

CHAPTER 5

INCINERATION AND OPEN BURNING OF WASTE

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5 INCINERATION AND OPEN BURNING OF WASTE

Users are expected to go to Mapping Tables in Annex 1, before reading this chapter. This is required to correctly understand both the refinements made and how the elements in this chapter relate to the corresponding chapter in the 2006 IPCC Guidelines.

5.1 INTRODUCTION

Thermal treatments of waste are classified into incineration, pyrolysis, gasification, plasma, and open burning of waste. Pyrolysis, gasification, and plasma are regarded as new technologies for treating solid wastes. In Chapter 5, Volume 5 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)*, the new technologies are not included. These new technologies have been applied worldwide and have become important in some countries. The refinement in this chapter provides CH₄ and N₂O emission factors of pyrolysis-melting and gasification-melting plant for treating municipal solid waste (MSW) to be used in their emission estimates. This chapter updates the oxidation factor for open burning of MSW from experiment data including uncertainty.

Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, long residence times, and efficient waste agitation while introducing air for more complete combustion. Types of waste incinerated include MSW, industrial waste, hazardous waste, clinical waste and sewage sludge¹. The practice of MSW incineration is currently more common in developed countries, while it is common for both developed and developing countries to incinerate clinical waste.

Pyrolysis is defined as a reduction process that thermochemically converts organic materials into gas and liquid products mainly containing hydrocarbon components and a solid residue with higher carbon content at elevated temperatures in the absence of oxygen (Box 5.0a New).

Gasification is a process that converts organic materials mainly into carbon monoxide, hydrogen, and carbon dioxide at temperatures above 700°C with different ratios of gasifying agent such as steam, carbon dioxide, oxygen, and air. The resulting gas mixture is called as synthesis gas (syngas), mainly used as fuel and/or chemical feedstock (Box 5.0b New).

Plasma is defined as a partial oxidation process of reacting organic materials in an oxygen starved environment at high temperature to produce gas and solid products. The highly reactive plasma zone consists largely of electrons, ions, and excited molecules along with high energy radiation. In a plasma zone, organic materials are cracked to high portion of gas products such as carbon dioxide, water, carbon monoxide, hydrogen, and light hydrocarbons along with low quantities of inorganic solid product (slag and metals) (Box 5.0c New).

The new technologies have been mostly applied to produce fuels and chemical feedstocks from waste tires and plastics, and they are also applied to treat MSW to avoid the generations of air pollutants that would arise from conventional MSW incineration. Although many pyrolysis, gasification, and plasma plants have been applied to treat wastes, many plants have been closed due to some technical problems as well as high cost. Rising environmental standards and clean energy demands have recently revived the interest in the new technologies and then new plants are getting installed in developed countries. However, few official data for the emissions of greenhouse gases are available for the new technologies. Especially, greenhouse gas emission data from plasma technology are rarely found.

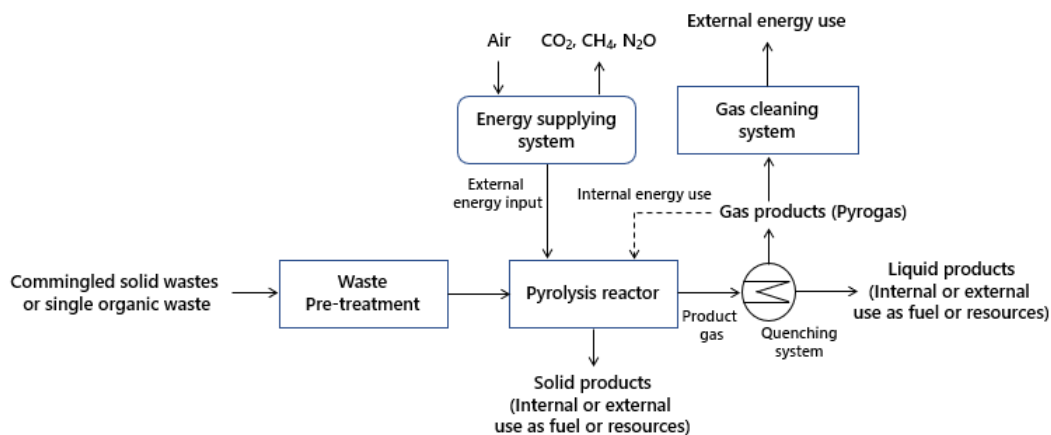
Since gas products generated from the new technologies are usually collected and used mostly as fuel or chemical feedstock, direct emissions of CH₄ and N₂O from the new technologies are expected to be quite low unless gas products containing CH₄ and N₂O are intentionally vented to the atmosphere. If the gas products would be combusted to supply energy to inside processes, the emissions of CH₄ and N₂O are reported under the Energy Sector. On the other hand, the emissions of CH₄ and N₂O in gas products are reported under the Waste Sector provided that the gas products would be released to the atmosphere. If gas, liquid, and solid products generated from the new technologies would be exported outside for their use or disposal, the emissions of

