

بيروت، في

## قرار رقم المعايير والشروط الدنيا المتعلقة بعملية التفكك الحراري

إن وزير البيئة،  
بناء على المرسوم رقم 8376 تاريخ 2021/10/10 (تشكيل الحكومة)،  
بناء على القانون رقم 216 تاريخ 1993/4/2 (إحداث وزارة البيئة)، لا سيما المادة الأولى منه،  
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يقرر ما يلي:

**المادة 1 - تحديد المعايير والشروط الدنيا**  
تحدد المعايير والشروط الدنيا الواجب التقيد بها بالنسبة لعملية التفكك الحراري وفق أحكام الملحق المرفق.  
يتوجب على كل جهة تتولى معالجة النفايات الصلبة البلدية من خلال التفكك الحراري اتخاذ الاجراءات  
الضرورية لوضع هذه المعايير والشروط الدنيا موضع التنفيذ

**المادة 2 - الملحق**  
يعتبر الملحق المرفق بهذا القرار جزءاً لا يتجزأ منه.

**المادة 3 - حق فرض معايير وشروط جديدة**  
تحتفظ وزارة البيئة بحق فرض معايير وشروط جديدة او تعديل اي منها عندما تدعو الحاجة.

**المادة 4 - الغاء القرارات المخالفة**  
تلغى كافة القرارات المخالفة لأحكام هذا القرار او غير المتفقة مع مضمونه.

**المادة 5 - نشر القرار والعمل به**  
ينشر هذا القرار ويعمل به فور نشره في الجريدة الرسمية ويبلغ حيث تدعو الحاجة.

وزير البيئة  
د. ناصر ياسين

# Standards and conditions for thermal disintegration and management of the ash

## Table of Contents

1. Scope.....	3
2. Definitions.....	3
3. General Requirements.....	4
3.1 Environmental Impact Assessment (EIA).....	4
3.2 Planning and sitting considerations.....	5
3.3 Application and permit.....	5
4. Design, construction and operation of WtEs.....	6
4.1 Reception of waste.....	6
4.2 Operating conditions.....	7
5. Air emission limit values.....	8
6. Water discharges.....	9
7. Residues.....	9
7. WtE Efficiency.....	10
7.1 Forms of WTE efficiency.....	10
7.2 Methods to measure boiler and steam turbine efficiencies.....	10
7.3 The EU R1 formula.....	11
ANNEX 1: The role of WtE in solid waste management.....	12
ANNEX 2: Thermal treatment technologies.....	13
Combustion.....	13
Combustion of Solid Alternative Fuel (SAF).....	13
Grate combustion.....	13
Fluidized bed combustion.....	15
Rotary kiln combustion.....	15
Gasification.....	16
Pyrolysis.....	16
Comparison of WTE options.....	16
ANNEX 3: Dioxins and furans.....	18
ANNEX 4: Additional requirements for EIAs about WtE facilities.....	19
ANNEX 5: Emission limits.....	22
Air emissions.....	22
ANNEX 6: Planning and design considerations for WtE plants.....	24
Selecting the Capacity of the WTE Plant.....	24
WTE plant configuration.....	24
Waste storage- the bunker.....	24
The combustion chamber.....	25
Waste Heat Utilization System.....	25
Cleaning of waste boilers, and refractory materials used.....	27
Hydraulic Transmission System.....	28
ANNEX 7: Air Pollution Control System, monitoring of emissions, and stack requirements.....	30
Brief overview of APC systems and pollutants.....	30
Deacidification System.....	30
Particulate Matter Removal System.....	31
Destruction of Dioxins.....	31
Removal of NOx.....	32

Monitoring of emissions .....	32
Stack requirements .....	33
ANNEX 8: Treatment of WTE by-products .....	34
WTE bottom ash discharge systems .....	34
Composition and Properties of WTE bottom ash .....	34
Management of WTE bottom ash.....	34
Composition and properties of WTE fly ash .....	35
Management of WTE fly ash.....	36
Characteristics of leachate produced in WTE plants .....	36
Leachate treatment .....	37
Odor treatment.....	37
ANNEX 9: Measurements.....	39

## 1 1. Scope

This regulation aims to establish minimum standards for facilities where municipal solid waste is processed through thermal treatment with energy recovery (further called “Waste to Energy facilities” or WtE).

These guidelines apply to the implementation of WtE for residential, commercial, and institutional solid wastes. Explicitly excluded are mining, agricultural, and industrial solid wastes; hazardous wastes; sludges; infectious wastes; classified or special waste. The role of WtEs in solid waste management and the relevant technologies are described in Annex 1. The different thermal treatment technologies that transform waste to energy are presented in Annex 2.

This regulation covers incineration plants. The following plants are excluded:

(a) Plants treating only the following wastes:

- (i) vegetable waste from agriculture and forestry,
- (ii) vegetable waste from the food processing industry, if the heat generated is recovered,
- (iii) fibrous vegetable waste from virgin pulp production and from production of paper from pulp, if it is co-incinerated at the place of production and the heat generated is recovered,
- (iv) wood waste with the exception of wood waste which may contain halogenated organic compounds or heavy metals as a result of treatment with wood-preservatives or coating, and which includes in particular such wood waste originating from construction and demolition waste,
- (v) cork waste,
- (vi) radioactive waste,
- (vii) animal carcasses as regulated by Directive 90/667/EEC without prejudice to its future amendments,
- (viii) waste resulting from the exploration for, and the exploitation of, oil and gas resources from off-shore installations and incinerated on board the installation;

(b) Experimental plants used for research, development and testing in order to improve the incineration process and which treat less than 50 tonnes of waste per year.

## 2 2. Definitions

For the implementation of this Decree, additionally, to the definitions of article 1 of Law No 80 “Integrated Solid Waste Management” dated 10 October 2018, the following definitions apply:

1. **Municipal waste:** means waste from households, as well as other waste which, because of its nature or composition, is like waste from households.
2. **Household Waste** is defined as waste produced within the curtilage of a building or self-contained part of a building used for the purposes of living accommodation.
3. **Feedstock:** means waste that contains materials that can decompose thermally.
4. **Residual Waste:** The fraction of collected waste remaining after a treatment or diversion step, which generally requires further treatment or disposal.
5. **Treatment/ Pre-Treatment** includes, in relation to waste, any manual, thermal, physical, chemical, or biological processes that change the characteristics of waste in order to reduce its volume, or hazardous nature or facilitate its handling, disposal or recovery.
6. **Thermal Treatment:** means incineration, gasification or pyrolysis as analysed below.

7. **Competent authority:** A regulatory body authorised by the government of the Republic of Lebanon to monitor compliance with the national statutes and regulations and carry out duties on behalf of the government in compliance with the law.
8. **Solid Alternative Fuel (SAF):** selected materials from the municipal and similar waste streams that have a high calorific value and can be shaped in a form that is safely used for energy recovery. Alternative terminology is Refuse Derived Fuel (RDF) and Solid Recovered Fuel (SRF)
9. **Incineration plant:** means any stationary or mobile technical unit and equipment dedicated to the thermal treatment of wastes with or without recovery of the combustion heat generated. This includes the incineration by oxidation of waste as well as other thermal treatment processes such as pyrolysis, gasification or plasma processes in so far as the substances resulting from the treatment are subsequently incinerated. This definition covers the site and the entire incineration plant including all incineration lines, waste reception, storage, on site pretreatment facilities, waste-fuel and air-supply systems, boiler, facilities for the treatment of exhaust gases, on-site facilities for treatment or storage of residues and wastewater, stack, devices and systems for controlling incineration operations, recording and monitoring incineration conditions.
10. **Nominal capacity:** means the sum of the incineration capacities of the furnaces of which an incineration plant is composed, as specified by the constructor and confirmed by the operator, with due account being taken, in particular, of the calorific value of the waste, expressed as the quantity of waste incinerated per hour.
11. **Emission:** means the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the plant into the air, water or soil.
12. **Emission limit values:** means the mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time
13. **Dioxins and furans:** means all polychlorinated dibenzo-p-dioxins and dibenzofurans listed in Annex 3
14. **Residue:** means any liquid or solid material (including bottom ash and slag, fly ash and boiler dust, solid reaction products from gas treatment, sewage sludge from the treatment of waste waters, spent catalysts and spent activated carbon) which is generated by the WtE facility, the exhaust gas or wastewater treatment or other processes within the WtE facility.
15. **Operator:** means any natural or legal person who operates or controls the plant or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the plant has been delegated;

## 3 3. General Requirements

### 3.1 3.1 Environmental Impact Assessment (EIA)

- (1) The siting, design, construction, operation, and closure of a WtE facility must be supported by an assessment of the environmental risk.
- (2) The competent authority must be informed by the environmental risk assessment submitted by a WtE owner/operator during the permitting process. The environmental risk assessment should address both normal, unusual, and unplanned operating conditions. It should cover the entire lifecycle of the WtE facility from initial construction to the point where the WtE facility no longer poses a risk to the environment. The eventual submission of the operational permit should form part of the environmental risk assessment and needs to be explicitly considered at the permitting stage.
- (3) The environmental risk assessment must inform permitting agencies for at least the following issues:
  - (a) Facility siting
  - (b) Protection of soil and water

- (c) Air pollution
- (d) Nuisances and hazards
- (e) Accidents and emergency response
- (f) Environmental monitoring system

(4) In addition, for the case of WtE facilities, an environmental risk assessment should include:

Air pollution modelling and expected health and environmental consequences

Bottom ash management plans and final use and/or disposal

Fly ash management plan

ANNEX 4 presents the details of the required additional environmental risk assessment for WtE plans.

### 3.2 3.2 Planning and siting considerations

The planning and siting considerations for WtE facilities should follow the requirements of “Standards and Conditions for the composting and biological disintegration process”. In addition, special emphasis should be given in the following criteria:

- Proximity to waste generation center: because WtE has no odours if it works properly, it can be easily located close to urban areas, this it can reduce a lot the costs of transportation.
- Proximity to electricity connection lines: the easy and close connection with the electricity network is an important criterion as it helps to avoid the high costs for expanding the network
- Proximity to district heating or cooling: this is an important criterion because it helps to increase the energy efficiency of the WtE plant
- Proximity to industrial steam consumers: this is an important criterion because it helps to increase the energy efficiency of the WtE plant
- Proximity to landfill (for ash disposal): this is also important to ensure easy and low-cost transportation of the ashes

### 3.3 3.3 Application and permit

(1) No incineration plant shall operate without a permit to carry out these activities.

(2) The application for a permit for an incineration plant to the competent authority shall include a description of the measures which are envisaged to guarantee that:

(a) the plant is designed, equipped and will be operated in such a manner that the requirements of this document are taking into account the categories of waste to be incinerated;

(b) the heat generated during the incineration process is recovered as far as practicable e.g. through combined heat and power, the generating of process steam or district heating;

(c) the residues will be minimized in their amount and harmfulness and recycled where appropriate;

(d) the disposal of the residues which cannot be prevented, reduced or recycled will be carried out in conformity with national legislation.

(3) The permit shall be granted only if the application shows that the proposed measurement techniques for emissions into the air and water comply with Annex 5.

(4) The permit granted by the competent authority for an incineration plant shall:

(a) list explicitly the categories of waste which may be treated. The list shall use at least the categories of waste set up in the European Waste Catalogue (EWC), if possible, and contain information on the quantity of waste, where appropriate;

(b) include the total waste incinerating capacity of the plant;

(c) specify the sampling and measurement procedures used to satisfy the obligations imposed for periodic measurements of each air and water pollutants.

(5) The permit granted by the competent authority to an incineration plant using hazardous waste shall in addition to paragraph 4:

(a) list the quantities of the different categories of hazardous waste which may be treated;

(b) specify the minimum and maximum mass flows of those hazardous wastes, their lowest and maximum calorific values and their maximum contents of pollutants, e.g. PCB, PCP, chlorine, fluorine, sulphur, heavy metals.

(6) The competent authority shall periodically reconsider and, where necessary, update permit conditions.

(7) Where the operator of an incineration plant for non-hazardous waste is envisaging a change of operation which would involve the incineration of hazardous waste, this shall be regarded as a substantial change and can not be implemented without the written approval of the MoE.

