BEST AVAILABLE TECHNIQUES (BAT) FOR PREVENTING AND CONTROLLING INDUSTRIAL POLLUTION

Activity 7: Cross Country analysis of BAT and BAT-associated emission and environmental performance levels in Iron and Steel, Paper and Pulp, and Waste Incineration industries

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Activity 7: Cross Country analysis of BAT and BAT-associated emission and environmental performance levels in Iron and Steel, Paper and Pulp, and Waste Incineration industries

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This publication was developed in the IOMC context. The contents do not necessarily reflect the views or stated policies of individual IOMC Participating Organizations.

The Inter-Organisation Programme for the Sound Management of Chemicals (IOMC) was established in 1995 following recommendations made by the 1992 UN Conference on Environment and Development to strengthen co-operation and increase international co-ordination in the field of chemical safety. The Participating Organisations are FAO, ILO, UNDP, UNEP, UNIDO, UNITAR, WHO, World Bank, Basel, Rotterdam and Stockholm Conventions and OECD. The purpose of the IOMC is to promote co-ordination of the policies and activities pursued by the Participating Organisations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

Foreword

The Best Available Techniques (BAT) project was initiated by the OECD in 2016 to identify and share the best practices of countries with BAT-based policies and to help those considering adopting this approach for the first time. The BAT project is aligned with the United Nations' Sustainable Development Goals (SDGs), notably Target 12.4, which focuses on the environmentally sound management of chemicals.

The OECD's BAT project is advised by an Expert Group (i.e. EG on BAT), which consists of members from governments in OECD member and non-member countries, along with environmental non-governmental organisations (NGOs), industry, academia, and inter-governmental organisations (IGOs). The EG on BAT is a platform for exchanging expertise and experiences implementing BAT approaches. The project has developed six publications, which are available at Monitoring and preventing industrial pollution | OECD:

i. Activity 1, Policies on BAT or Similar Concepts Across the World (OECD, 2017[1]), describes how BAT are defined and embedded in national legislation in different countries and regions;

ii. Activity 2, Approaches to Establishing BAT Around the World (OECD, 2018[2]), presents various jurisdictions' procedures to determine BAT;

iii. Activity 3, Measuring the Effectiveness of BAT Policies (OECD, 2019[3]), analyses methodologies and data for the evaluation of the effectiveness of BAT-based policies in a range of countries and regions;

iv. Activity 4, Guidance document on determining BAT, BAT-associated emission and environmental performance levels, and BAT-based permit conditions (OECD, 2020[4]);

v. Activity 5, Value chain approaches to determining BAT for industrial installations, studying potential challenges and opportunities to effectively consider an industry's entire value chain when determining BAT (OECD, 2021[5]); and

vi. Activity 6, A cross-country analysis of BAT and BAT-associated emission and environmental performance levels for the Thermal Power Plants, Cement, and Textile sectors (OECD, 2022[6]).

This report marks the 7th Activity of the OECD BAT project, serving as a continuation of the cross-country analysis initiated in Activity 6. It focuses on conducting another cross-country analysis of BAT and BAT-associated emission and environmental performance levels within the iron and steel, paper and pulp, and waste incineration installations. Together, Activity 6 and Activity 7 collectively contribute to a comprehensive understanding of global BAT implementation. Building upon the findings from Activity 6, this report extensively references its findings to evaluate their applicability to the industrial processes examined in Activity 7. Through this iterative approach, the report aims to deepen our understanding of BAT implementation within the iron and steel, paper and pulp, and waste incineration industries.

The report does not cover other general matters that are already covered by the other activities of the BAT project, including how BAT is defined, applied, or implemented (Activities 1, 2, and 4), policy effectiveness and actual emissions achieved at the sector or installation level (Activity 3), and the production and update of BAT Reference Documents (Activity 6).

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Acronyms

ACI	Activated carbon injection (or carbon adsorbent injection)
ADt	Air Dry tonnes (of pulp) expressed as 90 % dryness.
AOX	Adsorbable Organic Halogen
BAT	Best Available Techniques
BAT-AEL	BAT-Associated Emission Level
BAT-AEEL	BAT-Associated Energy Efficiency Level
BAT-AEPL	BAT-Associated Environmental Performance Level
BEP	Best Environmental Practice
BF	Blast Furnace
BREF	BAT Reference Document
BOD	Biochemical Oxygen Demand
BOF	Basic Oxygen Furnace
BOPF	Basic Oxygen Process Furnace
CBA	Cost-Benefit Analysis
CMP	Chemi-mechanical pulp
CTMP	Chemithermomechanical pulp
CCGT	Combined cycle gas turbine
COD	Chemical Oxygen Demand
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DMR	Discharge Monitoring Report Database
DR	Direct reduction
DRI	Direct reduced iron
DS	Dry solids, expressed as weight %
EAF	Electric arc furnace
EC	European Commission
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EU	European Union
ELV	Emission Limit Value
EPA	Environmental Protection Agency
EPEP	Environmental Performance Enhancement Programme
ESP	Electrostatic Precipitation
FGD	Flue Gas Desulphurisation
FF or BF	bag/fabric filter, baghouse
GATPPC	Guidelines of Available Technologies for Pollution Prevention and Control
HAP	Hazardous Air Pollutant
IED	Industrial Emissions Directive