¹ Waste generation, composition and management practices, including waste incineration and open burning, are addressed in detail in Chapter 2 of this volume.

greenhouse gases are not reported as those from the new technologies themselves, but at the point of their use or disposal.

BOX 5.0A (NEW)
PYROLYSIS

Pyrolysis is a reductive and endothermic reaction to convert carbonaceous substances into lower molecular weight compounds by applying external energy. The more energy is applied, the smaller size compounds are produced. CH₄ is one of the smallest compounds generated from pyrolysis process of carbonaceous substances. Pyrolysis of organic wastes is normally operated at temperature ranges between 300 and 700°C. The pyrolysis process can be shown as below:



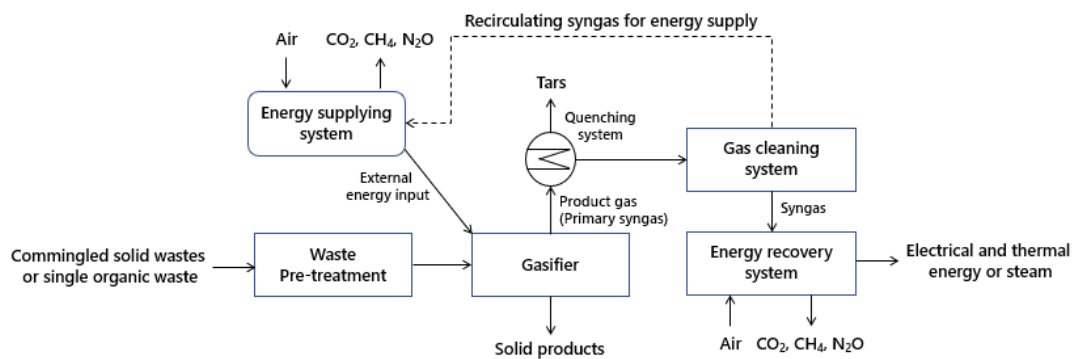
Solid wastes or single organic wastes (e.g., plastic and wood) are pre-treated (e.g., drying and pulverizing, etc.) to satisfy technical requirements for the succeeding pyrolysis reaction. Combustible components of solid wastes are thermally decomposed in pyrolysis reactor to produce gases and solid residues. The product gas is composed of condensable and non-condensable fraction which are separated into gas and liquid products, respectively, by a quenching process. The gas products mainly composed of volatile organic compounds (e.g., CH₄, C₂H₆, etc.), H₂, CO, and CO₂. Liquid products are composed of various aliphatic and aromatic compounds. Solid products include carbon residues (char) and inorganic components. The solid products may be combusted in situ for energy recovery within pyrolysis process or transferred outside for energy and/or chemical feedstock use. The gas products (pyrogases) are combusted in energy supplying system to provide energy to the pyrolysis reactor or transferred outside for energy or chemical feedstock use. The external energy-supplying system to the pyrolysis reactor is considered as the only emission source of greenhouse gases in the pyrolysis plant. The emissions of greenhouse gases from the energy-supplying system within the pyrolysis plant are reported under the Energy Sector. If pyrolysis products would be exported outside for their use or disposal, the emissions of greenhouse gases are not reported as those from the pyrolysis plant, but at the point of their use or disposal.

BOX 5.0B (NEW)
GASIFICATION

Gasification is a conversion process of carbonaceous substances to gas fuel with a high heating value. Depending upon reaction condition, gasification of solid wastes is accounted for by four primary reactions: partial oxidation reaction, Boudouard reaction, water gas reaction, and methanation reaction.

