating CH_4 emissions from wastewater handling requires three basic steps:

Step 1 - Determine the total amount of organic material in the wastewater produced for each wastewater handling system. The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material of the wastewater. The most common parameters used to measure the degradable organic component (DC) of the wastewater are the BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand). Data permitting, COD is the recommended parameter for estimating the DC of wastewater. The DC indicator, usually indicated in units of mass DC per unit volume (e.g., kg COD per m^3 wastewater) is multiplied by the volume of the source of wastewater (e.g., industry or domestic) to estimate the total amount of organic wastewater produced.

Step 2 - Estimate emissions factors for each wastewater handling system in kg CH_4 per kg DC. The emissions factors depend on the fraction of wastewater managed by each wastewater handling method, maximum CH_4 producing capacity of the wastewater, and the characteristics of the wastewater handling process (principally, the degree to which it is anaerobic).

Step 3 - Multiply the emissions factors for each wastewater handling system by the total amount of organic material in the wastewater produced for each system, and sum across the wastewater systems to estimate total CH_4 emissions.

Approach for Estimating Methane Emissions from Wastewater and Wastewater Sludge Handling

This approach is adapted from Doorn and Ecklund (1995) and Lexmond and Zeeman (1995).

Step 1 -Total Organic Wastewater and Sludge

The greenhouse gas (GHG) generation potential of the wastewater is driven by the organic content of the wastewater stream and the volume of wastewater. For the categories of wastewater types defined (domestic and industrial), the following is the method for estimating the total organic wastewater (TOW):

<u>Domestic</u>

Data needed are:

1. Degradable organic component (DC) indicator in kg DC per 1000 persons per year. For domestic wastewater and sludge, BOD is the recommended DC indicator. Although COD is considered a more appropriate indicator for the organic component of the waste, BOD is the more frequently reported indicator for domestic wastewater. Consequently, the use of BOD estimates will result in more precise calculations than when COD is used. (Default BOD values are provided for different regions in Table 6-5).
2. Country population in thousands (developing countries may choose to estimate wastewater and sludge handling emissions based only on the urban population of the country if wastes produced in rural areas decompose in an aerobic environment - see Table 6-4 for a list of anaerobic and aerobic handling methods).
3. Fraction of BOD removed as sludge.

Equation 6 presents the total domestic organic wastewater (TOW_{dom}) calculation.

EQUATION 6

$$TOW_{dom} = P \times D_{dom} \times (1 - DS_{dom})$$

Equation 7 presents the total domestic organic sludge (TOS_{dom}) calculation.

EQUATION 7

$$TOS_{dom} = P \times D_{dom} \times DS_{dom}$$

where:

TOW_{dom} = total domestic/commercial organic wastewater in kg BOD/yr

TOS_{dom} = total domestic/commercial organic sludge in kg BOD/yr

P = population in 1000 persons

D_{dom} = domestic/commercial degradable organic component in kg BOD/1000 persons/yr

DS_{dom} = fraction of domestic/commercial degradable organic component removed as sludge

Industrial

Data needed are:

1. Degradable organic component (DC) indicator in kg DC per m^3 of industrial wastewater/sludge produced per unit product. For industrial wastewater and sludge streams COD is the appropriate DC indicator. Data on COD values should be available in most countries. It is recommended that country-specific information, if available, be used. Default COD values are provided for different industries by region in Table 6-6. (Although the default values in Table 6-6 are provided by region, in most cases the default values are based on estimates for a single country within each region.)
2. Wastewater produced per unit product by industry in m^3/tonne of product. Default values are provided in Table 6-6. (Although the default values in Table 6-6 are provided by region, in most cases the default values are based on estimates for a single country within each region.)
3. Total industrial output in tonnes per year.
4. Fraction of COD removed as sludge.

Equation 8 presents the total organic wastewater (TOW_{ind}) calculation for a particular industry.