IMPEL	European Union Network for the Implementation and Enforcement of Environmental Law
IPPC	Integrated Pollution Prevention and Control
KEI	Key Environmental Issue –is a term used in some BREFs to identify priority substances and issues.
Kkg	kilograms per kilokilogram
MACT	Maximum Achievable Control Technologies
MSWI	Municipal Solid Waste Incineration
NESHAP	National Emission Standard for Hazardous Air Pollutants
OECD	Organisation for Economic Co-Operation and Development
SAB	Science Advisory Board
SCR	Selective Catalytic Reduction
SDG	Sustainable Development Goal
NGO	Non-governmental organisation
NCG	Non-condensable gases
PRTR	Pollutant Release and Transfer Registers
TOC	Total organic carbon
Total Bound Nitrogen (tot-N)	The sum of all nitrogen compounds and is standardised as DIN EN 12260:2003
tpd	Tons per day
Total phosphorus (tot-P)	Total phosphorus given as P includes dissolved phosphorus plus any insoluble phosphorus carried over into the effluent in the form of precipitates or within microbes.
TRS	Total Reduced Sulphur (composed of hydrogen sulphide, methyl mercaptan, dimethyl sulphide, dimethyl disulphide and other volatile compounds containing reduced sulphur).
TSS	Total suspended solids (in wastewater)
TWG	Technical Working Group
US	United States
VOC	Volatile organic compounds

Executive summary

Modern-day governments face challenges in strengthening their industrial regulations with the pressures stemming from achieving high-level environmental protection and moving forward with sustainable development goals. Best Available Techniques (BAT) are increasingly used by governments as a tool to establish evidence-based environmental permit conditions for industrial installations for better human health and environmental safety. These are the state-of-the-art techniques for preventing or minimising emissions from industrial activities and their impacts on the environment at a scale that enables implementation under economically and technically viable conditions. Relevant regulatory authorities are producing BAT reference documents (BREF) or BREF-like documents to assist local governments in setting achievable permit conditions for industrial facilities or entire industrial sectors.

The report investigates the BAT and their associated emission and environmental performance levels (BAT-AE[P]Ls) for three sectors: iron and steel, paper and pulp, and waste incineration. It covers the BAT used for emission control of pollutants, including resource and energy efficiency measures, across different countries and regions. It showcases the diverse BAT approaches adopted by the European Union (EU), the United States (US-EPA), India, Korea, China (People's Republic of China), and the World Bank Group to regulate these environmentally significant industries.

The key findings indicate divergence and possible areas of alignment among the six BREFs for each sector. While some consistencies are observed, variations in specific techniques for overarching pollution prevention control are noted. The BREF analysis identified descriptions of techniques and emission (or environmental performance) levels for different pollutants with varying degrees of stringency across sectors.

For the cross-country analysis, several pollutants were selected for an in-depth examination of their specific BAT and BAT-AE(P)Ls set in BREFs for three sectors, which are as follows:

- Iron and steel production sector: Air emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x), dust (Particulate Matter, PM), and heavy metals – mercury and dioxins from sinter plants. Air emissions of dust and water release of cyanides (CN–) and heavy metals (lead and zinc) from blast furnaces. Air emissions of dust, heavy metals – mercury and dioxins. From Electric Arc Furnaces (EAF), releases of heavy metals (zinc) to water.
- Paper and pulp production sector: Air emissions of total reduced sulphur (TRS), dust (Particulate Matter, PM) and nitrogen oxides (NO_x) from recovery boilers used in the kraft pulping process. Water releases of total suspended solids (TSS), chemical oxygen demand (COD) and adsorbable organic halides (AOX) from kraft pulping. Water releases of total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halides (AOX), total nitrogen (tot-N) and total phosphorus (tot-P) from paper manufacturing (from recycled paper). As a process efficiency measure, water consumption per tonne production was analysed for kraft pulping and recycled paper production.
- Municipal Solid Waste incineration: All incineration processes were included. Air emissions of dust (Particulate Matter, PM), nitrogen oxides (NOx), and ammonia (NH_3) resulting from the reduction

of NO_x, heavy metals (mercury, cadmium, and total metals), dioxins and furans (PCDD/F), hydrogen fluoride (HF), and hydrogen chloride (HCl).

- Carbon dioxide (CO_2) emissions from the three industries above are also recognised as an environmental concern and were briefly covered to indicate the national regulation strategies of governments.