- partial oxidation reaction: $C + 1/2O_2 \rightarrow CO$
- Boudouard reaction: $C + CO_2 \leftrightarrow 2CO$
- water gas shift reaction: $C + H_2O \leftrightarrow CO + H_2$
- methanation reaction: $2C + 2H_2O \rightarrow CH_4 + CO_2$

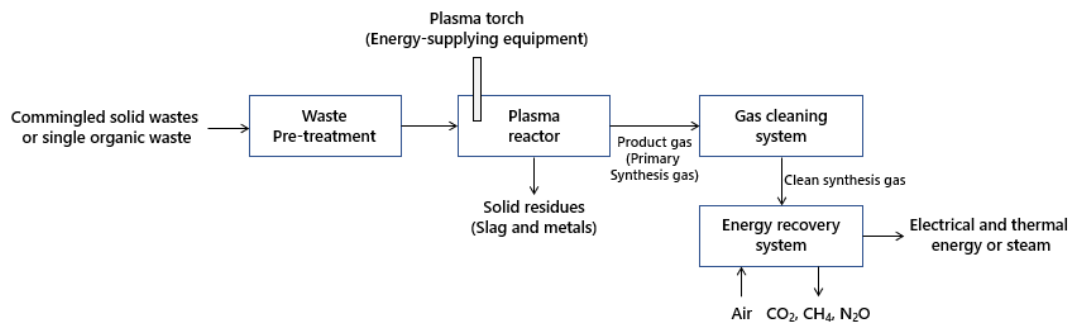
The above gasification reactions reveal that the product gas primarily consists of H_2 , CO , and CH_4 and is referred to as synthesis gas (syngas). Solid wastes or single organic wastes (e.g., plastic and wood) are pre-treated (e.g., drying and pulverizing, etc.) to answer technical requirements for the subsequent gasification reaction. The gasification of combustible components of solid wastes produces the primary syngas. The gas cleaning system after the gasifier removes acid gases, fine particulates, heavy metals, and moistures from the primary syngas. The clean syngas may be used as fuel for generating electrical and thermal energy or steam or exported to other processes for energy and/or chemical feedstock use. Some portion of clean syngas can be supplied to energy supplying system within the gasification plant to provide the energy to gasifier. The gasification of combustible components of solid wastes produces syngas together with liquid and solid products. Liquid products separated from product gas by a quenching process are known as tars, which are mainly composed of polyaromatic compounds, while the solid products are represented by inorganic components and a little carbon residue.



Since syngas generated from gasification process is used in situ and/or outside for fuel, CH_4 emissions are rarely expected during the gasification process. It is noted that syngas may be vented directly to atmosphere despite of its rare occurrence. The external energy-supplying system to the gasifier is considered as the only emission source of greenhouse gases in the gasification plant. The emissions of greenhouse gases from the energy-supplying system within the gasification plant are reported under the Energy Sector. If gasification products would be exported outside for their use or disposal, the emissions of greenhouse gases are not reported as those from the gasification plant, but at the point of their use or disposal.

BOX 5.0C (NEW)**PLASMA**

Plasma technology is regarded as an advanced and pure gasification process. Since plasma processes are operated at extremely high temperatures in an oxygen deficient condition, combustible components of solid wastes can be nearly completely converted into syngas. Reaction residues of plasma process consist of inorganic components including slag and metals. Primary syngas is produced in plasma reactor where one or more plasma arc torches are installed for plasma generation. The primary syngas is treated by gas cleaning system to produce clean syngas.



Since syngas generated from plasma process may be used in situ as fuel or exported to another process for energy and/or chemical feedstock use, CH₄ emissions are rarely expected from the plasma process itself. It is noted that syngas may be vented directly to atmosphere despite of its rare occurrence. The external energy-supplying system to the plasma reactor is considered as the only emission source of greenhouse gases in the plasma plant. The emissions of greenhouse gases from the energy recovery system within the plasma plant are reported under the Energy Sector. If syngas would be exported outside for its use, the emissions of greenhouse gases are not reported as those from the plasma plant, but at the point of its use.

Emissions of greenhouse gases from thermal treatment of waste include incineration, pyrolysis, gasification, plasma and open burning without energy recovery are reported in the Waste Sector, while those with energy recovery are reported in the Energy Sector, both with a distinction between fossil and biogenic carbon dioxide (CO₂) emissions. The methodology described in Chapter 5, Volume 5 of the *2006 IPCC Guidelines* is applicable in general both to incineration with and without energy recovery. In this refinement, emission factors of CH₄ and N₂O emissions from new technologies emitted directly to the atmosphere are provided. Co-firing of specific waste fractions with other fuels is not addressed in this chapter, as co-firing is covered in Volume 2, Energy. Emissions from agricultural residue burning are considered in the AFOLU Sector, Chapter 5 of Volume 4.