EQUATION 8

$$TOW_{ind} \text{ (kg COD/yr)} = W \times O \times D_{ind} \times (1 - DS_{ind})$$

Equation 9 presents the total organic sludge (TOS_{ind}) calculation for a particular industry.

EQUATION 9

$$TOS_{ind}\ (kg\ COD/yr) = W \times O \times D_{ind} \times DS_{ind}$$

where:

TOW_{ind} = total industrial organic wastewater in kg COD/yr

TOS_{ind} = total industrial organic sludge in kg COD/yr

W = wastewater consumed in m^3/tonne of product

O = total output by selected industry in tonnes/yr

D_{ind} = industrial degradable organic component in kg COD/m^3 wastewater

DS_{ind} = fraction of industrial degradable organic component removed as sludge

Step 2 - Emissions Factors

To calculate emissions factors for each wastewater and sludge type, a weighted average of methane conversion factors (MCF) is calculated using estimates of wastewater managed by each wastewater handling method. The average MCF is then multiplied by the maximum methane producing capacity (B_o) of the wastewater type.

- *Maximum methane producing capacity (B_o)*: The methane producing potential, B_o, is the maximum amount of CH_4 that can be produced from a given quantity of wastewater or sludge. The CH_4 producing potential varies by the composition of the wastewater/sludge and its degradability. The default (theoretical) value for B_o is 0.25 kg CH_4/kg BOD for wastewater and for sludge (Lexmond et al., 1995).[3]
- *Fraction of wastewater treated by certain handling systems (WS%)*: These are the fractions of wastewater treated by a specific handling system, i.e., aerobic or anaerobic. Country specific estimates for WS should be used where available. Default estimates of WS per cent for different countries are provided in Table 6-7 to 6-9.
- *Fraction of sludge treated by certain handling systems (SS%)*: These are the fractions of sludge treated by a specific handling system, i.e., aerobic or anaerobic. Country-specific estimates for SS should be used where available.
- *Methane conversion factor: The amount of methane that is actually emitted depends on* the CH_4 conversion factor. The MCF defines the portion of CH_4 producing potential (B_o) that is achieved. The MCF varies between 0.0 for a completely aerobic system to 1.0 for a completely anaerobic system. Countries should contact wastewater experts to

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[3] B_o is expressed in units of kg CH_4/kg DC, where DC is the indicator of degradable component of the waste (either COD or BOD). By definition, BOD is less than or equal to COD; the maximum BOD possible is, in fact, the COD. Therefore, when estimating the maximum CH_4 producing potential from BOD or COD, the maximum potential CH_4 produced per unit of BOD is equivalent to the maximum potential CH_4 produced per unit of COD. This value is 0.25 kg CH_4/kg COD.

determine MCFs. If no data are available, as a default, use 0 for *aerobic* systems, and 1.0 for *anaerobic*.[4]

Since aerobic and anaerobic handling are the only handling systems considered, the CH_4 conversion rate can be used to characterise a broad range of systems falling between aerobic and anaerobic handling systems.

Equation 10 presents the emission factor calculation for wastewater:

EQUATION 10

$$EF_i = B_{oi} \times \sum (WS_{ix} \times MCF_x)$$

where:

EF_i = emission factor (kg CH_4 /kg DC) for wastewater type (e.g., fertiliser industry, domestic, etc.)

B_{oi} = maximum methane producing capacity (kg CH_4/kg DC) for wastewater type i

WS_{ix} = fraction of wastewater type i treated using wastewater handling system x

MCF_x = methane conversion factors of each wastewater system x

Equation 11 presents the emission factor calculation for sludge:

EQUATION 11

$$EF_j = B_{oj} \times \sum(SS_{jy} \times MCF_y)$$

where:

EF_j = emission factor (kg CH_4 /kg DC) for sludge type j (e.g., fertiliser industry wastewater, domestic wastewater, etc.)