In the BAT analysis (Chapter 3), most BREFs promoted several common BATs for the pollutants investigated, depending on the environmental media of their emission (or release). These observations are notable for the air emissions of nitrogen oxides (NO_x) and dust (Particulate matter) in the three sectors. Several end-of-pipe techniques (selective catalytic reduction (SCR), electrostatic precipitators (ESP), fabric filters/baghouses) and process-integrated techniques (low-NO_x) are commonly among the BREFs for these two pollutants.

Variations in BAT-AELs for the same pollutants across different sectors are observed in the BREFs. These variations can largely be attributed to the specific characteristics of individual industrial installations. The initial input and the specific industrial process used significantly influence the final abatement efficiency. This is why BAT-AELs are presented as ranges rather than unique values, even within the same industrial sectors. Additional factors contributing to these differences may include the legal obligations surrounding the application of the BREFs, the technical-economic status of a given jurisdiction, and the environmental concerns of the governments/regions. Measurement conditions and monitoring standards for the emissions/releases of pollutants in different countries also significantly influence the variations in the BAT-AELs. Reference conditions and contextual information provided with each BAT-AEL need to be considered when comparing emission levels between BREFs. Significant differences in the measurements and assessment conditions in different countries/regions may exist. Where available, averaging periods, monitoring methods, the reference oxygen level and standard conditions are given next to the reported emission values/standards from the different OECD countries (Chapter 4.).

Many countries began establishing BAT-based emission standards in the last decade, including the associated abatement techniques and monitoring requirements. Other countries with already existing BAT-based emission levels are steadily planning to update their BREFs based on the sectors' technological advancements and operational progress. The diversity of regulatory approaches for industrial pollution and prevention across different countries presents opportunities and challenges. The findings of this report offer technical insights for governments, policymakers, and industry leaders to shape their environmental strategies for iron and steel, paper and pulp and municipal solid waste incineration. This collective information from six BREFs provided for each sector may encourage and assist countries in their progress towards developing sector-specific BREFs. By identifying commonalities and variations in these sectors, governments and industry may collaborate towards an aligned regulatory landscape for higher environmental and public health protection.

Chapter 1. Introduction

1.1. Background

Best Available Techniques (BAT) is a term used to describe methods used in industries to prevent and control their environmental impacts. To varying degrees, individual jurisdictions have adopted an approach to defining BAT by producing reference documents known as BREFs (BAT reference documents). Many governments are developing or updating their BREFs to align with the most recent state-of-the-art technologies (or techniques). These documents provide a basis for regulating various industries and cover multiple environmental issues. The BREFs determine technical, design, and operational approaches as BAT, as well as quantitative emission and other performance standards, known as BAT-associated emission/performance levels (BAT-AELs / BAT-AEPLs).

The OECD's Chemicals and Biotechnology Committee (CBC) agreed in 2022 to carry out a comparative study of the BAT and BAT-AELs or BAT-AEPLs for selected sectors. Its objective is to outline the similarities and disparities in the regulatory and technical aspects of BREFs for three industries. These sectors are iron and steel, paper and pulp, and municipal solid waste incineration. The report examined the BAT and BAT-AE(P)Ls for several pollutants per sector in BREFs submitted by the members of the Expert Group on BAT. Six BREFs were identified for each of the three industries analysed in this study from China (People's Republic of China), the European Union, India, Korea, the United States, and the World Bank Group (International Finance Corporation-IFC). These BREFs cover different plant types, end-of-pipe product types and industrial processes. This breadth arises from multiple key regulatory, technical and regional factors, such as:

a. Diversity in the industrial composition of different countries, their natural resources and development. BREFs developed are specific to the environmental challenges presented by the sectors in a particular region.

b. Differences in the environmental regulations and the environmental concerns of countries/regions.

c. Specific BAT and manufacturing practices vary between countries due to differences in economic development, infrastructure, and technological capabilities.

d. Differences in the availability of raw materials, natural resources, and energy between countries/regions influence the selection of industrial processes covered in BREFs.

The information in this report, gathered from BREFs across three sectors, may be used by countries to establish their permits and policies based on the BAT approach. It includes BAT and BAT-AE(P)Ls from up to six BREFs for governments to consider adopting in their national systems. In the long term, this report may help to promote international harmonisation of information in the BREFs by providing comparative sector-specific information from various countries/regions to the relevant governmental bodies responsible for developing and updating BREFs.

1.2. Selected sectors and emissions

At its 6th meeting on 8-9 November 2021, the OECD's Expert Group on BAT (i.e. EG on BAT) agreed to focus on iron and steel, paper and pulp, and waste incineration for this cross-country analysis.