Open burning of waste can be defined as the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open-air) or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or stack. Open burning can also include incineration devices that do not control the combustion air to maintain an adequate temperature and do not provide sufficient residence time for complete combustion. This waste management practice is used in many developing countries while in developed countries open burning of waste may either be strictly regulated, or otherwise occur more frequently in rural areas than in urban areas.

Incineration and open burning of waste are sources of greenhouse gas emissions, like other types of combustion. Relevant gases emitted include CO₂, methane (CH₄) and nitrous oxide (N₂O). Normally, emissions of CO₂ from waste incineration are more significant than CH₄ and N₂O emissions.

Consistent with the *1996 Guidelines* (IPCC, 1997), only CO₂ emissions resulting from oxidation, during incineration and open burning of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and should be included in the national CO₂ emissions estimate. The CO₂ emissions from combustion of biomass materials (e.g., paper, food, and wood waste) contained in the waste are biogenic emissions and should not be included in national total emission estimates. However, if incineration of waste is used for energy purposes, both fossil and biogenic CO₂ emissions should be estimated. Only fossil CO₂ should be included in national emissions under Energy Sector while biogenic CO₂ should be reported as an information item also in the Energy Sector. Moreover, if combustion, or any other factor, is causing long term decline in the total carbon embodied in living biomass (e.g., forests), this net release of carbon should be evident in the calculation of CO₂ emissions described in the Agriculture, Forestry and Other Land Use (AFOLU) Volume of the *2006 Guidelines*.

Guidance on methodological choices for estimating and reporting CO₂, CH₄ and N₂O emissions from incineration and open burning reported in Chapter 5, Volume 5 of the *2006 IPCC Guidelines* are valid to estimate CH₄ and N₂O from new technologies. This refinement provides guidance on choice of CH₄ and N₂O emission factors for pyrolysis and gasification for specific type of plant.

Traditional air pollutants from combustion - non-methane volatile organic compounds (NMVOCs), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x) - are covered by existing emission inventory systems. Therefore, the IPCC does not provide new methodologies for these gases here, but recommends that national experts or inventory compilers use existing published methods under international agreements. Some key examples of the current literature providing methods include EMEP/CORINAIR Guidebook (EMEP 2004), US EPA's Compilation of Air Pollutant Emissions Factors, AP-42, Fifth Edition (US EPA, 1995), EPA Emission Inventory Improvement Program Technical Report Series, Vol. III Chapter 16: Open Burning (US EPA, 2001).

The estimation of indirect N₂O emissions, resulting from the conversion of nitrogen deposition to soils due to NO_x emissions from waste incineration and open burning, is addressed in Section 5.4.3 of this chapter. General background and information on the reporting of the indirect N₂O emissions is given in Chapter 7, Precursors and Indirect Emissions, of Volume 1, General Guidance and Reporting.

5.2 METHODOLOGICAL ISSUES

The choice of method will depend on national circumstances, including whether incineration and open burning of waste are *key categories* in the country, and to what extent country- and plant-specific information is available or can be gathered.

For waste incineration, the most accurate emission estimates can be developed by determining the emissions on a plant-by-plant basis and/or differentiated for each waste category (e.g., MSW, sewage sludge, industrial waste, and other waste including clinical waste and hazardous waste). The methods for estimating CO₂, CH₄ and N₂O emissions from incineration and open burning of waste vary because of the different factors that influence emission levels. Estimation of the amount of fossil carbon in the waste burned is the most important factor determining the CO₂ emissions. The non-CO₂ emissions are more dependent on the technology and conditions during the incineration process.

Intentional burning of waste on solid waste disposal sites is sometimes used as a management practice in some countries. Emissions from this practice and those from unintentional fires (accidental fires on solid waste disposal sites) should be estimated and reported according to the methodology and guidance provided for open burning of waste.