B_{oj} = maximum methane producing capacity (kg CH_4/kg DC) for sludge type j

SS_{jy} = fraction of sludge type j treated using sludge handling system y

MCF_y = methane conversion factors of each sludge handling system y (See footnote 4)

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[4] If sludge is disposed of in landfills then the resulting emissions are already accounted for in the IPCC/OECD SWDS emission methodology (Section 6.2.4). If sludge is incinerated or burned as part of an energy recovery system, then the resulting emissions should be reported for in the Energy Chapter, classified as an industrial waste fuel. In these cases, to ensure that emissions are not counted twice an "MCF" of zero should be used in this methodology for sludge disposed in SWDSs or incinerated, or burned as part of an energy recovery system. In all other cases, an appropriate MCF value should be selected based on the specific characteristics of the system used to dispose of the sludge.

Step 3 - Wastewater Emissions

To estimate total emissions from wastewater, the selected emissions factors are multiplied by the associated organic wastewater production and summed. Subtract the amount of CH_4, if any, that is recovered and thus not emitted into the atmosphere for each handling method. If no data are readily available, the default assumption is that this amount is zero. Sum the results for each handling method to determine total CH_4 emissions from wastewater. In equation form, the estimate of total CH_4 emissions from wastewater handling is as follows:

EQUATION 12

$$WM = \Sigma_i (TOW_i \times EF_i - MR_i)$$

where:

WM = total methane emissions from wastewater in kg CH_4

TOW_i = total organic waste for wastewater type i in kg DC/yr. For domestic streams, the DC is BOD; for industrial streams it is the COD (Step 1)

EF_i = emission factor for wastewater type i in kg CH_4/kg DC (Step 2)

MR_i = total amount of methane recovered or flared from wastewater type i in kg CH_4. If no data are available, use the default value of zero

Step 4 - Sludge Emissions

To estimate total emissions from sludge, the selected emissions factors are multiplied by the associated organic sludge production and summed. Subtract the amount of CH_4, if any, that is recovered and thus not emitted into the atmosphere for each handling method. If no data are readily available, the default assumption is that this amount is zero. Sum the results for each handling method to determine total CH_4 emissions from wastewater. In equation form, the estimate of total CH_4 emissions from sludge handling is as follows:

EQUATION 13

$$SM = \Sigma_j (TOS_j \times EF_j - MR_j)$$

where:

SM = total methane emissions from sludge in kg CH_4

TOS_j = total organic waste for sludge type j in kg DC/yr. For domestic streams, the DC is BOD; for industrial streams it is COD (Step 1)

EF_j = emission factor for sludge type j in kg CH_4/kg DC (Step 2)

MR_j = total amount of methane recovered or flared from sludge type j in kg CH_4. If no data are available, the default is zero

Step 5 - Total Emissions

Total emissions from wastewater and sludge can be determined by summing the results of Steps 3 and 4. This is expressed as follows in Equation 14:

EQUATION 14

$$TM = WM + SM$$

where:

TM = total methane from wastewater and sludge handling in kg CH_4

WM = total methane emissions from wastewater in kg CH_4

SM = total methane emissions from sludge in kg CH_4

6.3.6 Uncertainties

The quality of CH_4 emissions estimates for wastewater handling is directly related to the quality and availability of the waste management data used to derive these estimates. Country specific data on wastewater quantities, characteristics, and wastewater management methods are very limited. The principal sources of uncertainty are described below.

Organic Wastewater Quantity and Composition

Often the amount of degradable organic wastewater that is produced and the volumes handled in the various systems is not well known. Consequently, limitations exist for quantifying the fraction of wastewater subject to specific systems.

Physical and Chemical Data

Country-specific data on wastewater characteristics are very limited. For example, reported organic component values in industrial source categories are averages from several processes. Accurate and detailed data on the chemical characteristics and volumes of process wastewater streams could improve the emissions estimates.

Wastewater Handling Facility Efficiency and Output

Aerobically treated wastewater by handling plants may be subject to anaerobic conditions due to poorly managed and functioning facilities. This contributes to an underestimate of emissions. Additionally, current estimates from wastewater handling lagoons are relatively uncertain due to the limited available data. Work is on-going to develop better emission factors from these sources.