The six BREF documents for each sector cover many processes, sub-sectors, issues, and substances. This report assesses BAT and BAT-AE(P)Ls for selected pollutants for air emissions and/or water releases in each sector. These selected pollutants are typically of concern for the relevant industry but may not represent a significant emission issue for each country or region included in this study. Therefore, it should be noted that the pollutants and the types of plants/(sub)processes analysed in this study do not necessarily provide a complete set of the most significant environmental impacts caused by the three sectors.

The scope and parameters defined in this study were determined by considering the input of the participating experts, comparability between the BREFs, and the resources available to the project. To permit a valid comparison, the pollutants selected for quantitative cross-country analysis needed adequate information in all BREFs for each sector. Other key pollutants which are individually significant for countries (or regions) are noted in Chapter 2. as part of their BREF scope; however, they are not quantitatively compared in the following chapters (Chapter 3. and Chapter 4.).

The sector-specific processes and their selected pollutants agreed by the EG members to analyse further across the six BREFs for each sector are as follows:

1.2.1. Iron and Steel

This report categorised iron and steel production processes based on the European Union BREF for the sector. The four common routes of iron and steel production and/or seven types of plants are all noted in the BREFs to various degrees. Table 1 summarises the iron and steel production plant coverage in each BREF submitted.

Table 1 Coverage of the Iron and Steel plants in each BREF

	EU	Korea	US	China	IFC	India
Pelletisation plants	X		X	X		
Sinter plants	X	X	X	X	X	X
Coke oven plants	X	X	X	X	X	X
Blast furnaces	X	X	X	X	X	X
Direct reduction plants	(X)[1]				X	X
Basic oxygen steelmaking and casting (BOF)	X	X	X	X	(only casting)	X
Electric arc furnace steelmaking and casting (EAF)	X	X	X	X	X	X

Considering the project resources available and information comparability in BREFs, the following selected plant types and pollutants were analysed in Chapter 3. and Chapter 4. :

- Sinter plants: Air emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x), dust (Particulate Matter, PM[2]), and heavy metals – mercury and dioxins.
- Blast Furnaces: Air emissions of dust and water releases of cyanides and heavy metals (lead and zinc).

[1] There are no plant-specific BAT conclusions.

[2] Dust as an emission covers Particulate matter (PM) for point source emissions.

- Electric Arc Furnaces (EAF): Air emissions of dust, heavy metals – mercury and dioxins and water releases of heavy metals (zinc).
- In addition to the emissions (or releases) of pollutants controlled or prevented using BAT-AELs in the BREFs, the carbon dioxide (CO_2) emissions from the iron-steel production are recognised as a key environmental concern (see Box 1).

These plant types represent different stages of iron and steel production and, therefore, aim to show variations in pollutant control and prevention within the sector. This report does not quantitatively analyse the environmental issues and respective emission levels for the other plants covered in Table 1; information on these plants is available in the individual BREFs.

1.2.2. Paper and Pulp

This report categorises paper and pulp production processes based on the European Union BREF for the sector. The coverage of the five common sub-processes in each BREF is summarised in Table 2.

Table 2 Coverage of sub-processes in each Paper and Pulp BREF

	EU	Korea	US	China	IFC	India
Kraft pulping process	X	X	X	X	X	
Sulphite pulping process	X		X	X	X	
Mechanical pulping and chemi-mechanical pulping	X	X	X	X	X	
Processing of paper for recycling (including treatment of residues from wastepaper sorting and processing, waste to energy)	X	X	X	X	X	
Papermaking and related processes	X	X	X	X		X

Considering the project resources available and information comparability in BREFs, the following selected pulping and paper-making paths and pollutants were analysed in Chapter 3. and Chapter 4.

- Kraft Pulping: Air emissions of total reduced sulphur (TRS), dust (Particulate Matter, PM) and nitrogen oxides (NO_x) from recovery boilers. Water releases of total suspended solids (TSS), chemical oxygen demand (COD) and adsorbable organic halides (AOX). Total Organic Carbon (TOC) is used where necessary to substitute COD.
- Paper manufacture from recycled paper: Water releases of total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halides (AOX), total nitrogen (tot-N) and total phosphorus (tot-P).
- Water consumption per tonne production as a process efficiency measure is analysed for kraft pulping and paper production.
- In addition to the emissions (or releases) of pollutants controlled or prevented using BAT-AELs in the BREFs, the carbon dioxide (CO_2) emissions from the paper-pulp production are recognised as an environmental concern (see Box 1).

Kraft pulping is the most employed pulping process in the world due to its effectiveness in being suitable for various paper types. Nevertheless, paper manufacture from recycled paper is becoming increasingly common globally. There is a variety of production processes for these two pulp and paper-making methods, which leads to diversities in pollutant control and prevention within the industry as well.

This report does not quantitatively analyse the environmental issues and emission levels for the other pulping and paper-making paths covered in Table 2; information on these processes is available in the individual BREFs.