The general approach to calculate greenhouse gas emissions from incineration and open burning of waste is to obtain the amount of dry weight of waste incinerated or open-burned (preferably differentiated by waste type) and to investigate the related greenhouse gas emission factors (preferably from country-specific information on the carbon content and the fossil carbon fraction). For CO₂ emissions from incineration and open burning of waste, the basic approach is given here as an example of a consecutive approach:

- Identify types of wastes incinerated/open-burned: MSW, sewage sludge, industrial solid waste, and other wastes (especially hazardous waste and clinical waste) incinerated/open-burned.
- Compile data on the amount of waste incinerated/open-burned including documentation on methods used and data sources (e.g., waste statistics, surveys, expert judgement): Regional default data are also provided in Table 2.1 (Updated) in Chapter 2, Waste Generation, Composition and Management Data, and country-specific data for a limited number of countries in Annex 2A.1 (Updated) of this Volume. The default data should be used only when country-specific data are not available. For open burning, the amount of waste can be estimated based on demographic data. This is addressed in Section 5.3.2.
- Use default values provided on dry matter content, total carbon content, fossil carbon fraction and oxidation factor (see Section 5.4.1.3) for different types of wastes: For MSW, preferably identify the waste composition and calculate the respective dry matter content, total carbon content, and fossil carbon fraction using default data provided for each MSW component (plastic, paper, etc) in Section 2.3, Waste composition, of this Volume.
- Calculate the CO₂ emissions from incineration and open burning of solid wastes.
- Provide data in the worksheets given in Annex 1 of this Volume 5 of the *2006 IPCC Guidelines*.

For other waste types and other greenhouse gases, the approach usually does not differentiate as much as for the MSW in terms of waste composition. Detailed guidance on the choice of method, activity data and emission

factors for all major types of waste to estimate the emissions from relevant waste incineration and burning practices is outlined in the following sections.

Methodology from the *2006 IPCC Guidelines* can be used to estimate emission from gasification, pyrolysis and plasma. Emission factors of CH₄ and N₂O from pyrolysis and gasification are provided in new Tables 5.3A and 5.4A.

5.2.1 Choice of method for estimating CO₂ emissions

No refinement.

5.2.1.1 TIER 1

No refinement.

5.2.1.2 TIER 2

No refinement.

5.2.1.3 TIER 3

No refinement.

5.2.1.4 CO₂ EMISSIONS FROM INCINERATION OF FOSSIL LIQUID WASTE

No refinement.

5.2.2 Choice of method for estimating CH₄ emissions

No refinement.

5.2.2.1 TIER 1

No refinement .

5.2.2.2 TIER 2

No refinement.

5.2.2.3 TIER 3

No refinement.

5.2.3 Choice of method for estimating N₂O emissions

No refinement.

5.2.3.1 TIER 1

No refinement.

5.2.3.2 TIER 2

No refinement.

5.2.3.3 TIER 3

No refinement.

5.3 CHOICE OF ACTIVITY DATA

No refinement.

5.3.1 Amount of waste incinerated

No refinement.

5.3.2 Amount of waste open-burned

No refinement.

5.3.3 Dry matter content

No refinement.

5.4 CHOICE OF EMISSION FACTORS

Emission factors in the context of incineration and open burning of waste relate the amount of greenhouse gas emitted to the weight of waste incinerated or open-burned. In the case of CO₂, this applies data on the fractions of carbon and fossil carbon in the waste. For CH₄ and N₂O, this primarily depends on the treatment practice and the combustion technology. For the estimation of CO₂, CH₄ and N₂O emissions from incineration and open burning of waste, guidance on choice of the emission factors is outlined in the following sections.

5.4.1 CO₂ emission factors

It is generally more practical to estimate CO₂ emissions from incineration and open burning of waste using calculations based on the carbon content in the waste, instead of measuring the CO₂ concentration.

Default values for parameters related to emission factors are shown in Table 5.2 (Updated). Each of these factors is discussed in detail in the sections below².

TABLE 5.2 (UPDATED)						
DEFAULT DATA FOR CO ₂ EMISSION FACTORS FOR INCINERATION AND OPEN BURNING OF WASTE						
Parameters	Management practice	MSW	Industrial Waste (%)	Clinical Waste (%)	Sewage Sludge (%) Note 4	Fossil liquid waste (%) Note 5
Dry matter content in % of wet weight		see Note 1	NA	NA	NA	NA
Total carbon content in % of dry weight		see Note 1	50	60	30	80
Fossil carbon fraction in % of total carbon content		see Note 2	90	40	0	100
Oxidation factor in % of carbon input	incineration	100	100	100	100	100
	Open-burning (see Note 3,6)	71	NO	NO	NO	NO

NA: Not Available, NO: Not Occurring

Note 1: Use default data from Table 2.4 in Section 2.3 Waste composition and equation 5.8 (for dry matter), Equation 5.9 (for carbon content) and Equation 5.10 (for fossil carbon fraction).

Note 2: Default data by industry type is given in Table 2.5 in Section 2.3 Waste composition. For estimation of emissions, use equations mentioned in Note 1.