TABLE 6-5
ESTIMATED BOD_5 VALUES IN DOMESTIC WASTEWATER BY REGION

Region	BOD_5 Value (kg/cap/day)	BOD_5 Value (kg/1000 persons/yr)
Africa	0.037	13,505
Asia, Middle East, Latin America	0.04	14,600
N. America, Europe, Former USSR, Oceania	0.05	18,250
Source: IPCC (1994)		

TABLE 6-6
INDUSTRIAL WASTEWATER DATA BY REGION

Industry Type and Region	Wastewater Produced (m^3/tonnes of product)	COD Value (kg COD/m^3 wastewater)	Country
Beverage - Distilled & Industry			
Generic - ethanol	13 m^3/ m^3 ethanol	40	
Generic - ethanol	NAV	5,000 kg/ m^3 ethanol	
South America	NAV	22	Brazil
Western Europe	NAV	4.0 - 5.0	Netherlands
Beverage - Malt & Beer			
Generic	5 m^3/ m^3 beer	17	
Generic	5-9 m^3/ m^3 beer	2.0 - 7.0	
Western Europe	NAV	1.0 - 1.5	Netherlands
Food - Meat & Poultry			
Generic	1.4 m^3/animal	NAV	
Western Europe	NAV	2.9	Netherlands
North America	NAV	15.0	USA
Food - Fish			
North America	NAV	2.5	USA
Food - Coffee			
North America	NAV	3.0 - 14.0	USA
Food - Dairy Products			
Generic	2.8	NAV	
Western Europe	NAV	1.5	Netherlands
Food - Fruits & Vegetables			
Generic (cannery)	26	NAV	
Generic Tomato processing	26	NAV	
North America, potatoes	NAV	3.0	USA
Western Europe, bean blanching	NAV	5.2	Netherlands
Western Europe, sauerkraut	NAV	10.0 - 20.0	Netherlands
Food - Oils			
Generic - Vegetable oil	1.6	0.3	
Middle East	NAV	42	Turkey
Asia	NAV	25	Malaysia
Food - Sugar			
Central America (cane)	NAV	98	Mexico
Iron And Steel			
South America	0.1	NAV	Brazil
Organic Chemicals			
Western Europe	NAV	20- 40	Netherlands
Pharmaceuticals			
Middle East	NAV	1.3	Egypt

TABLE 6-6 (CONTINUED)
INDUSTRIAL WASTEWATER DATA BY REGION

Industry Type and Region	Wastewater Produced (m^3/tonnes of product)	COD Value (kg COD/m^3 wastewater)	Country
Starch			
Generic, potato starch	NAV	4.0 - 16	
Generic, wheat starch	NAV	2.0 - 42	
Generic, corn starch	NAV	10	
Petroleum Production			
North America	NAV	0.3 -0.4	USA
North America	NAV	1.8	Canada
Pulp & Paper			
Generic (pulp)	58	2.0 - 15	
North America pulp mill	140	NAV	USA
Generic (paper)	NAV	2.0 - 8.0	
North America (virgin paper)	97	1.6	USA
North America (recycled paper)	44	3.0	USA
Western Europe (paper)	NAV	1.0 - 3.0	Netherlands
Textiles			
Rayon	501	NAV	
Greece	NAV	0.09	
North America, textile mills	NAV	1.0	USA
Leather Tanning			
North America, generic	NAV	5.8	USA

Source: Doorn and Eklund (1995). For a detailed list of references for each wastewater category, see Doorn and Eklund (1995). Wastewater production of COD values are not available (NAV) for every country and region. Research is ongoing to develop wastewater production and COD values for these countries and regions. Note that these data are currently undergoing revision and updating.