1.2.3. Waste Incineration

This report categorises waste types and incineration processes based on the European Union BREF for the sector. The coverage of waste and process in each BREF is summarised in Table 3.

Table 3 Coverage of waste type and processes in each Waste incineration BREF

	EU	Korea	US	China	IFC	India
Waste						
Municipal Solid Waste (MSW)	X	X	X	For Sludge from Municipal Wastewater and only Standards for municipal solid waste incineration	X	
Hazardous waste (including clinical waste)	X	X	X	Clinical waste only	X	Hazardous waste only
Processes						
Pre-treatment	X	X		For Sludge from Municipal Wastewater	For Hazardous Waste only	
Thermal treatment	X	X	X	X	X	
Energy recovery	X	X	X	X	X	
Applied flue-gas cleaning and control systems	X	X	X[3]	X		
Wastewater treatment	X	X	X	X	X	X
Solid residue treatment	X	X	X	X	X	

The most common waste type globally is difficult to pinpoint precisely due to variations in waste composition and management practices among different regions and countries. However, municipal solid waste (MSW) is one of the leading waste types worldwide. MSW includes various materials generated from households, commercial establishments, institutions, and small businesses.

Considering the available project resources and information comparability in BREFs, the EG BAT agreed to focus on *Municipal Solid Waste* incineration, including all applicable incineration processes. The air emissions of dust (Particulate Matter, PM), nitrogen oxides (NO_x) and ammonia (NH_3) resulting from the reduction of NO_x, dust/PM, heavy metals (mercury, cadmium and total metals), dioxins and furans (PCDD/F[4]), hydrogen fluoride (HF) and hydrogen chloride (HCl) were examined across the BREFs in Chapter 3. and Chapter 4. For other waste types, a quantitative analysis of the environmental issues and the respective emission levels has yet to be performed; the information is available in the individual BREFs. In addition to the emissions (or releases) of pollutants controlled or prevented using BAT-AELs in the BREFs, the carbon dioxide (CO_2) emissions from waste incineration are recognised as an emergent environmental concern (see Box 1).

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[3] In the NSPS and Emissions Guidelines (US-EPA), the Large Municipal Waste Combustors (LMWC) source category is mostly energy recovery. Also, the non-hazardous incinerators have applied some flue gas cleaning and control systems.

[4] Dioxins (PCDD/Fs) is the general term for polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). According to the number and position of chlorine atom substitution, they are divided into 75 isomers of PCDD and 135 PCDF isomers. Among them, 17 kinds of PCDD/Fs substituted at 2,3,7,8 plane positions are toxic. The dioxins are generated during the high-temperature gas phase mainly at 500°C–800°C, and they are formed when their precursors, such as chlorophenol, chlorobenzene, and polychlorinated biphenyls, are condensed. At the incinerators, low-temperature catalysis is the main way contributing to the formation of dioxins (Zhang et al., 2022[70]).

This report does not quantitatively analyse the environmental issues and respective emission levels for the other waste types and incineration processes in Table 3; information on these processes is available in the individual BREFs.

Box 1. Industrial Decarbonisation in Iron and Steel, paper and pulp production and Waste Incineration

Industrial decarbonisation is imperative for mitigating climate change, particularly in sectors like iron and steel, paper and pulp production, and waste incineration, collectively contributing significant greenhouse gas (GHG) emissions. Transitioning these industries towards low-carbon or carbon-neutral operations is essential for achieving global climate goals. This information box summarises existing regulations on CO2 emissions and emerging BREF approaches for CO2 (and other GHG) control in the six countries/regions as follows:

- The GATPPC (China) documents do not cover CO2 emissions. In China, enterprises with annual GHG emissions of more than 26,000 metric tons (with energy consumption of about 10,000 tonnes of standard coal) are required to report CO2 emissions to MEE under the policy.

- The EU IED limits the introduction of limit values for GHGs in permits to cases where "significant local pollution is caused." The main instrument that regulates CO2 emissions for energy-intensive industries in the EU is the Emissions Trading System (EU ETS). It includes many sectors, such as energy production and manufacturing. However, among BREFs for the three sectors, the EU WI BREF has BAT-AEPLs for energy efficiency, which indirectly influences the climate impact of these plants.

- US EPA BREFs do not cover CO2 emissions. In the US, owners or operators of facilities from stationary combustion, iron and steel production processes, and other source categories that emit more than 25,000 metric tons of GHGs per year or more must report CO2 emissions to the EPA under the Greenhouse Gases Reporting rule. Information on known and emerging techniques for reducing GHGs is also available to industry (US-EPA, 2012[1]).

- Korea launched its Korea Emissions Trading System (K-ETS) in 2015. This mandatory ETS includes 89% of the country's national GHG emissions (CO2, CH4, N2O, and fluorinated gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6)) (ICAP, 2022[2]). It covers several sectors: power, industrial, buildings, waste, transport, domestic aviation, and domestic maritime transportation sectors, which account for 804 of the country's largest emitters.