Note 3: A default value of 71 percent is provided from the experimental study in Japan. Its uncertainty is +/-8 percent. Reference: Yamada *et al.* (2010)

Note 4: See Section 2.3.2 Sludge in Chapter 2.

Note 5: The total carbon content of fossil liquid waste is provided in percent of wet weight and not in percent of dry weight (GIO, 2005).
References: *GPG2000* (IPCC, 2000), Lead Authors of the *2006 IPCC Guidelines*, Expert judgement.

Note 6: The residue after open-burning contains unburned carbon in the form of ash or other solid residue. The fate of the unburned carbon is to be tracked and the emissions from the disposition of the unburned carbon is to be accounted for in the appropriate category. When open-burning takes place in SWDS, burned fraction of DOC is subtracted from the DOC in SWDS (See Section 3.2.1 of Chapter 3, Volume 5 of the *2006 IPCC Guidelines*). If unburned carbon is placed at the surface of SWDS with aerobic condition, emission is not taken into account. When the condition is regarded as anaerobic by further piling of waste, this fraction is categorised in slowly degrading waste.

5.4.1.1 TOTAL CARBON CONTENT

No refinement.

5.4.1.2 FOSSIL CARBON FRACTION

No refinement.

² The parameters total carbon content in percent of dry weight and fossil carbon fraction in percent of total carbon content could be combined to the parameter: fossil carbon content in percent of dry weight.

5.4.1.3 OXIDATION FACTOR

When waste streams are incinerated or open-burned most of the carbon in the combustion product oxidises to CO₂. A minor fraction may oxidise incompletely due to inefficiencies in the combustion process, which leave some of the carbon unburned or partly oxidised as soot or ash. For waste incinerators it is assumed that the combustion efficiencies are close to 100 percent, while the combustion efficiency of open burning is substantially lower. If oxidation factors of waste incineration below 100 percent are applied, these need to be documented in detail with the data source provided. Table 5.2 (Updated) presents updated default oxidation factor for open burning of MSW and total carbon content in percent of dry weight of sewage sludge.

If the CO₂ emissions are determined on a technology- or plant-specific basis in the country, it is *good practice* to use the amount of ash (both bottom ash and fly ash) as well as the carbon content in the ash as a basis for determining the oxidation factor.

The 2006 IPCC Guidelines provide default oxidation factors for open burning of MSW. This refinement updates the default parameter of oxidation factor from experiment from Japan. The condition of combustion is smouldering with 35 percent of the moisture content. In updated Table 5.2, except the default values of oxidation factor of MSW and total C content in sewage sludge, all values are retrieved from the 2006 IPCC Guidelines.

5.4.2 CH₄ emission factors

CH₄ emissions from waste incineration are much dependent on the continuity of the incineration process, the incineration technology, and management practices. The most detailed observations have been made in Japan (GIO, 2004), where the following CH₄ emission factors based on technology and operation mode are obtained.

Continuous incineration includes incinerators without daily start-up and shutdown. Batch type and semi-continuous incineration mean that the incinerator is usually started-up and shutdown at least once a day. These differences in operation are at the origin of difference in emission factors. It is sometimes observed that the concentrations of CH₄ in the exhaust gas of the furnace are below the CH₄ concentrations in intake gas of the incinerator (GIO, 2005). Because of the low concentrations and high uncertainties, it is here *good practice* to apply an emission factor of zero (see Section 5.2.2.3).

For continuous incineration of MSW and industrial waste, it is *good practice* to apply the CH₄ emission factors provided in Volume 2, Chapter 2, Stationary Combustion. For other MSW incinerators (semi-continuous and batch type), Table 5.3 shows CH₄ emission factors reported by Greenhouse Gas Inventory Office of Japan (GIO, Japan). The CH₄ emission factors of other industrial waste incinerators are differentiated by waste type, rather than technology (GIO, 2005). In Japan, the CH₄ emission factors of waste oil and of sludge are 0.56 g CH₄/t wet weight and 9.7 g CH₄/t wet weight, respectively.

For open burning of waste, a CH₄ emission factor of 6500 g / t MSW wet weight has been reported (EIIP, 2001). This factor should be applied as a default, unless another CH₄ emission factor seems more appropriate.

If country-specific data are available, these should be applied instead and the method used to derive them as well as the data sources need to be documented in detail.