TABLE 6-7
DOMESTIC WASTEWATER TREATMENT EMISSIONS FACTOR DERIVATION DATA

Region	Type of Treatment	Fraction of Wastewater Treated (%)	MCF (%)
Africa			
Kenya	Lagoons	50	NAV
Tunisia	Lagoons	20	NAV
Zimbabwe	Activated Sludge	50	NAV
Other Africa	Lagoons	5	80
Asia			
Indonesia	not specified	1	NAV
Singapore	not specified	1	NAV
South Korea	not specified	1	NAV
Taiwan	not specified	1	NAV
Other Asia	not specified	5	75
Latin America And Caribbean	not specified	10	80
Australia And New Zealand	not specified	80	70

Source: Doorn and Eklund (1995). For a detailed list of references for each region, see Doorn and Eklund (1995). Methane correction factor (MCF) data are not available (NAV) for some countries and regions. Research is ongoing to provide MCF estimates for these countries and regions. Note that these data are currently undergoing revision and updating.

TABLE 6-8
INDUSTRIAL WASTEWATER TREATMENT EMISSIONS FACTOR DERIVATION

Region	Type of Industry	Type of Treatment	Fraction of Wastewater Treated (%)	MCF (%)
Africa				
Kenya	textiles	Lagoons	60	NAV
Kenya	coffee production	Lagoons	5	NAV
Other Africa	All	Lagoons	10	90
Asia				
Indonesia	All	not specified	10	NAV
Malaysia	palm oil	not specified	90	NAV
Singapore	All	not specified	10	NAV
South Korea	All	not specified	10	NAV
Taiwan	All	not specified	10	NAV
Thailand	breweries	activated sludge	50	NAV
Other Asia	All	not specified	20	90
North America				
Canada	All	not specified	90	70
USA	All	not specified	90	70
Latin America & Caribbean	All	not specified	20	90
Australia & New Zealand	All	not specified	95	70

Source: Doorn and Eklund (1995). For a detailed list of references for each region, see Doorn and Eklund (1995). Methane correction factor (MCF) data are not available (NAV) for some countries and regions. Research is ongoing to provide MCF estimates for these countries and regions. Note that these data are currently undergoing revision and updating.

TABLE 6-9
UNSPECIFIED WASTEWATER TYPE EMISSIONS FACTOR DERIVATION DATA

Region	Type of Treatment	Fraction of Wastewater Treated (%)	MCF (%)
Africa			
South Africa	not specified	10	NAV
Asia			
Afghanistan	not specified	1	NAV
Latin America And Caribbean			
Colombia	Lagoons	3	NAV
Argentina	Lagoons	3	NAV
Europe			
Albania	not specified	1-92	NAV
Austria	not specified	65	NAV
Belgium	not specified	85	NAV
Bulgaria	not specified	10-100	NAV
Belarus	not specified	10-80	NAV
Croatia	not specified	57	NAV
Czech Rep	not specified	10-5	NAV
Denmark	not specified	90	NAV
Estonia	not specified	10-80	NAV
Finland	not specified	68	NAV
France	not specified	50-85	NAV
Germany	not specified	90	NAV
Hungary	not specified	44	NAV
Ireland	not specified	66	NAV
Italy	not specified	92	NAV
Latvia	not specified	10-80	NAV
Lithuania	not specified	10-80	NAV
Moldavia	not specified	10-80	NAV
Netherlands	not specified	90	NAV
Norway	not specified	94	NAV
Poland	not specified	10-50	NAV
Portugal	not specified	42	NAV
Romania	not specified	10-46	NAV
Russia	not specified	10-80	NAV
Serbia	not specified	57	NAV
Slovenia	not specified	87	NAV
Spain	not specified	67	NAV
Sweden	not specified	98	NAV
Switzerland	not specified	88	NAV
Turkey	not specified	38	NAV
Ukraine	not specified	10-80	NAV
United Kingdom	not specified	90	NAV
Slovakia	not specified	10-65	NAV

Source: Doorn and Eklund (1995). Methane correction factor (MCF) data are not available (NAV). Research is ongoing to provide MCF estimates for these and other wastewater treatment systems. Note that these data are currently undergoing revision and updating.