- In India, the MINAS and COINDS frameworks lack provisions specifically addressing CO2 emissions.

- In the UK, where the EU BREF is currently used as a regulatory reference point, market interest in the application of Carbon Capture (CC) to waste incineration has prompted the development of regulatory guidance for permitting post-combustion CC plants (PCCCP), initially for the power sector . However, noting that the application of CC to the incineration sector is developing, meaning full-scale plant information is not yet available, this is now being developed for the waste incineration sector as Guidance on Emerging Technology (GET), rather than full BAT or BREF documentation. The UK government has also announced its intention to expand the UK ETS scheme to the waste incineration sector starting 1 January 2028.

- The World Bank's Environment, Health and Safety (EHS) Guidelines for integrated steel mills cover CO2 emissions under greenhouse gasses (GHGs) and note that steel manufacturing facilities are energy-intensive and emit significant amounts of carbon dioxide (CO2). GHG emissions from integrated steel mills are mainly generated from the combustion of fossil fuels such as coal for energy (heat), ore reduction, electrical energy production, and the use of lime as feedstock. The average value of carbon dioxide intensity in the sector is estimated at 0.4 t C/t of crude steel (only EAF route). In addition to the sector-specific information below, the General EHS Guidelines contain recommendations for energy efficiency and GHG management (IFC, 2007[3]).

1.3. Report structure and scope

In the subsequent chapters of this report, the three selected sectors were individually analysed. The main structure of this report consists of categorising issues based on their qualitative and technical aspects. This approach allowed for a more comprehensive comparison of the diverse range of information presented in the BREFs.

- Chapter 2 on BAT- Reference Documents (BREF) – This chapter presents supporting information on the BREFs analysed for their technical coverage of selected pollutants for each sector. It notes the scopes of BREFs, the environmental issues covered, and other critical information particular to the BREF.
- Chapter 3 on Best Available Techniques (BAT) —This chapter outlines the three sectors' technical approaches specified as BAT in the submitted BREFs. It aims to compare BAT for selected pollutants analysed for each industry, whether techniques are legally binding, whether they form the basis for quantitative standards, and which technical processes and procedures are mentioned for controlling that substance, including pollution prevention and substance abatement systems.
- Chapter 4 on BAT-associated emission or performance levels (BAT-AE[P]Ls) – This chapter compares the *emission* and *other quantitative performance standards* specified as BAT-associated for the selected environmental issues and pollutants in the BREFs submitted for the three sectors.

Chapter 2. BAT-Reference Documents

2.1. Introduction

Many jurisdictions develop BREFs to regulate specific environmental issues that mainly arise from industrial activities or sectors. BREFs typically describe industrial processes, emissions, and consumption levels of applied techniques. They may also define BAT for installations within an industry, which local regulators use as a basis for operating permits.

This chapter provides a description of the industrial processes in the three sectors and includes supporting information from BREFs (or BREF-like documents) that have been analysed. It also gives a summary of the contents covered in each BREF, including their scope, the environmental issues covered, and other relevant information such as:

- Background information – Full title, issuing organisation, most recent update, publication date, and legal status.
- BREF Scopes – Brief descriptions of the scopes of BREFs analysed, including information depending on availability, scope constraint issues such as fuel, process or plant types, capacity/scale of production, raw material inputs, and installation scope or boundary-related information, e.g. whether matters such as energy production, effluent treatment, and waste management.
- Other installation-specific information that is key to the sector.

2.2. Iron and Steel Production

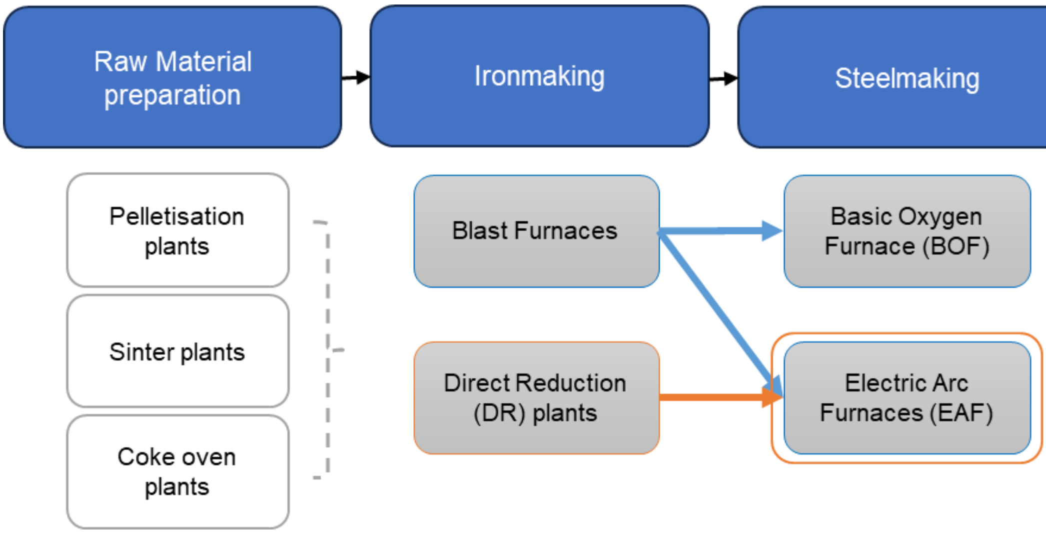
Iron and steel production is essential for the global market due to its pivotal role in modern industrialisation, the economy, and infrastructure development. The sector has been under international scrutiny due to its various adverse environmental impacts, such as air emissions, including greenhouse gases (GHG) and water releases of pollutants, including large quantities of raw materials and energy.