9. If an incineration plant does not comply with the conditions of the permit, in particular with the emission limit values for air and water, the competent authority shall take action to enforce compliance.

## 4 4. Design, construction and operation of WtEs

The design, construction and operational requirements of WtE plants are divided in two parts.

The first part concerns the general requirements on waste reception, supporting infrastructure, operational requirements, and management aspects, recording and reporting data etc. These requirements should follow the ANNEX 3 of the document “Standards and conditions for the mechanical sorting process”.

The second part concerns specific requirements that are for WtEs only. Annex 6 presents the main planning, design, construction and operational characteristics that should be considered for a WtE plant.

### 4.1 4.1 Reception of waste

(1) The operator of the WtE plant shall take all necessary precautions concerning the delivery and reception of waste in order to prevent or to limit as far as practicable negative effects on the environment, in particular the pollution of air, soil, surface water and groundwater as well as

odours and noise, and direct risks to human health. These measures shall meet at least the requirements set out in paragraphs 3 and 4.

(2) The operator shall determine the mass of each category of waste, if possible according to the European Waste Catalogue (EWC), prior to accepting the waste at the WtE plant.

(3) Prior to accepting hazardous waste at the WtE plant, the operator shall have available information about the waste for the purpose of verifying, inter alia, compliance with the permit requirements. This information shall cover:

(a) all the administrative information on the generating process contained in the documents mentioned in paragraph 4(a);

(b) the physical, and as far as practicable, chemical composition of the waste and all other information necessary to evaluate its suitability for the intended incineration process;

(c) the hazardous characteristics of the waste, the substances with which it cannot be mixed, and the precautions to be taken in handling the waste.

(4) Prior to accepting hazardous waste at the WtE plant, at least the following reception procedures shall be carried out by the operator:

(a) the checking of all the supporting documents on the supervision, and control of shipments of waste and by dangerous-goods transport regulations;

(b) the taking of representative samples, unless inappropriate, e.g. for infectious clinical waste, as far as possible before unloading, to verify conformity with the information provided for in paragraph 3 by carrying out controls and to enable the competent authorities to identify the nature of the wastes treated. These samples shall be kept for at least one month after the incineration.

(5) The competent authorities may grant exemptions from paragraphs 2, 3 and 4 for industrial plants and undertakings incinerating or co-incinerating only their own waste at the place of generation of the waste provided that the requirements of this legislation are met.

## 4.2 4.2 Operating conditions

(1) Incineration plants shall be operated in order to achieve a level of incineration such that the slag and bottom ashes Total Organic Carbon (TOC) content is less than 3 % or their loss on ignition is less than 5 % of the dry weight of the material. If necessary appropriate techniques of waste pretreatment shall be used.

Incineration plants shall be designed, equipped, built and operated in such a way that the gas resulting from the process is raised, after the last injection of combustion air, in a controlled and homogeneous fashion and even under the most unfavourable conditions, to a temperature of 850 °C, as measured near the inner wall or at another representative point of the combustion chamber as authorised by the competent authority, for two seconds. If hazardous wastes with a content of more than 1 % of halogenated organic substances, expressed as chlorine, are incinerated, the temperature has to be raised to 1100 °C for at least two seconds.

Each line of the incineration plant shall be equipped with at least one auxiliary burner. This burner must be switched on automatically when the temperature of the combustion gases after



the last injection of combustion air falls below 850 °C or 1100 °C as the case may be. It shall also be used during plant start-up and shut-down operations in order to ensure that the temperature of 850 °C or 1100 °C as the case may be is maintained at all times during these operations and as long as unburned waste is in the combustion chamber.

During start-up and shut-down or when the temperature of the combustion gas falls below 850 °C or 1100 °C as the case may be, the auxiliary burner shall not be fed with fuels which can cause higher emissions than those resulting from the burning of gasoil, liquefied gas or natural gas.

(2) Incineration plants shall have and operate an automatic system to prevent waste feed:

(a) at start-up, until the temperature of 850 °C or 1100 °C as the case may be or the temperature specified according to paragraph 4 has been reached;

(b) whenever the temperature of 850 °C or 1100 °C as the case may be or the temperature specified according to paragraph 4 is not maintained;

(c) whenever the continuous measurements required by this legislation show that any emission limit value is exceeded due to disturbances or failures of the purification devices.

(3) Conditions different from those laid down in paragraph 1 and, as regards the temperature, paragraph 3 and specified in the permit for certain categories of waste or for certain thermal processes may be authorised by the competent authority, provided the requirements of this legislation met. The change of the operational conditions shall not cause more residues or residues with a higher content of organic pollutants compared to those residues which could be expected under the conditions laid down in paragraph 1.

(4) Incineration plants shall be designed, equipped, built and operated in such a way as to prevent emissions into the air giving rise to significant ground-level air pollution; in particular, exhaust gases shall be discharged in a controlled fashion and in conformity with relevant community air quality standards by means of a stack the height of which is calculated in such a way as to safeguard human health and the environment.

(5) Any heat generated by the WtE process shall be recovered as far as practicable.

(6) Infectious clinical waste should be placed straight in the furnace, without first being mixed with other categories of waste and without direct handling.

(7) The management of the WtE plant shall be in the hands of a natural person who is competent to manage the plant.

## 5 5. Air emission limit values

1. Incineration plants shall be designed, equipped, built and operated in such a way that the emission limit values set out in Annex 5 are not exceeded in the exhaust gas.

2. Air Pollution Control systems should follow, at least, the technologies described in Annex 7.

3. The results of the measurements made to verify compliance with the emission limit values shall be standardized with respect to the conditions laid down in Annex 9.

## 6 6. Water discharges

(1) Wastewater from the cleaning of exhaust gases discharged from an incineration plant shall be subject to a permit granted by the competent authorities.

(2) Discharges to the aquatic environment of wastewater resulting from the cleaning of exhaust gases shall be limited as far as practicable, at least in accordance with the emission limit values set in Annex 5.

(3) Subject to a specific provision in the permit, the wastewater from the cleaning of exhaust gases may be discharged to the aquatic environment after separate treatment on condition that:

(a) the requirements of relevant national and local provisions are complied with in the form of emission limit values; and

(b) the mass concentrations of the polluting substances referred to in Annex 5 do not exceed the emission limit values laid down therein.

(4) The emission limit values shall apply at the point where waste waters from the cleaning of exhaust gases containing the polluting substances referred to in Annex 5 are discharged from the incineration plant.

The operator shall take appropriate mass balance calculations in order to determine the emission levels in the final wastewater discharge that can be attributed to the wastewater arising from the cleaning of exhaust gases in order to check compliance with the emission limit values set out in Annex 5 for the wastewater stream from the exhaust gas cleaning process.

Under no circumstances shall dilution of wastewater take place for the purpose of complying with the emission limit values set in Annex 5.

(5) The permit shall set operational control parameters for wastewater at least for pH, temperature and flow.

(6) Incineration plant sites, including associated storage areas for wastes, shall be designed and in such a way as to prevent the unauthorised and accidental release of any polluting substances into soil, surface water and groundwater in accordance with the provisions provided for in relevant legislation. Moreover, storage capacity shall be provided for contaminated rainwater run-off from the incineration or co-incineration plant site or for contaminated water arising from spillage or fire-fighting operations. The storage capacity shall be adequate to ensure that such waters can be tested and treated before discharge where necessary.

Leachate treatment methods and management from WtE plants are referred to Annex 8.

## 7 7. Residues

Residues resulting from the operation of the WtE plant shall be minimized in their amount and harmfulness. Residues shall be recycled, where appropriate, directly in the plant or outside in accordance with relevant legislation.

Transport and intermediate storage of dry residues in the form of dust, such as boiler dust and dry residues from the treatment of combustion gases, shall take place in such a way as to prevent dispersal in the environment e.g. in closed containers.

Prior to determining the routes for the disposal or recycling of the residues from incineration and co-incineration plants, appropriate tests shall be carried out to establish the physical and chemical characteristics and the polluting potential of the different incineration residues. The analysis shall concern the total soluble fraction and heavy metals soluble fraction.

The management of residues (bottom and fly ash) is detailed in Annex 8.

## 8 7. WtE Efficiency

### 8.1 7.1 Forms of WtE efficiency

Combustion efficiency: Moving grate efficiency. Total Organic Carbon (TOC) and excess air in the exhaust steam. Associated with type of fuel.

Thermal efficiency: Heat exchanger of the boiler. Heat transfer from combustion process to water or steam in the boiler. Does not account for radiation and convection losses due to the boiler's shell, water column, or other components. Should not be used in economic evaluations.

Boiler efficiency: Fuel-to-steam efficiency. Typical defined by the manufacturer. It is defined as:

heat exported by the fluid (water, steam) / heat provided by the fuel.

Electrical efficiency: Fuel to electricity efficiency

Energy efficiency: Fuel to energy potential efficiency. Includes district heating/cooling/industrial steam.

### 8.2 7.2 Methods to measure boiler and steam turbine efficiencies

Boiler efficiency can be measured by the following methods:

#### **Method 1: Input-Output Method**

Ratio of the output/ input of the boiler.

Boiler output (in BTUs) by the boiler input (in BTUs) and multiplying by 100.

The actual input and output of the boiler are determined through instrumentation and the data are used in calculations that result in the fuel-to-steam efficiency.

#### **Method 2: The Heat Balance efficiency measurement method**

Accounts for all the heat losses of the boiler.

Subtracting from 100 percent the total percent stack, radiation, and convection losses.

**Stack Losses:** Stack temperature is a measure of the heat carried away by dry flue gases and the moisture loss. The stack temperature is the temperature of the combustion gases (dry and water vapor) leaving the boiler and reflects the energy that did not transfer from the fuel to the steam or hot water.

**Radiation and Convection Losses:** heat radiating from the boiler (radiation losses) and heat lost due to air flowing across the boiler (convection losses)

The steam turbine power output is mainly dependent on:

1) mass flow of steam (given by the size of the boiler)

2) inlet & outlet enthalpy (given by steam parameters, and available cooling, which sets the final expansion pressure)

Mollier diagrams, and/or thermodynamic tables are often used to estimate the steam turbine efficiency.

### 8.3 7.3 The EU R1 formula

Co-generation of electricity and heat can result in much higher recovery of energy. To encourage WtE plants to aim for high thermal efficiencies, the R1 rule is adopted. According to this rule, a WTE is considered as a recovery facility when the R1 factor, calculated as follows:

$$R1 = (2.6 MWh_{elec} + 1.1 MWh_{-heat}) / 0.97 MWh \text{ stored in the MSW}$$

Where the factors 2.6 and 1.1 express the energy required to produce electricity and heat, respectively, and the factor 0.97 the 3% expected heat loss in transforming chemical to thermal energy is greater than 0.6 (> 0.65 for recently built WTE plants). The challenge in many regions that want to build WTE plants is to find, or locate, companies near the WTE who can use the low-pressure steam, e.g. paper recycling or food processing plants.

## 9 ANNEX 1: The role of WtE in solid waste management

The waste hierarchy is a guide to sustainable waste management, according to the Law 80 on waste management. It lays down a priority order of what constitutes the best overall environmental option for managing waste. The order of the hierarchy (prevention, preparation for reuse, recycling, other recovery and disposal) means that energy from waste is generally considered to have an environmental performance inferior to recycling but superior to disposal through landfill or combustion without energy recovery.

In a perfect world all waste would be prevented, and the hierarchy would be unnecessary. However, in reality a range of social, economic, practical and technological reasons mean that different waste streams are currently best dealt with at different levels of the hierarchy – including through energy recovery.

In most countries it is readily acknowledged that many waste materials that could theoretically be recycled are not currently and go to energy recovery or landfill. It is important that the presence of energy recovery as an option does not diminish efforts to overcome the range of barriers to capturing and recycling these. However, it is equally important that while those barriers do exist, energy from waste is used effectively to ensure those materials do not go to a worse environmental fate in landfill. In this context energy from waste needs to support, not compete with, both increased diversion from landfill and increased recycling whilst also ensuring waste reduction and reuse is not compromised.