6.4 Nitrous Oxide from Human Sewage

Since N_2O emissions from human sewage are closely linked to the agricultural N cycle, the method is further discussed in the Agriculture Chapter. For a detailed description of the proposed methodology, the reader is referred to Section 4.5.4 (on indirect N_2O emissions from nitrogen used in agriculture).

The emissions of N_2O from human sewage are calculated as follows:

EQUATION 15

$$N_2O_{(S)} = \text{Protein} \times \text{Frac}_{NPR} \times \text{NR}_{PEOPLE} \times EF_6$$

where:

$N_2O_{(s)}$ = N_2O emissions from human sewage (kg N_2O-N/yr)

Protein = annual per capita protein intake (kg/person/yr)

NR_{PEOPLE} = number of people in country

EF_6 = emissions factor (default 0.01 (0.002-0.12) kg N_2O-N/kg sewage-N produced) (See Table 4-18 in Agriculture Chapter)

Frac_{NPR} = fraction of nitrogen in protein (default = 0.16 kg N/kg protein) (See Table 4-19 in Agriculture Chapter)

6.5 Emissions from Waste Incineration

6.5.1 Introduction

Waste incineration like other types of combustion, is a source of GHG emissions. Few data have been compiled on the global emissions from waste incineration. Preliminary indicators are that this source represents a small percentage of the total GHG output from the waste source category.

6.5.2 Emissions

Certainly waste incineration produces CO_2, but it is difficult to identify the portion which should be considered **net** emissions. A large fraction of the carbon in waste combusted (e.g., paper, food waste) is derived from biomass raw materials which are replaced by regrowth on an annual basis. These emissions should not be considered net anthropogenic CO_2 emissions in the IPCC Methodology. If the agricultural or forestry sources are not being sustainably managed, net CO_2 emissions (equivalent to reductions in biomass stocks) should be accounted for in those source categories. On the other hand, some carbon in waste is in the form of plastics or other products based on fossil fuel. Combustion of these materials, like fossil fuel combustion, releases net CO_2 emissions. In estimating emissions from waste incineration, the desired approach is to separate carbon in the incinerated waste into biomass and fossil fuel based fractions. Only the fossil based portion should be considered net carbon emissions. Any such detailed analysis should ensure that carbon emissions are not double counted in the treatment of stored carbon under energy emissions. See *Overview to the IPCC Guidelines*.

A recent Belgian analysis (Debruyn and Van Rensbergen, 1994) offers an example of a very detailed approach.

Other relevant gases released from combustion are net GHG emissions. Methane emissions from waste incineration are highly uncertain. An expert working group recognised waste incineration as a source of methane production, but was not able to give global estimates or default emissions factors. Although this source is considered to be relatively small compared to the other CH_4 sources in waste, it was recognised as an area for further research in the future (Berdowski et al., 1993).

Recent studies have also shown that N_2O may be an important GHG produced from incineration. Table 6-10 provides data from studies of several incineration plants and the N_2O produced from the waste incineration (de Soete, 1993). Studies in Belgium (IPCC, 1993), Japan (Tanaka et al., 1992) and Norway (Rosland, 1993) have estimated N_2O production from their waste incineration processes. It has also been found that the emission level depends on the nature of the waste burned. Research in Japan has noted that while all types of incineration produce N_2O, sludge incinerators produce the highest emissions rates (Tanaka et al., 1992).

Traditional air pollutants from combustion - NO_x, CO, NMVOC - are characterised in existing emissions inventory systems. The IPCC does not provide a new methodology for these gases, but recommends that national experts use existing published methods. Some key examples of the current literature providing methods are: Default Emission Factor Handbook (CORINAIR, 1994), as well as the US EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (US EPA, 1985) and Criteria Pollutant Emission Factors for the 1985 NAPAP Emissions Inventory (Stockton and Stelling, 1987).