Steel production has a diverse range of methods employed, but the following routes are commonly used globally:

- the traditional blast furnace coupled with a basic oxygen furnace,
- electric arc furnace (EAF) - that may involve the direct melting of recycled scrap steel,
- smelting reduction and
- direct reduction in combination with a subsequent melting process (e.g. in an EAF).

Modern, high-performance blast furnaces require adequate raw material preparation, which improves gas permeability and reducibility. This preparation entails agglomerating the furnace charge either by sintering or pelletisation. The most common types of plants can be categorised for their processes involving *raw material preparation*, *ironmaking* and *steel-making, see* Figure 1 (EIPPCB, 2013[1]).

Figure 1 Iron and Steel production plants (EU BREF)



Raw material Preparation

- *Pelletisation plants* - Pellets are formed from the raw materials fine ore and additives of <0.05 mm into 9 – 16 mm spheres using high temperatures, mainly carried out at the mine site or its shipping port.
- *Sinter plants* - The charge of a sintering process consists of a mixture of fine ores, additives (e.g., lime, olivine), and recycled iron-bearing materials from downstream operations (including, but not limited to, coarse dust and sludge from BOF gas cleaning, mill scale), to which coke breeze is added to enable the ignition and sintering of the charged material.
- *Coke oven plants* – In the EU BREF for iron and steel production, coke pyrolysis is described as the heating of coal in an oxygen-free atmosphere to produce solid coke, gases and liquids, which at high temperatures is called carbonisation (EIPPCB, 2013[1]). In this process, the temperature of the flue gases from underfiring is usually 1150 – 1350 °C, indirectly heating the coal up to 1000 – 1100 °C for 14 – 28 hours. This duration varies depending on the width of the oven (in the case of heating by the side), the density of coal and the quality of the desired coke (e.g. use in foundries or blast furnaces). The most critical reducing agent in hot metal production is coke, which indirectly removes oxygen by forming carbon monoxide or directly using its inherent carbon content. The gasification of the coke in the blast furnace also supplies the heat necessary for the reduction process. Coke also forms the matrix that enables gas circulation in the blast furnace. Therefore, coal or other fuels cannot wholly replace coke in the blast furnace.

Ironmaking

- *Blast furnace (BF)* – The blast furnace is the most essential process for producing hot metal (pig iron). In integrated steelworks, the blast furnace is the central operational unit where the primary reduction of oxide ores leads to liquid iron, also called ‘hot metal’ or ‘pig iron’. Modern high-performance blast furnaces require physical and metallurgical preparation of the burden. The two types of iron ore preparation plants are the sinter plants and the pellet plants (EIPPCB, 2013[1])
- *Direct Reduction plants:* In direct reduction (DR) plants, the iron ore (mainly in the form of pellets) is reduced in the solid state using coal gas, natural gas or (eventually) pure hydrogen (Lu, Pan and Zhu, 2015[2]). To produce steel, the Direct Reduced Iron (DRI) is melted in a separate furnace, usually an Electric Arc Furnace (Otto, 2017[3]). The DR-EAF route offers an alternative steel

production route to the Blast Furnace-Basic Oxygen Furnace (BF-BOF) route and scrap-EAF routes to transition to a sustainable steelmaking route.

Steelmaking

- *Basic oxygen steelmaking and casting* - The Basic Oxygen Furnace (BOF)[5] and the Electric Arc Furnace (EAF) are commonly used methods to convert pig iron produced by the BF into steel. During the process, oxygen is injected to oxidise undesirable impurities present in the metallic feedstock. This is necessary to ensure that the feedstock can be used effectively. In order to use the basic oxygen furnace (BOF) process on a large scale in a cost-effective manner, it is essential to have access to the necessary tonnage of technically pure oxygen and water-cooled lance technology to introduce the oxygen into the converter. These are the prerequisites for efficient implementation of the BOF process (EIPPCB, 2013[1]).
- *An Electric Arc Furnace (EAF)* is used in steel-making plants to melt iron sources using electric energy, such as scrap and direct-reduced iron (DRI). An EAF uses an electric arc to heat the metal to a very high temperature and does not need molten iron, which improves the smelting efficiency. The scrap-based EAF are 60-70% less energy intensive than the other routes due to the use of recycled metal (IEA, 2021[4]).