The real challenge is to generate value from waste in terms of saved natural resources. Material recovery is better than energy recovery in this respect when it comes to sorted, pure and homogenous high-value materials that are easily recovered such as plastic from industry, newsprint and where energy processes add no value such as pure glass and metals.

Energy recovery has, however, its place when it comes to materials that are not easily recycled such as soiled or contaminated materials, composite materials and materials with a quality not suited for recovery for instance due to deterioration of quality through cascading in the course of several recycling sequences. Energy recovery may also be the better choice for low-value materials such as wood and materials that require disproportionate resources to collect, handle, and recover in a separate process system.

WtE, where waste is thermally converted with energy recovery, generates primarily electricity and heat. A common benefit of energy and fuels, like SAF, from waste is that these outputs replace other energy resources, particularly fossil fuels and thereby their emissions of carbon dioxide. Plants for energy recovery from waste are thus dual purpose, replacing other energy resources and being part of the waste management system.

Energy recovery serves the same high-level objective as many material-recycling activities. For instance, one objective of recycling plastic is saving oil or natural gas, which are normally used for energy purposes. In similar manner oil, gas, or other primary energy resources are saved through energy recovery of plastics in WtE facilities producing electricity. Which process system is used depends on the outputs, processing efficiencies and local circumstances.

The feedstock for production of energy and fuels is basically municipal solid waste (MSW) collected at households and commercial waste with a character similar to household waste. It may also include certain types of industrial, construction and demolition waste (C&D waste) although these fractions are not normally counted as MSW.

WtE is used not only in large-scale applications, but also in small WtE plants that serve communities as small as 10,000 inhabitants. However, economies of scale dictate that for a WtE plant to be financially viable its capacity should not be below 150,000-200,000 tonnes/year. In this context, small cities may band together to build a WtE plant.

## 10 ANNEX 2: Thermal treatment technologies

### 10.1 Combustion

Complete combustion refers to thorough decomposition of combustible substances in the waste for the purpose of maximally reducing the waste and environmental pollution. The system operates with excess air, and temperatures  $>850\text{ }^{\circ}\text{C}$  and  $<1,100\text{ }^{\circ}\text{C}$ . The residence time of waste in the system is between 0.75 and 1.25 hours. The boiler, steam turbine, and air pollution control systems of the technologies described below, i.e. grate, circulating fluidized bed, and rotary kiln combustion are very similar. The heat generated by combustion is transferred through water walls and superheater tubes to the high-pressure steam that drives the turbine generator. The low-pressure steam from the generator exhaust can be used for district heating/cooling/industrial purposes. The most efficient WtE facilities are co-generators of electricity ( $> 0.5\text{ MWh/tonne}$  to the grid) and district heating/cooling/industrial steam ( $> 0.6\text{ MWh/tonne}$  to the grid).

The major index for combustion efficiency is CO content and excess air in the stack gas, and Total Organic Carbon of WtE bottom ash. The daily mean value of CO in the stack gas should be  $< 80\text{ mg/Nm}^3$ , and ideally  $< 50\text{ mg/Nm}^3$ . The excess air of the stack gas should be  $<10\%$ , and ideally  $<8\%$ . The total organic carbon of WtE bottom ash should be  $< 3\%$ , and ideally  $<1\%$ . Most WtE plants built in the last decade are of the grate combustion type.

The residence time (Volumetric flow of gases/ cross-section area= velocity; height/velocity=residence time) of combustion gases should be over 2 seconds within the combustion chamber ("first pass"). The flue gas velocity is about 2.5 m/s.

Air plays an important role in combustion, providing the oxygen required, so that waste can be completely burnt. The air system consists of primary, and secondary air. Primary air is extracted from the waste bunker to maintain negative pressure and prevent escape of odor therein. Secondary air is extracted from the top of the combustion chamber or the waste bunker.

#### 10.1.1 Combustion of Solid Alternative Fuel (SAF)

This process consists of feeding a thermal treatment plant with solid alternative fuel (SAF). A variation of the SAF process is also used in Mechanical Biological Treatment (MBT) processes, which treat mixed MSW and produce an SAF product that is co-combusted with coal in power and/or cement plants that must be equipped with Air Pollution Control (APC) systems. The specifications of SAF production are described in the document "Standards and Conditions for Alternative Fuel production".

#### 10.1.2 Grate combustion

Grate combustion is the most popular technology in mixed waste combustion plants.

A hydraulic piston is used to push waste into the grate, after it has fallen from the hopper. The grate can be inclined either forward or reverse-acting to the direction of solids flow; or roller grates, or horizontal grates; also, grates are either air-cooled, by means of the primary air flow, or water-cooled by water flowing through tubes installed within the grate bars. It is recommended that air cooled grates are used when the calorific value of the waste is between 6 and 10 MJ/kg; a partly water cooled grate if calorific value ranges between 10 and 12 MJ/kg; water-cooled grate if calorific value is over 12 MJ/kg.

The mechanical motion of the grate, and also the gravity force in the case of an inclined grate, slowly moves the bed of solids through the combustion chamber. The high temperature oxidation in the combustion chamber reduces objects as large as a big suitcase to ash that is discharged at the lower end of the grate. As of this time, there is no clear answer as to which type of moving

grate is the optimum one to use because this issue goes way beyond transport and chemical rate phenomena; it also involves capital and operating costs, maintenance, and plant availability. The choice of grate technology is made on the basis of proven performance and plant availability and the overall proposal and guarantees submitted by various providers of grate combustion technology. An important criterion for grate performance is the amount of carbon that is left in the ash leaving the furnace.

The excess air required for stoichiometric combustion in a moving grate reactor is about 4,000 Nm<sup>3</sup>/ ton of waste and the excess air amount is 60-80%. Grates usually have five to six sections with different amounts of primary air provided and temperature. The first section consumes 15% of the primary air distributed in the system, the second 20%, the third 30%, the fourth 20%, the fifth 10%, and the sixth 5%. The first section has temperature <150C, where drying of waste occurs. The second to fourth sections have temperatures between 850 and 1000C, and in many cases can go up to 1100C, and it is where combustion occurs. The fifth and sixth section is where the complete burnout of the organics occur.

Each line has 5 to 10 fans (1 to 2 for each combustion section), which convey primary air to the system. The fans are controlled by a frequency converter and can be independently adjusted based on the combustion of different areas, to control air for each chamber. Adjustment is flexible, reducing power consumption. In addition to the primary air used, the combustion chamber sidewall is cooled with air, reducing coke formation on the wall. Each line has a sidewall cooling fan. Air is sucked from the combustion chamber, and the sidewall cooling air heated can be mixed with primary air. The temperature of the mixed primary air reaches 180-200°C, effectively utilizing energy, and improving the thermal efficiency of the combustor. Secondary air nozzles are arranged on the front and rear walls of the secondary combustion chamber. Their number and position are determined by computational fluid dynamics (CFD) to ensure sufficient decomposition of harmful gases, complete combustion of combustible gasses, and reduction in pollutants such as CO, and NO<sub>x</sub> in the flue gas. Each combustion line has one secondary air blower, which is controlled through the frequency converter.

The reasons for the global dominance of the grate combustion technology are as follows:

Simplicity of operation: Grate combustion is a fully automated process, except for the two crane operators that feed the hoppers of the combustion furnace; even this part has been automated in some very recent WTE plants.

High plant availability: Grate combustion has been developed over half a century and the cumulated industrial experience has led to continuous improvement of equipment and operating methods. This, plus its simplicity of operation, has resulted in relatively low maintenance and downtime of grate combustion plants. Several providers of grate combustion furnaces will guarantee over 8,000 hours of operation in a year, that is, over 90% plant availability.

Personnel requirements and training: The accumulated experience of moving grate WTE plants have resulted in the fact that a grate combustion plant consisting of three parallel furnaces (lines) and combusting 960 tons per day each (40 tons/hour per line) requires full-time personnel of about 60 people. Also, the existence of operations of the same type elsewhere in other nations allows for easy training of personnel in nations that introduce WTE for the first time.

Although grate combustion is the dominant WTE technology at this time, novel WTE processes are constantly advancing and an alternative that is less capital intensive than grate combustion

may emerge. Therefore, it is recommended that municipal requests for proposals for thermal treatment of MSW include both older and new technologies, provided they meet the required performance criteria described later.

### 10.1.3 Fluidized bed combustion

The fluidization process converts a bed of solids into a fluid by introducing a gas flow through the bottom of the bed. As a gas is injected through the plate at a constantly increasing flow rate, at the beginning the particles remain at rest. However, as the gas flow increases the particles are lifted and the bed of solids starts behaving as a boiling liquid. At this stage, the bed motion is described as “bubbling fluid bed” (BFB); if there is an opening through the wall, some of the material from the bubbling bed will flow out through this opening (“overflow stream”). If the gas flow rate is increased further, the particles are lifted from the fluid bed and can be carried out of the reactor by the gas flow (“carryover stream”).

Most frequently “circulating fluid bed” is used to process mixed wastes, where the carryover stream from the fluid bed reactor passes through a cyclone that separates most of the solids from the gas stream and returns them to the fluid bed reactor for further processing. A heat transfer medium, such as sand, is added to the fluid bed and recirculated.

The excess air required for stoichiometric combustion in circulating fluidized bed (CFB) reactor is about 3,000 to 3,500 Nm<sup>3</sup>/ton of waste. The system usually operates with 40% excess air. The grate area of the system is 25 m<sup>2</sup>, and the height of the CFB reactor, measured from the air distributor to the top of the reactor, is between 20 and 25 m. The CFB reactors indicate a flue gas velocity of about 4.5 m/s.

The operating temperature in the combustion chamber is in the range of 840-950°C, for the following reasons:

- Ash does not melt at this temperature.
- The optimal desulfurization reaction temperature is 850°C.
- Alkaline metal in the waste do not sublime at this temperature, reducing cinder on the heated surface of the boiler.

A high combustion temperature also has advantages. Combustible loss of the fluidized-bed boiler mainly refers to loss of unburnt carbon in fine particles escaping from the separator, which depends on reaction dynamics. Therefore, high combustion temperature can shorten the burnout time, reducing combustion loss. Meanwhile, production of PCDD/Fs can be reduced. In view of combustion and pollutant emissions, it is desired to set the temperature at 900-950°C.

### 10.1.4 Rotary kiln combustion

A typical rotary kiln is connected to a secondary combustion chamber or afterburner. The kiln is the primary combustion chamber. These are generally 3 to 4.5 meters in diameter and 12 meters or so long, although there are up to 18-meter-long kilns. Wastes are fed in multiple locations to the front of the kiln on the left, solids are tumbled towards the discharge end of the kiln as the kiln rotates at several revolutions per minute. Organics are volatilized out of the solid waste and burned-out ash falls off the end of the kiln into either a wet or dry ash handling system, while the volatilized organics pass into the afterburner where their combustion is completed using additional burners mounted in the afterburner that can fire waste and/or auxiliary fuels. Hot gases exiting the afterburner pas into the air pollution control section of the system for additional gas clean-up. The temperature of the system is usually between 800 and



970 °C, whereas in the afterburner section the temperature can go up to 1,200 °C. Inside a rotary kiln stationary liquid nozzle and the feed chute for feeding solids should exist. Another important feature of proper operation of a rotary kiln is the ability to minimize and control fugitives at the feed and discharge ends of the kiln where the rotating kiln meets the stationary structures at either end. This is typically accomplished with some type of kiln seal system. Typically, overlapping steel plates mounted on the stationary wall adjacent to where the kiln meets up with it are used. The leaves are flexible and installed so that they exert pressure on the outside shell of the kiln. This system provides a good mechanical seal around the kiln at each end. There are also other seal systems in use in the industry that are equally effective.