TABLE 6-10
NITROUS OXIDE EMISSIONS FROM WASTE INCINERATION

			N_2O Emission				
Nature of Waste (reference)	Facility	T°C	ppmv[a] min.	ppmv[a] average	ppmv[a] max.	O_2 (%)	g N_2O / tonne waste
Municipal refuse	10 furnaces (65-300 tonnes/day)		1.2	8	18		
Municipal refuse	Stepgrate	780-880	0.8		4.9	10	11-43
	Stepgrate	780-980	4		24	8-14	40-220
	Fluid. bed	830-850	6.7		10.5	13-15	14-123
Municipal solid waste	5 stokers (20-400 tonnes/day)		3	7	12		26-270
	3 Fluid. bed		5.6	9.8	17.1		97-293
	rot. koln (120 tonnes/day)		10.2	11.1	12.1		35-165
Sewage-sludge	4 incin. (150-300 tonnes/day)		57	87	125		
Sludge	Rotary grate	750		50.7			227
	Fluid. bed	770-812	270		600		580-1528
	Fluid. bed	838-854	135		292		684-1508
	Fluid. bed	834-844	100		320		275-886
	Fluid. bed	853-887	45		145		101-307

Source: de Soete, 1993.
[a] ppmv = parts per million by volume

6.6 References

Aitchison, E.M, M.P. Meadows, M.J. Wenborn, I.T. Marlowe, M. Mikkelson, M. Milton, C. Harries and R. Pocock (1996) " A Methodology for Updating Routinely the Annual Estimate of Methane Emissions from Landfill Sites in the UK. " ETSU, AEA Technology, Report RYWA/18678001/R4.

Berdowski, J.J.M., L. Beck, S. Piccot, J.G.J. Oliver and C. Veldt (1993), "Working Group Report: Methane emissions from fuel combustion and industrial processes." In: *Proceedings of an International IPCC Workshop on Methane and Nitrous Oxide: Methods in National Emissions Inventories and Options for Control.* A.R. van Amstel (ed.), RIVM Report No. 481507003, Bilthoven, The Netherlands, pp. 231-237.

Bingemer, H.G. and P.J. Crutzen (1987), "The production of methane from solid wastes." *Journal of Geophysical Research,* 92 (D2): 2181-2187.

CORINAIR, 1994. Technical Annexes Volume 2 - *Default emission factors handbook* EUR Report 12586, Office for Official Publications of the European Communities, Luxembourg. (Originally published in 1992 by EEATF.)

Debruyn W. and J. Van Rensbergen (1994), *Greenhouse Gas Emissions from Municipal and Industrial Wastes,* ENE.RA9410, VITO, Energy Division, Belgium.

de Soete, G. (1993), "Nitrous oxide from combustion and industry: chemistry, emissions, and control", pp. 324-325. Working Group Report: Methane Emissions from Biomass Burning. In : *Proceedings of an International IPCC Workshop on Methane and Nitrous Oxide: Methods in National Emissions Inventories and Options for Control.* A.R. van Amstel (ed.), RIVM Report No. 481507003, Bilthoven, The Netherlands.

Doorn, M. and M.A. Barlaz (1995), *Estimate of Global Methane Emissions from Landfills and Open Dumps.* Prepared for US EPA Office of Research and Development, February 1995, EPA-600/R-95-019.

Doorn, M. and B. Eklund (1995), *Greenhouse Gases from Wastewater Treatment: Collection and Review of Country-Specific Data and Preliminary Emission Models.* Prepared for US EPA Office of Research and Development,

EMEP/CORINAIR (1996), Joint Atmospheric Emission Inventory Guidebook (1st edition).

Environment Canada (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990.* Report EPS 5/AP/4.

Gloyna, E.F. (1971), Waste Stabilization Ponds. World Health Organization, Geneva, Switzerland.

IPCC (1992), Climate Change 1992. *The Supplementary Report to the IPCC Scientific Assessment.* (J.T. Houghton, G.J. Jenkins and J.J. Ephraums (eds)). Published for The Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization/United Nations Environment Programme, Cambridge University Press, UK.