Type of incineration/technology		CH ₄ Emission Factors (kg/Gg waste incinerated on a wet weight basis)
Continuous incineration	stoker	0.2
	fluidised bed ^{Note1}	~0
Semi-continuous incineration	stoker	6
	fluidised bed	188
Batch type incineration	stoker	60
	fluidised bed	237
Note 1: In the study cited for this emission factor, the measured CH ₄ concentration in the exhaust air was lower than the concentration in ambient air. Source: Greenhouse Gas Inventory Office of Japan, GIO 2004.		

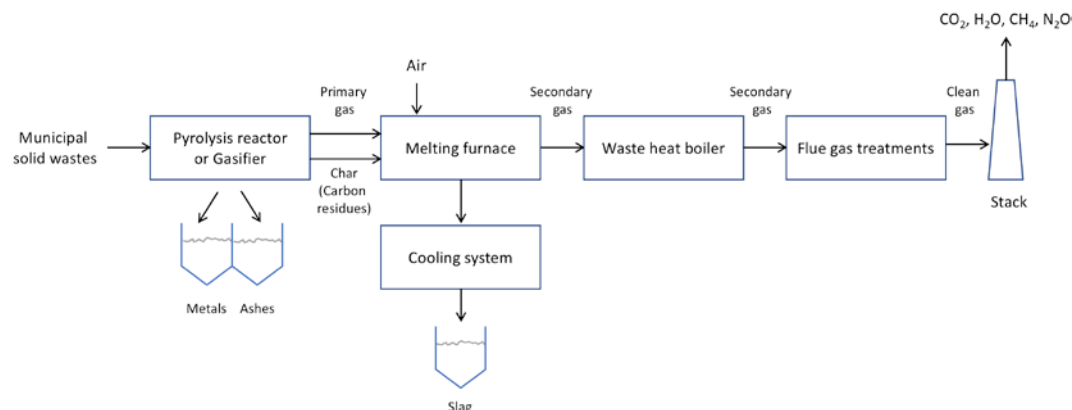
This refinement presents the emission factors of CH₄ for new technologies of pyrolysis and gasification. Although a plenty of information on CH₄ emissions from the pyrolysis and gasification of solid wastes are available from scientific research literatures (Box 5.2 (New)), very few data are obtainable for commercial plants of new technologies. Table 5.3a (New) shows the CH₄ emission factors of MSW from a combined system of pyrolysis-melting and gasification-melting processes on a commercial scale (Box 5.3 (New)). In commercially operated pyrolysis-melting and gasification-melting plants, condensable and non-condensable gases including CH₄ generated from the pyrolysis and gasification reactor are mostly oxidized at the subsequent melting furnace, leading to the low CH₄ emissions from the stack. If country-specific data are unavailable for pyrolysis-melting and gasification-melting plants, it is *good practice* to apply the default CH₄ emission factor corresponding to reactor type for both pyrolysis-melting and gasification-melting plants. The emissions of greenhouse gases from the combined system with energy recovery system are reported under the Energy Sector.

TABLE 5.3A (NEW)			
CH₄ EMISSION FACTORS FOR PYROLYSIS-MELTING AND GASIFICATION-MELTING PLANT OF MSW			
Process	Operating temperature (°C)	CH₄ Emission Factors (g/t waste on a wet basis)	Reactor Type
Pyrolysis-melting and gasification-melting	Pyrolysis: 300 ~ 600°C	5.81 ^{1,2} (n=11)	Shaft type
	Gasification: 700~900°C	9.70 ¹ (n=10)	Fluidized bed type
	Melting: 1300~1700°C	5.40 ¹ (n=5)	Rotary kiln type
¹ Ministry of the Environment, Japan (2010)			
² Lee <i>et al.</i> (2015)			

BOX 5.2 (NEW)	
INFORMATION ON CH₄ EMISSION FACTORS IN LABORATORY SCALE	
<p>A plenty of information on CH₄ emission from pyrolysis and gasification process in laboratory scale are available for various waste types and reaction conditions. According to the scientific research literatures (Rahman <i>et al.</i> 2001, He <i>et al.</i> 2010, and Wu <i>et al.</i> 2016), CH₄ emission from the pyrolysis and gasification process of solid wastes are dependent on the types of waste and technology as well as the operating conditions. CH₄ emissions from the pyrolysis and gasification process of solid wastes increase with increasing operating temperature. The higher pyrolysis temperature can supply more energy to break down the high-molecular-weight components of solid organic wastes into low-molecular-weight compounds such as CH₄.</p>	

BOX 5.3 (NEW)
COMBINED SYSTEM

For MSW treatment, a combined system of two processes was mostly introduced. The first process of the combined system is either pyrolysis or gasification, whereas the second one is represented by melting process.