## 10.2 Gasification

When organic materials are heated to temperatures over 450 °C with oxygen lower than that required for full combustion, they decompose to liquid and gaseous products. Hydrogen and carbon monoxide are the main gases produced, in addition to water, methane, and carbon dioxide. The process is called “gasification” and it is a combination of partial oxidation and volatilization of the contained organic compounds. Gasification in the first furnace is followed by combustion of the volatile gases (“syngas”) in a second furnace and boiler to produce steam: or by using the syngas in a gas engine or turbine to produce electricity. Waste should be pre-treated waste and it is then processed in a bed of sand, fluidized by air injection through nozzles in the floor of the furnace. Waste particle size is normally <200mm. Proportion of waste in the sand is in the region of 2-10%. Performance is dependent on the pre-treatment of the waste to appropriate particle size and the presence of abrasive material in the sand. The main advantage over grate combustion is the dramatic decrease in process gas flow, up to 75%. Also, the reducing atmosphere in the gasification process should result in lower NOX emissions than in the grate combustion process. However, the capital cost per ton of capacity were of the same magnitude as in grate combustion. Because of the use of electricity for high temperature gasification, it is expected that the energy production per ton of feedstock will not be higher than in the case of grate combustion. For example, a typical gasification process is expected to generate about 0.6 MWh/ton of MSW, considering that in case the syngas is combusted in a secondary chamber, the process is closer to a multiple stage combustion.

### 10.2.1 Pyrolysis

Pyrolysis is the thermal treatment of wastes using only external energy, that is, without any significant combustion of the wastes; no air is provided in the system and the temperature is between 400 and 600 °C. Pyrolysis can only be applied to source-separated plastic wastes that contain about 8 MWh of chemical energy per ton, to produce a liquid product that can be used as fuel in industrial boilers or the cement and energy sectors, and a char that can be used in cement manufacturing. The process usually uses a horizontal rotary chamber with length between 10 and 20 meters. The retention time of the source separated plastic wastes is up to 4 hours.

## 10.3 Comparison of WTE options

Waste to energy comes in several forms, as presented in Table 1, however only combustion based WtE is proven for mixed wastes. It has been applied successfully for many decades within the urban environment, in about 1,000 installations.

*Table 1: Comparison of Waste to Energy technologies*

	Pyrolysis	Gasification	Combustion
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Air provided to the system	No air	Sub stoichiometric air	Excess air
Feedstock	Source separated plastic materials	Source separated high calorific value materials, e.g. plastics, and paper, and biomass	Mixed wastes
Products	Liquid fuels, e.g. oil	Syngas (CO and H <sub>2</sub> )	Energy- electricity, and/or heat
By products	High char, unconverted solid will remain  Pollutants in reduced form (H <sub>2</sub> S, COS)	Char in low temperature; Vitrified slag at high temperature  Lower fly ash carry over, compared to combustion  Pollutants in reduced form (H <sub>2</sub> S, COS)	Bottom ash (inert), fly ash (hazardous)  Pollutants in oxidized form (SO <sub>x</sub> , NO <sub>x</sub> , etc.)
Maturity	Not proven for mixed waste - small scale, ~10 tpd	Not proven for mixed waste - many failures reported	Proven and dominant, ~1000 plants worldwide with capacities from 100 tpd up to 5,000 tpd  Flexible and optimized system

## 11 ANNEX 3: Dioxins and furans

### Equivalence factors for dibenzo-p-dioxins and dibenzofurans

For the determination of the total concentration (TE) of dioxins and furans, the mass concentrations of the following dibenzo-p-dioxins and dibenzofurans shall be multiplied by the following equivalence factors before summing:

		Toxic equivalence factor
2,3,7,8	— Tetrachlorodibenzodioxin (TCDD)	1
1,2,3,7,8	— Pentachlorodibenzodioxin (PeCDD)	0,5
1,2,3,4,7,8	— Hexachlorodibenzodioxin (HxCDD)	0,1
1,2,3,6,7,8	— Hexachlorodibenzodioxin (HxCDD)	0,1
1,2,3,7,8,9	— Hexachlorodibenzodioxin (HxCDD)	0,1
1,2,3,4,6,7,8	— Heptachlorodibenzodioxin (HpCDD)	0,01
	— Octachlorodibenzodioxin (OCDD)	0,001
2,3,7,8	— Tetrachlorodibenzofuran (TCDF)	0,1
2,3,4,7,8	— Pentachlorodibenzofuran (PeCDF)	0,5
1,2,3,7,8	— Pentachlorodibenzofuran (PeCDF)	0,05
1,2,3,4,7,8	— Hexachlorodibenzofuran (HxCDF)	0,1
1,2,3,6,7,8	— Hexachlorodibenzofuran (HxCDF)	0,1
1,2,3,7,8,9	— Hexachlorodibenzofuran (HxCDF)	0,1
2,3,4,6,7,8	— Hexachlorodibenzofuran (HxCDF)	0,1
1,2,3,4,6,7,8	— Heptachlorodibenzofuran (HpCDF)	0,01
1,2,3,4,7,8,9	— Heptachlorodibenzofuran (HpCDF)	0,01
	— Octachlorodibenzofuran (OCDF)	0,001

## 12 ANNEX 4: Additional requirements for EIAs about WtE facilities

### Air pollution modelling and expected health and environmental consequences

Air pollution modelling is a minimum requirement for an EIA concerning WtE facilities. Air pollution modelling should involve:

1. Identification of main emissions and pollutants including dioxins and furans, particulate and suspended particulate matter, sulphur dioxide, heavy metals, nitrogen oxide
2. Simulation of air pollution and dispersion modelling

The following factors that affect the transport, dilution, and dispersion of air pollutants should be considered:

- emission or source characteristics
- the nature of the pollutant material
- meteorological characteristics
- the effects of terrain and anthropogenic structures

3. Air quality assessment in the most vulnerable areas and closest residential areas

The impacts (caused by a given source) depends upon:

- The source characteristics like emission rate, stack height, and stack parameters like diameter, emission temperature and the momentum of the flue gas (its exit velocity); Since these parameters can be assumed to be the same for each location (they are spatially invariant), they will not enter the analysis. They will be kept constant in a reference scenario.
- The weather characteristics: depending on the distance of the different sites from each other, we can assume that they are subject to the same meteorological conditions (if they are close to each other), or that for each, a different micro-climate applies (e.g., a different wind rose); Therefore, the meteorological conditions may or may not be spatially invariant, depending on location.
- The location of the source relative to the target areas. While the the results for the same emission and meteorological parameters will always be the same irrespective of the absolute location of the source, the impacts depend on the characteristics of the target area such as landuse and population density: If the area near a source, or downwind of it is heavily populated (an urban center) the impacts will be considered greater than if that area is under, say, agricultural landuse.

Assessment of the expected health and environmental consequences should be implemented considering all the above requirements and steps.

### Bottom Ash management plans and final use and/or disposal

The non-combustible fraction of the waste charged to the furnace forms a residue (ash) remaining on the grate at the completion of the combustion cycle. This material is generally referred to as bottom ash, but is also called grate ash, slag or clinkers. About 20–25 wt% of the waste input to incineration is transferred to so-called incinerator bottom ash (IBA), which represents the major solid residue from municipal solid waste incineration. It is similar in appearance to a porous, greyish, silty sand with gravel, and contains small amounts of unburnt

organic material and chunks of metal. The bottom ash stream consists primarily of glass, ceramics, ferrous and nonferrous metals, and minerals.

Operating conditions of any WtE should ensure a proper conversion of the waste in such a manner that the resulting bottom ashes show either total organic carbon contents lower than 3 wt% or their loss on ignition is less than 5 wt%. The operators of such plants are required to minimise the amount and harmfulness of the residues and to recycle them, where appropriate, on or off site. Prior to recycling, chemical and physical properties and the polluting potential shall be assessed including the determination of the total soluble fraction and soluble fraction of heavy metals. In any case, bottom ash involves substances like heavy metals that may have an environmental impact, so this restricts the use of bottom ash from waste incineration mainly to well defined road construction purposes. Thus, there are only two ways to manage bottom ash:

- Disposal in landfills
- Use of bottom ash in road construction

For the disposal of bottom ash to landfills, the question is if it should go to a normal sanitary landfill or it can be disposed of to inert waste landfills. The main criterion for relevant decision should be the result of a leaching test, as it is presented in Annex 7.

Based on the previous, an EIA should provide a complete bottom ash management plan that will provide:

- The expected bottom ash quantities and composition
- The landfill that will be used for the bottom ash disposal
- The way bottom ash will be transferred and the way it will be disposed of
- The expected leachate generation from bottom ash (quantities and composition)
- The way bottom ash will be stabilized and the way the leachate will be treated
- An assessment of the environmental impacts that the disposal of bottom ash will create and how it will change the behaviour of the landfill body

If the bottom ash is going to be used in constructions, then the EIA should incorporate a relevant risk assessment considering all the criteria mentioned below. The following criteria should be considered:

- Composition; the content of mineral matter, inert fractions (glass and ceramics), metals and organic matter of the bottom ash has to be within a specified range.
- Stability of volume; the volume of the bottom ash has to be nearly constant to ensure, that technical buildings do not suffer any damage after the completion of the building.
- Resistance against frost; the bottom ash has to maintain its physical abilities at temperatures well below 0 °C.
- Resistance against sudden impacts; the bottom ash has to withstand high load impacts and shall not suffer in structure.
- Distribution of grain size; the size of the mineral grain has to be within a certain range to ensure, that the physical properties of the material are stable.
- Shape of the grain; the surface structure of the grain is important for the physical properties of the mineral material.
- Defined density to which the bottom ash can be compressed during construction (Proctor density).

- Characteristics of the material to interact with water; the bottom ash has to be stable against water penetration. The leaching of harmful substances has to be reduced to a minimum.

#### Fly ash management plan

Any WtE plant produces fly ash which consists of products in particulate form which are produced either as a result of the chemical decomposition of burnable materials or are unburned (or partially burned) materials drawn upward by thermal air currents in the incinerator and trapped in pollution control equipment. Fly ash may experience wide swings in the chemical composition of it. The major constituents of WtE fly ash are heavy metals, particularly lead, cadmium, and mercury. These metals may impact human health and the environment if improperly handled, stored, transported, disposed of, or reused.

Fly ash, usually in the order of 1-1.5% of the input waste is a hazardous waste stream and it should be either disposed of in a hazardous waste landfill or pre-treated before disposal in order to be stabilised and neutralised. Pre-treatment methods include cement stabilization, vitrification, melting, acid washing plus thermal treatment, stabilization by other chemicals like  $\text{FeSO}_4$ ,  $\text{CO}_2$ ,  $\text{PO}_4$ .

Based on the previous, an EIA should provide a complete fly ash management plan that will provide:

- The expected fly ash quantities and composition
- The pre-treatment method that will be applied
- The landfill that will be used for the fly ash disposal
- The way fly ash will be transferred and the way it will be disposed of
- The expected leachate generation from fly ash (quantities and composition)
- The way fly ash will be stabilized and the way the leachate will be treated
- An assessment of the environmental impacts that the disposal of fly ash will create and how it will change the behaviour of the landfill body

## 13 ANNEX 5: Emission limits

### 13.1 Air emissions

(a) **Daily average values**

Total dust	10 mg/m <sup>3</sup>
Gaseous and vaporous organic substances, expressed as total organic carbon	10 mg/m <sup>3</sup>
Hydrogen chloride (HCl)	10 mg/m <sup>3</sup>
Hydrogen fluoride (HF)	1 mg/m <sup>3</sup>
Sulphur dioxide (SO <sub>2</sub> )	50 mg/m <sup>3</sup>
Nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ) expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	200 mg/m <sup>3</sup> (*)
Nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity of 6 tonnes per hour or less	400 mg/m <sup>3</sup> (*)

### 13.2

(b) **Half-hourly average values**

	(100 %) A	(97 %) B
Total dust	30 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>
Gaseous and vaporous organic substances, expressed as total organic carbon	20 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>
Hydrogen chloride (HCl)	60 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>
Hydrogen fluoride (HF)	4 mg/m <sup>3</sup>	2 mg/m <sup>3</sup>
Sulphur dioxide (SO <sub>2</sub> )	200 mg/m <sup>3</sup>	50 mg/m <sup>3</sup>
Nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	400 mg/m <sup>3</sup> (*)	200 mg/m <sup>3</sup> (*)

### 13.3

(c) **All average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours**

Cadmium and its compounds, expressed as cadmium (Cd)		
Thallium and its compounds, expressed as thallium (Tl)	total 0,05 mg/m <sup>3</sup>	total 0,1 mg/m <sup>3</sup> (*)
Mercury and its compounds, expressed as mercury (Hg)	0,05 mg/m <sup>3</sup>	0,1 mg/m <sup>3</sup> (*)
Antimony and its compounds, expressed as antimony (Sb)		
Arsenic and its compounds, expressed as arsenic (As)		
Lead and its compounds, expressed as lead (Pb)		
Chromium and its compounds, expressed as chromium (Cr)		
Cobalt and its compounds, expressed as cobalt (Co)	total 0,5 mg/m <sup>3</sup>	total 1 mg/m <sup>3</sup> (*)
Copper and its compounds, expressed as copper (Cu)		
Manganese and its compounds, expressed as manganese (Mn)		
Nickel and its compounds, expressed as nickel (Ni)		
Vanadium and its compounds, expressed as vanadium (V)		

### 13.4

These average values cover also gaseous and the vapour forms of the relevant heavy metal emissions as well as their compounds.