IPCC (1993), Parts I & II: *National GHG Inventories: Transparency in Estimation and Reporting.* Part III: *Preliminary IPCC National GHG Inventories: In-Depth Review.* Prepared by The Intergovernmental Panel on Climate Change (IPCC) and Organisation for Economic Co-operation and Development, World Meteorological Organization/United Nations Environment Programme.

IPCC (1994), "*IPCC Guidelines for National Greenhouse Gas Inventories, 3 Volumes: Volume 1, Reporting Instructions; Volume 2, Workbook; Volume 3, Draft Reference Manual.*" Intergovernmental Panel of Climate Change.

IPCC (1995), "*IPCC Guidelines for National Greenhouse Gas Inventories, 3 Volumes: Volume 1, Reporting Instructions; Volume 2, Workbook; Volume 3, Reference Manual.*" Intergovernmental Panel of Climate Change.

IPCC (1996), Climate Change 1995. *The Science of Climate Change.* (J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (eds)). Published for The Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization/United Nations Environment Programme, Cambridge University Press, UK.

LANDTEC (1994), "Coursewares" material provided at Landfill Gas System Engineering Design Seminars.

Lexmond M.J. and G. Zeeman (1995), *Potential of Uncontrolled Anaerobic Wastewater Treatment in Order to Reduce Global Emissions of the Greenhouse Gases Methane and Carbon Dioxide*, Department of Environmental Technology, Agricultural University of Wageningen, Wageningen, The Netherlands. Report No. 95-1.

OECD (1995), *OECD Environmental Data Compendium 1995.* Organisation for Economic Co-operation and Development.

Rosland, A. (1993*), Greenhouse Gas Emissions in Norway: Inventories and Estimation Methods*, pp.14. Prepared for the Norwegian Ministry of the Environment, Oslo, Norway.

Stockton, M.B. and J.H.E. Stelling (1987), Criteria Pollutant Emission Factors for the 1985 NAPAP Emissions Inventory. US EPA Washington, Ouverage, EPA-600/7-87-015 XV-211.

Tabasaran, O. (1981), "Gas production from landfill". In *Household Waste Management in Europe, Economics and Techniques*, A.V. Bridgewater and Lidgren K. (eds.), Van Nostrand Reinhold Co., New York, USA, pp. 159-175.

Tanaka, M., M. Miyazaki and I. Watanabe (1992), "CH_4 and N_2O Emission from Waste Disposal Facilities in Japan", pp. 18-19. Presented at the *CH_4 and N_2O Workshop* held by the National Institute of Agro-Environmental Sciences (NIAES), Tsukuba, Japan, March 25-26,1992.

UK department of the Environment (1993), An Assessment of Methane Emissions from UK landfills. UK DoE report CWM 063/93.

US Environmental Protection Agency, Office of Air Quality Planning and Standards (1985), *Compilation of Air Pollutant Emission Factors* (Fourth Edition), Volume I: "Stationary Point and Area Sources." EPA-AP-42 (GPO 055-000-00251-7), Research Triangle Park, North Carolina, USA.

US Environmental Protection Agency (1991), *Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines.* EPA-450/3-90-011a, US EPA, Research Triangle Park, North Carolina, USA.

US Environmental Protection Agency (1994), *International Anthropogenic Methane Emissions Report to Congress.* EPA Office of Policy, Planning and Evaluation, EPA 230-R-93-010.

US Environmental Protection Agency (1995), Section 2.4, Landfills, in *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*, Fifth Edition, AP-42. US EPA Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, USA.

Van Amstel, A.R., R.J. Swart, M.S. Krol, J.P. Beck, A.F. Bouwman and K.W. Van der Hoek (1993*), Methane, the Other Greenhouse Gas..* Research and policy in the Netherlands. RIVM Report No. 481507001.

Westlake, K. (1990), "Landfill microbiology". In *Proceedings of the International Conference: Landfill Gas: Energy and Environment '90*. Bournemouth, UK.