In the first reactor where pyrolysis or gasification occurs, MSW are thermally decomposed to yield the primary gas with high heating values and carbon residues (char) in the absence of oxygen or oxygen starved environment. The primary gas and char are transported to the melting furnace operating at high temperatures ($>1000^{\circ}\text{C}$) under oxidation conditions. Primary gas and char are oxidized to produce the secondary gas at the melting furnace. After removing the air pollutants from the secondary gas, the flue gas mainly composed of CO_2 and H_2O is emitted to the air through the stack. Since pyrogas and syngas generated from pyrolysis and gasification, respectively, are mostly oxidized at the melting furnace, the emissions of greenhouse gases from the stack is expected to be negligibly low.

5.4.3 N_2O emission factors

Nitrous oxide emissions from waste incineration are determined by a function of the type of technology and combustion conditions, the technology applied for NO_x reduction as well as the contents of the waste stream. As a result, emission factors can vary from site to site.

Several countries have reported N_2O emissions from waste incineration in their national inventory reports. Table 5.4 shows examples of emission factors that have been used for incineration of MSW.

The differences in the emission factors are mainly caused by varying technologies in the context of NO_x removal.

TABLE 5.4
N₂O EMISSION FACTORS FOR INCINERATION OF MSW

Country	Type of Incineration / Technology		Emission factor for MSW (g N ₂ O/t MSW incinerated)	Weight basis
Japan ¹	Continuous incineration	Stocker	47	wet weight
		Fluidised bed	67	wet weight
	Semi-continuous incineration	Stocker	41	wet weight
		Fluidised bed	68	wet weight
	Batch type incineration	Stocker	56	wet weight
		Fluidised bed	221	wet weight
Germany ²			8	wet weight
Netherlands ³			20	wet weight
Austria ⁴			12	wet weight

¹ GIO, 2005.
² Johnke 2003.
³ Spakman 2003.
⁴ Anderl *et al.* 2004.

The emission factors of N₂O for pyrolysis, gasification, and plasma technology of waste vary with types of waste, reactor type, and operating conditions. In this refinement, updated N₂O emissions from pyrolysis-melting and gasification-melting plants for treating MSW are provided.

Since most national regulations for air pollutants rarely require monitoring N₂O emissions from thermal treatment plants of solid wastes, a few official data are available for N₂O emission from pyrolysis, gasification, and plasma plants. Especially, N₂O emission data are unavailable for plasma technology. Table 5.4a (New) indicates the N₂O emissions from pyrolysis-melting and gasification-melting plants of MSW on a commercial-scale basis. The emission factor of N₂O from pyrolysis-melting plant is much lower than that from shaft furnace reactor, indicating that the reactor type plays an important role in N₂O generation. It is also expected that the waste type and operating conditions influence the generation patterns of N₂O. If country-specific data are unavailable for pyrolysis-melting and gasification-melting plants, it is *good practice* to apply the default N₂O emission factor corresponding to reactor type for both pyrolysis-melting and gasification-melting plants.

TABLE 5.4A(NEW)			
N ₂ O EMISSION FACTORS FOR PYROLYSIS-MELTING AND GASIFICATION-MELTING PLANT OF MSW			
Process	Operating temperature (°C)	N ₂ O Emission Factors, (g/t waste on a wet basis)	Reactor Type
Pyrolysis-melting and gasification-melting	Pyrolysis: 300 ~ 600°C	17.4 ^{1,2} (n=11)	Shaft type
	Gasification: 700~900°C	5.80 ¹ (n=10)	Fluidized bed type
	Melting: 1300~1700°C	8.38 ^{1,3} (n=6)	Rotary kiln type

¹Ministry of the Environment, Japan (2010)
²Lee *et al.* (2015)
³Yoon (2017)

5.5 COMPLETENESS

No refinement.

5.6 DEVELOPING A CONSISTENT TIME SERIES

No refinement.

5.7 UNCERTAINTY ASSESSMENT

No refinement.

5.7.1 Emission factor uncertainties

No refinement.

5.7.2 Activity data uncertainties

No refinement.

5.8 QA/QC, REPORTING AND DOCUMENTATION

5.8.1 Inventory Quality Assurance/Quality Control (QA/QC)

No refinement.

5.8.2 Reporting and Documentation

No refinement.

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