- (d) **Average values shall be measured over a sample period of a minimum of 6 hours and a maximum of 8 hours. The emission limit value refers to the total concentration of dioxins and furans calculated using the concept of toxic equivalence in accordance with Annex I.**

Dioxins and furans	0,1 ng/m <sup>3</sup>
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- (e) **The following emission limit values of carbon monoxide (CO) concentrations shall not be exceeded in the combustion gases (excluding the start-up and shut-down phase):**

- 50 milligrams/m<sup>3</sup> of combustion gas determined as daily average value;
- 150 milligrams/m<sup>3</sup> of combustion gas of at least 95 % of all measurements determined as 10-minute average values or 100 mg/m<sup>3</sup> of combustion gas of all measurements determined as half-hourly average values taken in any 24-hour period.

Exemptions may be authorised by the competent authority for incineration plants using fluidised bed technology, provided that the permit foresees an emission limit value for carbon monoxide (CO) of not more than 100 mg/m<sup>3</sup> as an hourly average value.

## 13.5

## 13.6 Emission limit values for discharges of wastewater from the cleaning of exhaust gases

Polluting substances	Emission limit values expressed in mass concentrations for unfiltered samples	
	95% 30mg/l	100% 45mg/l
1. Total suspended solids as defined by Directive 91/271/EEC		
2. Mercury and its compounds, expressed as mercury (Hg)	0,03 mg/l	
3. Cadmium and its compounds, expressed as cadmium (Cd)	0,05 mg/l	
4. Thallium and its compounds, expressed as thallium (Tl)	0,05 mg/l	
5. Arsenic and its compounds, expressed as arsenic (As)	0,15 mg/l	
6. Lead and its compounds, expressed as lead (Pb)	0,2 mg/l	
7. Chromium and its compounds, expressed as chromium (Cr)	0,5 mg/l	
8. Copper and its compounds, expressed as copper (Cu)	0,5 mg/l	
9. Nickel and its compounds, expressed as nickel (Ni)	0,5 mg/l	
10. Zinc and its compounds, expressed as zinc (Zn)	1,5 mg/l	
11. Dioxins and furans, defined as the sum of the individual dioxins and furans evaluated in accordance with Annex I	►C1 0,3 ng/l ◀	

## 13.7



## 14 ANNEX 6: Planning and design considerations for WtE plants

### 14.1 Selecting the Capacity of the WtE Plant

Deciding on the required capacity of a WtE plant is critical. The served municipalities must consider the amount of waste that can be consistently delivered to the plant, day by day, throughout the year, considering:

- Current rate of waste generation and projected rate for next 20 years; projections should be based on population growth with time and also on further economic development.
- Current and projected rates of recycling and composting. International experience has shown that rigorous recycling and composting programs can increase the sum of recycling and composting rates to as much as 40% - 60% of the MSW generated in developed nations through long-term coordinated efforts including regulation, incentives, and public education. It is recommended that plans for a new WtE be accompanied by planning for single stream collection of designated recyclables (paper fiber, metals, and certain types of plastic and glass). Preferably, the collected recyclables should be brought to a Materials Recycling Facility built adjacent to the WtE plant where they are sorted out to marketable materials and the residue is combusted in the WtE. Collection of the recyclables can be done either formally, by the community, or informally by individuals who follow rules established by the community.

### 14.2 WtE plant configuration

In the case of communities where there is large seasonal variation of waste due to tourism, it may be necessary to provide for temporary storage of waste during the tourist season. Grate combustion WtE plants can be guaranteed to have 90% availability, i.e., to be in full operation 8,000 hours per year. For example, a 40 ton/hour line will process 40 x 8000 tons per year = 320,000 tons of MSW; however, smaller and larger capacity grates have been designed and are in operation. Most WtE plants consist of one to three lines in parallel. However, there are some larger plants with six combustion lines. Each line is provided with its own furnace, boiler and Air Pollution Control system. However, a common steam turbine can use the superheated steam generated in two or more lines. Also, the cleaned gas from all lines is led to a common stack. The number of lines and their capacity will depend on the requirements of each community. A community can plan the capacity of the plant according to its needs. It is important to mention that if the community cannot afford to build a plant as large as it would like to, it can always start by building fewer lines and expand the plant later. In such cases, the building housing the initial plant should be designed so as to allow for future expansion at minimum cost.

Besides the design, construction and operational characteristics that are mentioned in the regulations “Standards and Conditions for the composting and biological disintegration process” and “Standards and conditions for the Mechanical sorting process”, the following elements should be considered for WtE plants.

#### 14.2.1 Waste storage- the bunker

The collection trucks are weighed at the plant entrance and then enter the receiving area of the plant. This building is under negative pressure so that no odors are emitted to the surroundings when the building doors are open. The building air is used for combustion in the WtE furnaces. In the moving grate combustion process, the wastes are discharged from the collection vehicles into the waste bunker in a fully enclosed building. An overhead claw crane loads the solids into the feed hopper of the WtE furnace and a ram feeder at the bottom of the hopper pushes the wastes onto the moving grate.

The waste bunker should be large enough to hold over a seven (7) days feedstock.

#### 14.2.2 The combustion chamber

The combustion chamber is the heart of the WTE plant. The types of systems used to combust waste materials are described in Annex 2.

#### 14.2.3 Waste Heat Utilization System

Waste heat energy utilization methods include power generation, heat supply, and co-generation of heat and power. The heat contained in the combustion gases is transferred, through the water-cooled furnace water wall and superheater tubes, to the high-pressure steam that drives the turbine generator. Commonly used steam parameters for the production of electricity are 4 MPa/400°C, which relates to a typical threshold to avoid corrosion problems. The low-pressure steam from the generator exhaust can be used for district heating/cooling. The typical parameters are <1 MPa/80-120 °C for district heating, and <1 MPa/5-10 °C for district cooling. The exhaust heat can also be used for industrial operations, e.g. copper smelters, paper mills, desalination plants, etc. It should be noted that about 10-15% of the produced electricity is used to cover the needs of the plant, and about 10% are the convention and conduction losses of the process. The most efficient WTE facilities are co-generators of electricity (> 0.5 MWh to the grid) and district heating (> 0.6 MWh to the grid) per ton of MSW processed, depending on the calorific value of the waste and the needs of the market.

#### Waste Heat Boiler and Turbo Generator Unit

A Heat Recovery Steam Generator (HRSG) is an energy recovery heat exchanger that recovers heat from the waste gas stream. It produces steam that can be used in a process (cogeneration) or used to drive a steam turbine (combined cycle). In a WtE plant it consists of four passes: First pass: vertical radiation pass made of evaporator membrane walls with refractory lining and/or Inconel cladding on flue gas side; Second pass: vertical radiation pass made of evaporator membrane walls and possibly with additional evaporation bundle sections; Third pass: vertical convection pass made of evaporator membrane walls as well as with bundles of superheater and evaporator sections; Fourth pass: vertical convection pass with steel casing and bundles of economizer sections.

The steam boiler (passes 1-3) can be bottom or mid supported or even suspended. The fourth boiler pass is bottom supported. The steam drum is placed above the first boiler pass on the steel structure. HRSG boilers can be classified into vertical and horizontal boilers based on the arrangement. The structural difference between the two is that the heated surface of vertical boilers is arranged vertically in the flue, while that of horizontal boilers is arranged horizontally. During design and manufacturing, special technical requirements to prevent wear, ash blockage, corrosion, and air leakage should be taken into consideration. HRSG used for power generation usually use water pipes.

The process flow path for water-steam (left) and flue gas (right) in a WTE facility is presented in Figure 1.

The HRSG is one of the critical facilities of the whole waste combustion power plant. Its most important features are efficiency, flexibility, adaptability, and maintainability. Among these, adaptability appears to be most important, due to changes in heating value. Steam should be produced as continuously as possible, in such a way that the turbo generator unit can work efficiently. Combustors with large volumes are equipped with horizontal boilers, and boilers for

large-volume combustors are sometimes arranged in a  $\pi$  shape. The turbine type can be condensate, condensate extraction or backpressure, based on whether there are heat consumers. Air-cooled condenser installations are necessary where there are no other means of cooling. Low pressure high volume steam from a steam turbine exhaust is routed to a four-row air-cooled-condenser unit, where the steam is condensed in finned tube bundles; large fans (often 10 meters in diameter) force air flow across the condenser heat surface areas, thus removing the heat. The exhaust steam is condensed into water and pumped to the steam-sealing heater and low-pressure heater through the condensed water pump, finally entering the deaerator to start the next cycle.

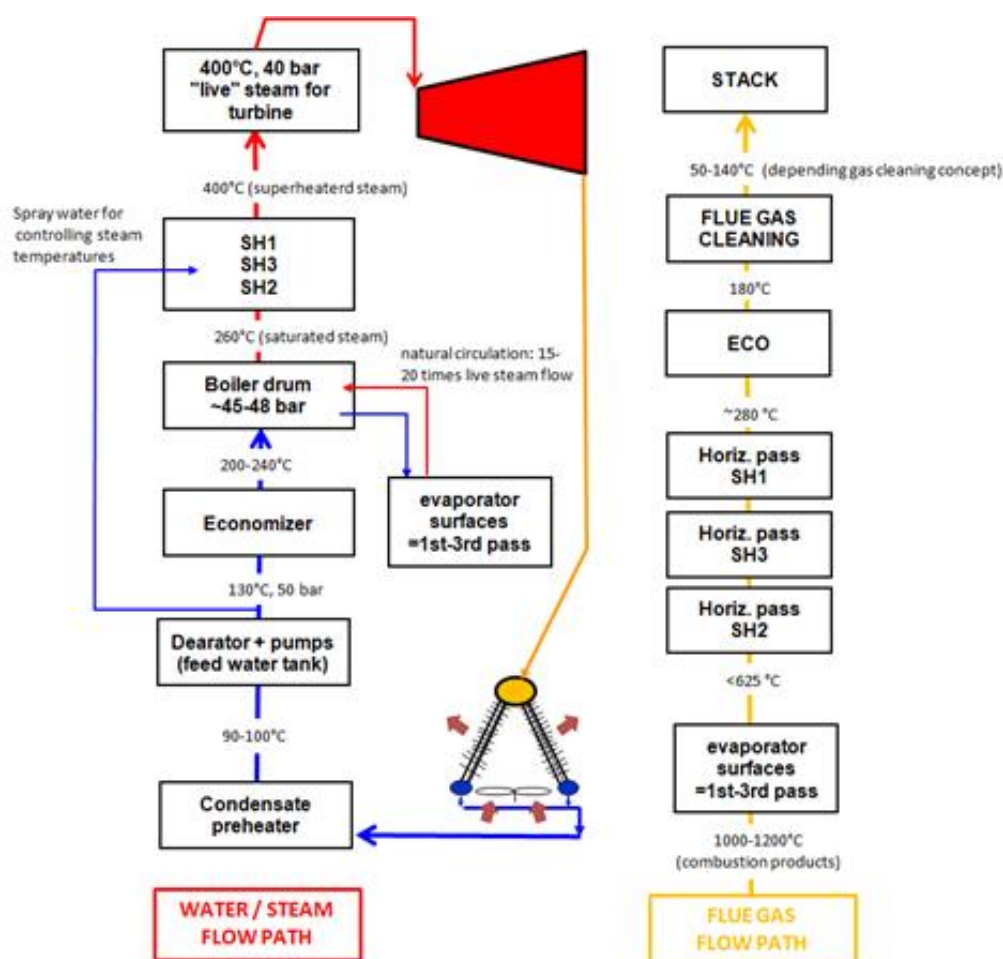


Figure 1: Process flow path for water-steam (left) and flue gas (right) in a WTE facility

As the fault rate of the turbo generator unit is low, two combustion lines can be equipped with one turbo generator when multiple combustion lines are built at the same time, making the system flexible and efficient. A common header system may be considered for the primary steam system, so that the generator unit and combustor can be coordinated more flexibly during maintenance. Waste combustion power plants should treat waste first and be equipped with a steam bypass system to guarantee normal operation of the power plant. When the turbo generator unit undergoes maintenance or breaks down, steam generated by the combustor/HRSG is condensed through the bypass system, so the generator unit can shut down without stopping the combustor, guaranteeing treatment capacity for the waste. The steam bypass condenser system can be independently arranged, or the turbine condenser can be

equipped with a bypass condenser system. During turbine stoppage, primary steam enters the bypass condenser through the bypass by way of the temperature and pressure reducers, and condensate is pumped into the deaerator through the condensate water pump. During normal system operations, the bypass system remains on standby, and is cut off through the bypass cutoff valve.

#### Combined Heating/Cooling and Power Generation System

The major forms include supply of power and hot water, and steam cooling. In this way, low-grade heat energy produced during power generation is used for heating or cooling. Electricity only plants indicate an efficiency of between 20-25%. Combined heat cooling and power generation indicate efficiencies of up to 50-70%. District heating condensers should be used for district heat production to upgrade the steam parameters. The steam temperature should be between 80 and 120 C, and the steam pressure usually <1MPa, both depending on the market. In case of cooling, absorption chillers should be used to reduce the steam temperature to 5-10 C. Such a setup does not require an air-cooled condenser, since all the heat is transferred to the heating/cooling/industrial network. Cross-over valve are used to drive steam to the district heating condensers as per required heating/cooling/industrial demand.

#### Improving Waste Heat Utilization Efficiency

WTE plants with classical steam parameters can consider the following to optimize energy production:

- Lowering deaerator temperature from the common 135 °C to 115 °C
- Lowering boiler outlet temperature of 180 °C further till 150 °C.
- After dust separation a second economizer (for condensate preheating or for district heating) cooling the flue gasses till 90 to 100 °C (below the acid condensation point)
- A third economizer at the end of the flue gas cleaning (before induced draft fan) to extract the condensation heat of the flue gases (for condensate preheating).
- Large condenser design to improve turbine vacuum.
- Flue gas recirculation as high quantity secondary air/gas, with tertiary air above it.
- Low stoichiometric combustion at 1.4 resulting in oxygen surplus of 6%.
- Highly efficient motor drives and the use of frequency converters to control them in order to avoid throttling by control valves.
- Recovery of heat from blow-down water and steam bleeds (like de-aerator off gas).
- Optimized steam bleeds from the turbine for staged heating of condensate, two stage heating of water for district heating and primary air heating.

### **14.3 Cleaning of waste boilers, and refractory materials used**

A waste incineration boiler is inevitably exposed to high fly ash loads. Hence, the effectiveness of the heat exchanger surface is reduced during the operation time by fouling. The purpose of on-line cleaning of the heat exchange surfaces is to extend the operating period and reduce maintenance cost. This can be accomplished by various means. The main options are:

- water shower cleaning
- sootblowers
- rappers

The refractory is different in various sections of the furnace and is optimized for:

- proper ignition of waste
- improved burnout of waste on the grate
- protection of heating surfaces from furnace erosion
- protect heating surfaces from high flue gas temperatures (corrosion protection)
- achievement of high residence time of the flue gases at high temperatures for a complete burnout

These requirements are satisfied by choosing appropriate materials and thickness of refractory in different zones. Bricks are used and replaced once damaged. Kiln or furnace re-bricking can take a week or more depending on how extensive the work is. Old, damaged refractory must first be removed, typically with jack hammers and intense manual labor once the unit has cooled sufficiently to allow workers inside. Then, once old materials are cleaned out, new brick or other types of refractory (like gunnite or castable refractory) can be installed. It is not unusual for several different refractory materials to be used in a single unit based on different physical and chemical resistance properties that need to be addressed.

Superheater tubes producing 400°C steam on a municipal waste facility are estimated to have a lifetime of up to 10-15 years, under the best conditions and with a modern boiler design. Waste boiler manufacturers generally do not recommend higher steam temperatures than 440-450°C unless special circumstances dictate otherwise. Methods of reducing corrosion include choosing high alloy steels, or especially resistant coatings.

#### 14.4 Hydraulic Transmission System

The hopper, hydraulic baffle, pusher, slag discharger, and grates share the same hydraulic station. The hydraulic device includes an oil tank, a motorized oil pump, and an oil-water heat exchanger. Each waste combustor is equipped with a dedicated hydraulic system, comprised of a hydraulic pump station, hydraulic valve station, an electrical control cabinet, and hydraulic pipelines. The hydraulic pump station supplies oil to the hydraulic valve station, the chain conveyor hydraulic cylinder, and the closed baffle hydraulic cylinder. The hydraulic valve station is integrated with the hydraulic valves of the feeding grates and the combustion grates. The hydraulic valve station valves control the movement direction and speed of the grates through the central control cabinet. Each pump station is provided with three adjustable plunger pumps (two for normal operation and one for backup). Pilot security valves and electromagnetic unloading valves are arranged at their outlets. Two working oil pumps, plus one standby, can be used alternatively, guaranteeing the reliability of the system. The adjustable plunger pumps can provide proper flow and pressure in accordance with the load requirements, avoiding unnecessary energy loss, saving energy, and reducing hot starts and temperature rises. A multilevel filter system is provided. The system oil outlet has a 5m fine filter, and the oil return port has a 10m filter. The system also has an independent oil filter system used to filter hydraulic oil in the oil tank, whose filtration accuracy is 3m. During operating of the hydraulic system, the filter system keeps running to guarantee good oil quality.



## 15 ANNEX 7: Air Pollution Control System, monitoring of emissions, and stack requirements

### 15.1 Brief overview of APC systems and pollutants

The Air Pollution Control (APC) systems of modern WTE facilities are amongst the most advanced of all high temperature industrial processes, including coal-fired power plants, metal smelters and cement plants. These results have been achieved by means of various APC systems. The simplest, effective and most frequently used APC system consists of:

- ammonia or urea injection for reducing the NO<sub>x</sub> content of the combustion gases,
- dry or semi-dry scrubbing with calcium hydroxide for SO<sub>2</sub> and HCl,
- injection of activated carbon for adsorbing organic and volatile metal molecules, and
- a fabric filter baghouse for removing particulate matter from the process gas before the stack.

### 15.2 Deacidification System

Three types of equipment for scrubbing acid gases are predominant for municipal waste combustors: dry injection, wet scrubbers, and semi dry scrubbers/adsorbers.

Capital and the specific sorbent costs should be primary selection criteria. Sorbents used: limestone, hydrated lime, natural trona and sodium bicarbonate. Lime sorbents must be injected near the high temperatures of the furnace and further down the flue-gas train in the range 450 °C to 600 °C. Trona, natural sodium carbonate or sodium bicarbonate can be injected in one place at much lower mass rates than the limestone products. These are injected at temperatures above 550 °C and a calcination process produces a very porous carbonate. The acid gasses react well with the high surface area of the carbonate. The effectiveness of the process requires stable temperatures at the injection point.

Dry injection of sorbent has the least capital cost for equipment, but has relatively poor stoichiometric efficiency, requiring more sorbent for a given reduction of acid gasses. Wet scrubbers have been used to a large extent in Europe for waste combustion facilities. They indicate higher stoichiometric efficiency and allow better separation of APC byproducts for potential reuse, e.g. gypsum. Typically, particulates are removed prior to the scrubber to limit solids in the caustic solution. Wet scrubbers spray a caustic solution of sodium hydroxide or calcium carbonate to cause a wet chemical acid base reaction. The spray can be in an open spray tower or over a packed bed. Sulfur can be recovered as calcium sulfate in a simple process when calcium sorbents are used. Sulfuric acid can be simply formed by mixing with water, but sulfuric acid is not very soluble in pure water. Sodium hydroxide is often used to control the acidity of the scrubber solution. In a semi-dry scrubber/adsorber system the first step is to introduce water and sorbent chemicals into the flue-gas stream through dual fluid nozzles or rotary atomizers (homogenize ashes by mixing ->more effective). Up-flow design exists, but the down-flow design is more widely used (in accordance with the use of fabric filters as the downstream particulate collectors); Fabric filters generally introduce the exhaust flue gasses into the bottom of the units; Prior to the gas drying wet alkaline reactions occur, but it is not until the gas has evaporated completely that the true chemical adsorption processes are optimized. Reactions continue with sorbent that remains in the ashcake deposited on the bags of a fabric filter, increasing the stoichiometric efficiency of the process. The primary design factor is flue-gas residence time after the gas is fully dried.

In WTE plants, a semi-dry reactor is typically used, by injection of hydrated lime ( $\text{Ca}(\text{OH})_2$ ) into the flue gas at the entry of a reactor or conditioning tower, located in front of the dedusting unit. The neutralization of acid gas starts at the injection point and continues down to the filter. The lime used ranges from 12 to 20 kg/ ton waste, depending on the feedstock. The working principle of rotation is that lime slurry is atomized into small particles of 30-100 $\mu\text{m}$  to improve deacidification efficiency. The revolving speed of the atomizing disc reaches 8000-15000 RPM.

### 15.3 Particulate Matter Removal System

In combination with the wet method, the particulate matter collector, e.g. baghouse filter or electrostatic precipitator, should be arranged upstream of the combined technology to avoid corrosion. In the dry or semi-dry combined method, it is arranged downstream. Baghouse dust collectors are more efficient in controlling dioxin emissions than the electrostatic precipitators and are most commonly used. The baghouse dust collector is a filtration device mainly for screening, while also separating gas from solids and collecting the particles in the filter bag, using short-range physical effects such as inertial collision, interception, and diffusion, and under certain conditions electrostatic effect and gravity, when the flue gas reaches the filter bag. The solids are removed through vibration and spraying using timed or fixed-resistance control. The dust collection efficiency is related to flue gas flow, temperature, dust content, particle size, filter speed, and filter bag materials. The baghouse dust collector consists of an ash hopper, baghouse, frame, maintenance and overhaul channel device, an isolation baffle for each chamber inlet and outlet, an ash hopper heater, bag sweep controller, and pulse valve, etc. Each collector is equipped with an airtight welding steel casing and isolation chambers, which can be fully separated from the flue gas during dust removal. The design of the housing and isolation chambers can bear the maximum system pressure difference. The support structure is made of steel. The filter bags of each chamber can be replaced while the dust collector is running. Flue gas containing dust enters from the air inlet, and large particles fall into the ash hopper with inertia and gravity. Fine dust enters the middle tank along with the flue gas and is filtered through the bag and retained on its outer surface. Dust accumulates on its surface, increasing filter resistance. When the internal and external pressure difference on the bag reaches a certain value, the blowing system starts working to remove dust. Clean air enters the upper tank and is emitted into the atmosphere. The key to whether the baghouse dust collector can realize its anticipated effect lies in the quality of filter materials on the dust collection equipment.

Filter materials commonly used are PPS, Nomex, P84, glass fibers, and pure PTFE, etc. Comparing various filtration materials and actual engineering applications, glass fiber PTFE and PTFE + PTFE membranes are superior in temperature, wear, hydrolysis, corrosion, and oxidation resistance. Glass fibers have poor folding ability, so they have strict requirements for transport, storage, and installation. Their thermal expansion rate is high, and back blowing will lead to breakage, affecting the service life of the filter materials. Using PTFE as the basic material can avoid these problems, prolonging the service life of the filter. PTFE film is a permeable and compact material. Dust on the filter material covered with film will not permeate into the fabric, causing blockage of the filter material. So-called "Surface filtration" not only prolongs the service life of the filter material, but also has lower resistance than "deep filtration."

### 15.4 Destruction of Dioxins

Dioxins (PCDD/PCDFs, etc.) are toxic and carcinogenic to humans and animals, so countries around the world have strict controls for their emission. For the purpose of controlling the emission concentration of dioxins, temperature and oxygen should be controlled, by considering NO<sub>x</sub> emissions as well.



Powder Activated Carbon (PAC) is a widely used absorbent, and its main principle of adsorption depends on a large specific surface area (its specific surface area is about 5,000-10,000 times that of carbon particles of the same quality). The system consists of a PAC silo, a feeder, an injection blower and an in-pipe reactor with injection nozzle and injection valve. The system removes heavy metals and organic compounds. PAC is transferred pneumatically from the silo to the exit pipe of the scrubber and is injected in the entrained reactor between the semi-dry scrubber and the bag filter. On average, 0.4-0.5 kg PAC/ton of waste is used, depending on the feedstock.

### 15.5 Removal of NO<sub>x</sub>

Formation of NO<sub>x</sub> in waste-to-energy plants is related to waste composition, combustion temperature, and nitrogen in the air. Generation of NO<sub>x</sub> can be reduced by optimizing the combustion and post-combustion process and controlling the combustion temperature at 850-1000°C. The amount of air in the first pass of the boiler should be adjusted, by conducting stoichiometric calculations on the amount of NO<sub>x</sub> produced. Typically,  $\lambda$  varies between 1.1 and 1.8, but advanced systems use 1.1 in the lower level, 0.8 in the middle level, and 1.4 in the upper level. The system is called very low NO<sub>x</sub>-gasification mode and achieve lower NO<sub>x</sub> emissions. Alternatively,  $\lambda$  in the lower and middle level should be 1.2 and in the upper level 1.5. The system is known as Very Low NO<sub>x</sub>.

The NO<sub>x</sub> removal methods mainly include SCR (selective catalytic reduction) and SNCR (selective non-catalytic reduction) or their combination, depending on the desired NO<sub>x</sub> levels. If the permit requires NO<sub>x</sub> levels <100 ppm, then SCR or a combined system that includes SCR should be used. SNCR involves the injection of ammonia (NH<sub>3</sub>) or urea (CH<sub>4</sub>N<sub>2</sub>O) into the backend of the combustion chamber to reduce NO to N<sub>2</sub>. Urea is a solid dissolved in water, and though the decomposition may start at 60 to 70 °C, it doesn't commence very fast until the water is completely evaporated. Ammonia though, is a gas dissolved in water and can thus be released immediately after having passed the nozzle where the pressure is lower and the temperature higher. It is easier to penetrate the bulk of the flue gas flow with urea, as it takes some time for the urea to be released, during which the droplets may travel quite far. Ammonia on the other hand is better at covering the area close to the injector / nozzle and may be the better choice if the residence time at the right temperature is short. Urea or ammonia are stored in a double- or single walled, horizontal or vertical non-pressurized vessels constructed from steel or FRP (fiber reinforced polyester) – complete with all necessary valves and instruments. In an SCR system, the reduction of NO by NH<sub>3</sub> is achieved at the surface of a catalyst, e.g. on V<sub>2</sub>O<sub>5</sub> stabilized in TiO<sub>2</sub>. First catalysts operated at temperatures between 300°C and 350°C. There are now catalysts available, which show satisfactory efficiency at temperatures between 220°C and 250°C, which can often be honeycomb type.

### 15.6 Monitoring of emissions

Continuous emissions monitoring systems (CEMS) should be used. Data should be collected every 10-30 minutes, and dioxins/furans should be monitored on a regular basis. Several methods should be used to ensure emissions comply with the established limits. These are typically: Direct measurement, which usually involves continuous measurement, and use of in situ or in-line measurement unit and/or use of on-line measurement unit for continuous sampling and measurement. Discontinuous measurements are encouraged that involve mobile measurement units, and/or lab measurement of samples collected in-situ or on-line. Calculation of surrogate parameters is often used, and mass balances should be developed. Calculations

should be conducted with regard to the quality and quantity of waste and established emission factors.

## 15.7

### 15.8 Stack requirements

Clean gas will reach the atmosphere with the use of an induced draught (ID) fan and a chimney. The fan will be centrifugal with a changing speed control. The fan wings will be made of material resistant to friction and the impeller will be placed among two bearings with grease lubrication and direct clutch with differentiating speed. The moving part will be placed in a cell with outer insulation to reduce thermal losses and noise. An outer part of steel and an inner part of steel plates resistant to corrosion. The outer part should be insulated too. Also, a layer of paint will be used. A metallic door at the lower part should be used, a lightning rod, a proper beam for airplanes and appropriate lighting for warning of aviation. Points for manual sampling should be established, as well as connection points for on-line measurement of emissions. Access platforms to the sampling points and a ladder with a platform at its top should be used. Local conditions such as wind parameters and landscape as well as the expected amount of flue gases determine the chimney height for efficient dispersion. Usually, the height is not less than 65m in flat areas, and >80 m in mountainous areas.

## 16 ANNEX 8: Treatment of WTE by-products

### 16.1 WTE bottom ash discharge systems

WtE bottom ash is normally discharged into water on leaving the combustion chamber, producing wet-discharged bottom ash. Recent developments allow the use of dry-discharge systems that indicate improved metal recovery. In a wet discharge system, bottom ash is discharged into a water tank below the furnace. The discharge rate is typically between 4.5 to 12.0 m<sup>3</sup>/h. Temperature and water absorption of bottom ash control the water consumption. The amount of water provided to the discharger is sufficient to quench the bottom ash and recirculation or overflow of water is not required. The discharger is usually filled with water and a constant amount of bottom ash up to the level of the front air sealing wall. This creates an air seal against the furnace and therefore preventing flue gas and thermal pollution in the basement and false air ingress into the boiler. The discharging ram forces bottom ash under the air sealing wall towards the drop-off edge without creating any dust or odours. There is a drain-off section before the drop-off edge where excess water is extracted by the compressing action of the discharging ram. Bottom ash is therefore moist rather than wet when discharged. The discharger is driven either by a separate or a central hydraulic unit. A pressure piston is typically pushing the quenched bottom ash out of the discharge system and onto conveyor belts leading to a bottom ash bunker/silo. The cadence of the pressure piston can be regulated by timer or by the height of bottom ash in the shaft using sensor techniques. Some instalments use a metal belt conveyor or chain belt conveyor to continuously remove the quenched slag. The water used is about 50 m<sup>3</sup>/1,000 tonnes bottom ash discharged. In a dry ash discharge technology, bottom ash is cooled by the aid of tertiary air and transferred by a rotating metallic conveyor belt to a screen that removes oversize particles (>9 mm). The fine fraction (<1 mm) is removed by a cyclone separator and very fine particles (<500µm) entrained in the tertiary air are recirculated into the combustion chamber. Tertiary air is adjusted with respect to the secondary air of the combustion process to keep the amount of air the same. Wet systems are typically used.

#### 16.1.1 Composition and Properties of WTE bottom ash

WTE bottom ash, accounts for 80 to 90% of the total WtE residues, and its appearance is similar to porous sand with larger grey gravels. Bottom ash consists of glass, ceramics, ferrous and non-ferrous metals and inorganic and unburnt organic materials and corresponds to the residues occurring during waste combustion in the grate furnace. The molten aluminium, zinc, copper and lead can drip down into the hoppers and agglomerate as small stalagmites. These molten metals, together with fine glass and stones comprise the bulk of grate siftings, normally enriched in Al, Cu, Pb, Zn and Si. WtE bottom ash does not contain dioxins and volatile metals and its chlorine and sulfur concentrations are very low, and it is usually characterized as an inert material.

#### 16.1.2 Management of WTE bottom ash

Bottom ash processing typically uses standard drum or flat screen decks with mesh sizes to sort different size fractions and further metal recovery using magnetic and eddy current separators. These techniques are low cost and effective methods. Magnetic separation is typically applied for the removal of ferrous metals in the bottom ash recycling plants. Stainless steel, which is also present in the total ferrous fraction of bottom ash, cannot be removed by magnetic separation. There are many different types and setups of magnetic separation. The most common in bottom ash sorting are magnetic drum and overhead suspension magnets. The setup of the magnets varies depending on the material flow, particle size, magnet strength and size and material velocity. A very important step in the removal of metals is an efficient fractioning system of bottom ash. Sorting of metals is strongly dependent on the accurate definition of fractions. The

sieve type in the sorting system depends on the sizing. Eddy current separation (ECS) is a technique for separating nonmagnetic metals from a material stream. The eddy current machine consists of a conveyor with a non-magnetic drum. The drum is equipped with an internal rotating set of magnets. The magnets inside the drum create repulsive forces, pushing non-ferrous metals on a path away from the drum. Other processes are available, e.g. induction sorting, but not used.

In several nations, the >2 mm sorted fraction of bottom ash after metals separation, is used beneficially for civil engineering applications, e.g. road construction, remediation of extinct mines, etc.; most often as substitute for stone aggregates and sand. The bottom ash aggregates must comply with stringent environmental, e.g. Leaching Assessment Framework (LEAF), and civil engineering standards.

The <2 mm does not have beneficial uses, and it is usually disposed of in landfills.

The following table present the EU limits for inert waste suitable for inert waste landfills. The compliance with limit values for inert waste landfills can be determined either by the test methods batch test at liquid to solid ratio 2 or 10 l/kg and percolation test at liquid to solid ratio 0.1 l/kg. The test methods correspond to the leaching test methods EN 12457/1-4 and EN 14405, which are in place in the investigated countries. These limit values are assumed to result in equal protection levels for soil and groundwater.

*Table 2: Leaching test criteria for acceptance of bottom ash in inert waste landfills – bottom ash characteristics should not exceed the values of table below*

Liquid to solid ratio [l/kg]	EU landfill for inert waste		
	batch tests		percolation test
	2	10	0.1
Unit	mg/kg	mg/kg	mg/l
As	0.1	0.5	0.06
Ba	7	20	4
Cd	0.03	0.04	0.02
Cr (total)	0.2	0.5	0.1
Cu	0.9	2	0.6
Hg	0.003	0.01	0.002
Mo	0.3	0.5	0.2
Ni	0.2	0.4	0.12
Pb	0.2	0.5	0.15
Sb	0.02	0.06	0.1
Se	0.06	0.1	0.04
Zn	2	4	1.2
Chloride	550	800	460
Fluoride	4	10	2.5
Sulphate	560	1,000	1,500
Phenol index	0.5	1	0.3
DOC	240	500	160
TDS	2,500	4,000	-

## 16.2 Composition and properties of WTE fly ash

Fly ash accounts for 1 to 3wt.% of the total WTE residues, and it consists of products in particulate form which are produced either as a result of the chemical decomposition of burnable

materials or are unburned (or partially burned) materials drawn upward by thermal air currents in the incinerator and trapped in pollution control equipment. Constituents in both ash and scrubber product vary, depending on the materials burned. The major constituents of concern are heavy metals, particularly lead, cadmium, and mercury. These metals may impact human health and the environment if improperly handled, stored, transported, disposed of, or reused (for example, using stabilized ash in construction materials such as concrete blocks). The more volatile elements (e.g. Cd, Hg, As, Pb and Zn) are partitioned in the fly ash and acid gas scrubbing residues. Fly ash is often characterized as hazardous material, however, because of the injection of lime in the APC systems, fly ash indicates cementitious properties.

### 16.2.1 Management of WTE fly ash

Cement is the most commonly used hazardous waste stabilizer. Cement-based solidification is a method of solidifying waste based on hydration and gelatinization of cement. The cement is an inorganic gelatinization material and can be hard cement solidified through hydration. Fly ash is incorporated into the cement base, and the mobility ratio of waste in the waste-cement base can be decreased through physical and chemical actions under specific conditions. Typically, the ratio of water and cement: fly ash is 90-95: 5-10. At present solidification technology using cement as a base material has proven to be one of the most widely applicable technologies. Water is used as reactant for this technology, and the process indicates low cost and equipment investment. The use of chemical additives greatly improves the stabilization level and has a profound effect on the safety of the hazardous waste treatment system. Inorganic chemical additives are generally sulfur-containing or phosphate-based compounds, which form different sediments by reacting with heavy metals in the fly ash to stabilize the metals. Organic chelating additives mostly include sulfur-containing alkaline agents, which dissolve soluble heavy metals. With the combined use of chemical additives, e.g. chelating agent, and cement, the problem of the poor stability of cement-based solidification is avoided, and the leaching toxicity of waste is reduced.

Often, the WTE fly ash is mixed with WTE bottom ash, and cement to form concrete blocks that can be used for civil engineering applications, if they comply with strict leaching standards. Thermal treatment methods have been used, e.g. melting, vitrification, but are not cost-effective as yet, considering that the heat required is typically >2,000 °C, and the energy consumption is significant.

## 16.3 Characteristics of leachate produced in WTE plants

Aside from the bottom ash and fly ash, waste-to-energy plants produce wastes such as leachate, wastewater and leachate treated sludge. The waste leachate is dark brown, sticky and odorous. It is a form of high-concentration organic wastewater that contains heavy metal and phytonutrients (e.g. ammonia nitrogen) in addition to organic pollutants. In general, food waste accounts for 45-60% of the total amount of waste. The more food waste contained in the municipal solid waste, the higher the COD and BOD5 concentration in leachate. COD in leachate is usually between 20,000mg/L and 70,000mg/L, and can be up to 80,000mg/L in some regions. B/C is mostly over 6, and water biodegradability is good. The ammonia-nitrogen concentration of leachate can reach 1500-2500mg/L, nitrogen in the leachate always exists in the form of ionic ammonia nitrogen, accounting for 75-90% of total nitrogen. Leachate contains a high content of heavy metals such as Fe, Cu, Zn, Pb, Cr, As, and Cd. Waste leachate contains an abundance of sodium salt, sylvite, calcium salt, and magnesium salt, mostly existing in the form of chloride and sulfate. TDS is generally up to 10,000mg/L, and its hardness is always over 1000mg/L (calculated as calcium carbonate). Data indicates that the daily output of waste leachate is 15-30% of entry waste. The temperature, season and regions have a strong impact on the production of leachate.

The leachate production of the waste-to-energy plant is determined based on the following formula:

$$Q = [(C \times f) / (1 - b)] \times b + q$$

where Q refers to leachate production, m<sup>3</sup>/d; C refers to the intended entry waste volume, t/d; f refers to overload coefficient of the combustion power plants, which should be 1.0-1.2; b refers to moisture content of entry waste, which should be 20-35%; q refers to other sewage volume, m<sup>3</sup>/d.

### 16.3.1 Leachate treatment

The Water Quality Standard for Industrial Uses (GB/T 19923-2005) should be considered. Leachate from waste-to-energy plants can be divided into three stages: pretreatment, biological treatment, and advanced treatment. The combination of processes can be selected based on the quality and quantity of the leachate influent water, as well as discharge or reuse requirements. Pretreatment mainly refers to removing large-particle contaminants, inorganic impurities, and some organic pollutants through coagulation and sedimentation or screening. Biological treatment refers to performing aerobic treatment, anaerobic treatment, and their combination on organic pollutants in the leachate such as nitrogen and phosphorus. Advanced treatment refers to the use of measures such as nanofiltration and reverse osmosis on the suspended particulates, colloidal substances, macromolecular organic matter, salt, bacteria, and viruses in the leachate. Proper disposal of leachate in conformance with discharge or reuse requirements is necessary to avoid secondary pollution caused by waste combustion.

### 16.4 Odor treatment

A municipal solid waste leachate unit is always installed at waste-to-energy plants. Odor emitted from the leachate state is low in concentration and can be incinerated in the waste-to-energy unit as primary air, and in general this does not require independently equipping the deodorization system. Tailgas produced from odor combustion will enter the air pollution control system matched with the waste-to-energy unit and emitted after treated to satisfy standards. If a waste-to-energy plant is not equipped to accept odors, arrangements should be made for the odor treatment system to treat odor as required before emission. The emission standard should satisfy the requirements of EIA and local governments for the project. If no special requirements are specified, the emission standard should observe the relevant stipulations in the Emission Standards for Odor Pollutants (GB14554-93). If consideration is being given to building the independent odor treatment systems, methods such as chemical absorption, biotreatment, advanced oxidation, adsorption, and combustion can be employed, and odor should be emitted only when purified to meet standards.

Odor pollutants produced by leachate treatment, including high-concentration odorous substances of the water intake section (primary sedimentation tank, and regulating reservoir), the anaerobic section (distribution well, and de-nitrification tank), the sludge treatment section (sludge tank, dehydration-liquid temporary storage tank, sludge hopper, sludge dehydration chamber, sludge dehydration unit, and sludge conveyor), should be collected and treated in a sealed manner. Odorous pollutants produced by leachate treatment are classified into five categories: sulfocompounds (H<sub>2</sub>S, SO<sub>2</sub>, CS<sub>2</sub>, mercaptan, and thioether etc.), nitrogenous compounds (ammonia gas, amine, amide, and indol etc.), halogens and derivatives (chlorine, and halohydrocarbon etc.), hydrocarbons and aromatic hydrocarbons, oxy-organics (alcohol, phenol, aldehyde, ketone, and organic acid etc. There are eight odorous substances that have the

greatest impact on human health - H<sub>2</sub>S, ammonia, trimethylamine, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, carbon disulfide, and styrene.

With regard to position of the leachate treatment station, odor-producing buildings should be grouped together at a site that is always downwind and kept a significant distance away from office areas and living areas by means of greenbelts. The source of odor should be closed and sealed (with fully closed covers) and equipped with an effective odor collector, and odorous air should eventually be dispatched to the waste-to-energy plant for combustion through air pipes and blowers. Selection of technologies to eliminate odors should be based on the odor composition and concentration, production, emission laws, biodegradability and toxicity, composition solubility, temperature, humidity, particle content, facility land area, investment cost, as well as operating and maintenance costs.

## 17 ANNEX 9: Measurements

(1) The following measurements of air pollutants shall be carried out in accordance with Box 1 at any WtE plant:

(a) continuous measurements of the following substances: NO<sub>x</sub>, provided that emission limit values are set, CO, total dust, TOC, HCl, HF, SO<sub>2</sub>;

(b) continuous measurements of the following process operation parameters: temperature near the inner wall or at another representative point of the combustion chamber as authorised by the competent authority, concentration of oxygen, pressure, temperature and water vapour content of the exhaust gas;

(c) at least two measurements per year of heavy metals, dioxins and furans; one measurement at least every three months shall however be carried out for the first 12 months of operation. Member States may fix measurement periods where they have set emission limit values for polycyclic aromatic hydrocarbons or other pollutants.

### Box 1: Measurement techniques

1. Measurements for the determination of concentrations of air and water polluting substances have to be carried out representatively.
2. Sampling and analysis of all pollutants including dioxins and furans as well as reference measurement methods to calibrate automated measurement systems shall be carried out as given by CEN-standards. If CEN standards are not available, ISO standards, national or international standards which will ensure the provision of data of an equivalent scientific quality shall apply.
3. At the daily emission limit value level, the values of the 95 % confidence intervals of a single measured result shall not exceed the following percentages of the emission limit values:

Carbon monoxide:	10 %
Sulphur dioxide:	20 %
Nitrogen dioxide:	20 %
Total dust:	30 %
Total organic carbon:	30 %
Hydrogen chloride:	40 %
Hydrogen fluoride:	40 %.

(2) The residence time as well as the minimum temperature and the oxygen content of the exhaust gases shall be subject to appropriate verification, at least once when the incineration plant is brought into service and under the most unfavourable operating conditions anticipated.

(3) The continuous measurement of HF may be omitted if treatment stages for HCl are used which ensure that the emission limit value for HCl is not being exceeded. In this case the emissions of HF shall be subject to periodic measurements as laid down in paragraph 1(c).



(4) The continuous measurement of the water vapour content shall not be required if the sampled exhaust gas is dried before the emissions are analysed.

(5) Periodic measurements as laid down in paragraph 1(c) of HCl, HF and SO<sub>2</sub> instead of continuous measuring may be authorised in the permit by the competent authority in WtE plants, if the operator can prove that the emissions of those pollutants can under no circumstances be higher than the prescribed emission limit values.

(6) The results of the measurements made to verify compliance with the emission limit values shall be standardised at the following conditions and for oxygen according to the formula referred to Box 2:

(a) Temperature 273 K, pressure 101,3 kPa, 11 % oxygen, dry gas, in exhaust gas of WtE plants;

(b) when the wastes are incinerated or co-incinerated in an oxygen-enriched atmosphere, the results of the measurements can be standardised at an oxygen content laid down by the competent authority reflecting the special circumstances of the individual case;

Box 2: Formula to calculate the emission concentration at the standard percentage oxygen concentration

$$E_S = \frac{21 - O_S}{21 - O_M} \times E_M$$

$E_S$  = calculated emission concentration at the standard percentage oxygen concentration

$E_M$  = measured emission concentration

$O_S$  = standard oxygen concentration

$O_M$  = measured oxygen concentration

(7) All measurement results shall be recorded, processed and presented in an appropriate fashion in order to enable the competent authorities to verify compliance with the permitted operating conditions and emission limit values laid down in this legislation in accordance with procedures to be decided upon by those authorities.

(8) The emission limit values for air shall be regarded as being complied with if:

(a) none of the daily average values exceeds any of the emission limit values set out in Annex 5;

- 97 % of the daily average value over the year does not exceed the emission limit value set out in Annex 5;

(b) either none of the half-hourly average values exceeds any of the emission limit values set out in Annex 5, column A or, where relevant, 97 % of the half-hourly average values

over the year do not exceed any of the emission limit values set out in Annex 5, column B;

(c) none of the average values over the sample period set out for heavy metals and dioxins and furans exceeds the emission limit values set out in Annex 5;

(9) The half-hourly average values and the 10-minute averages shall be determined within the effective operating time (excluding the start-up and shut-off periods if no waste is being incinerated) from the measured values after having subtracted the value of the confidence interval specified in point 3 of Box 1. The daily average values shall be determined from those validated average values.

To obtain a valid daily average value no more than five half-hourly average values in any day shall be discarded due to malfunction or maintenance of the continuous measurement system. No more than ten daily average values per year shall be discarded due to malfunction or maintenance of the continuous measurement system.

(10) The average values over the sample period and the average values in the case of periodical measurements of HF, HCl and SO<sub>2</sub> shall be determined in accordance with the requirements of the EIA permit and Box 1.

(11) The following measurements shall be carried out at the point of wastewater discharge:

(a) continuous measurements of pH, flow and temperature

(b) spot sample daily measurements of total suspended solids;

(c) at least monthly measurements of a flow proportional representative sample of the discharge over a period of 24 hours of the polluting substances referred to in Annex 5;

(d) at least every six months measurements of dioxins and furans; however one measurement at least every three months shall be carried out for the first 12 months of operation.

(12) The monitoring of the mass of pollutants in the treated waste water shall be done in conformity with the national legislation and laid down in the permit as well as the frequency of the measurements.

(13) The emission limit values for water shall be regarded as being complied with if:

(a) for total suspended solids (polluting substance number 1), 95 % and 100 % of the measured values do not exceed the respective emission limit values as set out in Annex 5;

(b) for heavy metals no more than one measurement per year exceeds the emission limit values set out in Annex 5;

(c) for dioxins and furans, the twice-yearly measurements do not exceed the emission limit value set out in Annex 5.

(14) Should the measurements taken show that the emission limit values for air or water laid down in this legislation have been exceeded, the competent authorities shall be informed without delay.