2.2.1. Environmental Issues

Air emissions are often described as the primary concern in iron and steel production. However, water releases are also usually noted as an important issue, and some BREFs also highlight the impact of waste production, energy efficiency, and greenhouse gases (GHG).

Substances addressed in the BREFs for air emissions include nitrogen oxides (NO_x), ammonia (NH_3), sulphur oxides (SO_x), dust (Particulate Matter, PM[6]), heavy metals (nickel, lead, and mercury), dioxins, carbon dioxide (CO_2), hydrogen fluoride (HF), hydrogen chloride (HCl), and hydrogen sulphide (H_2S).

For water releases, the substances/parameters addressed in the BREFs include chemical oxygen demand (COD), biochemical oxygen demand (BOD), heavy Metals (lead, zinc, nickel, chromium, iron, tot-HM), cyanide and thiocyanate, total hydrocarbons, sulphides (S^{2-}), polycyclic aromatic hydrocarbons (PAHs), phenols, and total nitrogen (TN). Table 4 provides a concise summary of the substances covered in each BREF for the iron and steel sector, reflecting the comprehensive approach adopted by different regulatory authorities:

Table 4 Coverage of emissions in each Iron and Steel BREF

No	Substance	BREF
Air emission		
1	Nitrogen oxides (NO_x)	China, EU, World Bank, US EPA*, India, Korea
2	Sulphur oxides (SO_x)	China, EU, World Bank, India (SO_2), Korea
3	Dust/PM	China, EU, World Bank, US EPA, India, Korea
4	Heavy metals (nickel, zinc, manganese, lead, arsenic and mercury)	China has general BAT, but no AELs set. EU - Mercury US EPA – Mercury limit for BOFs, total metal HAP for iron and steel foundries World Bank – Nickel and lead. India - lead

[5] Referred as Basic Oxygen Process Furnace (BOPF) in US-EPA documents.

[6]Particulate matter (PM) refers to total suspended particulate matter (TSP), which includes PM10 (particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometre).

5	Dioxins	China, EU
6	Carbon dioxide (CO_2)	World Bank
7	Hydrogen fluoride (HF) and hydrogen chloride (HCl)	HF – China, EU, World Bank HCl – EU, World Bank, US EPA
8	Hydrogen sulphide (H_2S)	EU, World Bank
Water release		
9	Chemical oxygen demand (COD)	US EPA – only BAT, China, EU, India
10	Biochemical oxygen demand (BOD)	US EPA – only BAT, China (coke oven), EU (coke oven), India (BOD 3-27)
11	Heavy metals (lead, zinc, nickel, chromium, tot-HM)	US EPA, China, EU, World Bank, India (lead)
12	Cyanide (CN^-) and thiocyanate (SCN^-)	US EPA, China (coke oven), EU (coke oven + BF), World Bank, India
13	Total hydrocarbons	US EPA – only BAT, China (coke oven), EU (BOF. and EAF)
14	Sulphides (S^{2-})	US EPA – only BAT, China (coke oven), EU (coke oven)
15	Polycyclic aromatic hydrocarbons (PAHs)	US EPA, China (coke oven), EU (coke oven), World Bank
16	Phenols	US EPA, China, EU (coke oven), World Bank, India
17	Total nitrogen (TN)	US EPA – only BAT, China (coke oven), EU (coke oven + Pell. plants), World Bank
18	Suspended solids	EU (sinter plant, blast furnace, pelletisation plant, continuous casting and casting machines)

*For US-EPA: NO_x has no sector-specific AELs, although they might appear in permits based on the New Source Review process.

2.2.2. Country and Region BREF information

The following section provides the full names of the six BREFs analysed, including further information on specific details about the area (or country) represented in the BREF(s).

2.2.2.1. China (China (People's Republic of China))

China presents BAT and BAT-AELs for all industries in the Guidelines on Best Available Technologies of Pollution Prevention and Control (GATPPC) documents. The following GATPPCs are used to regulate pollution in the iron and steel sector:

- Guideline on Best Available Technologies of Pollution Prevention and Control for the Sintering and Pelletizing Process of the Iron and Steel Industry (on Trial) (MEE, 2014[5]),
- Guidelines on Best Available Technologies of Pollution Prevention and Control for the Steel-making Process of the Iron and Steel Industry (on Trial) (MEE, 2010[6]),
- Guidelines on Best Available Technologies of Pollution Prevention and Control for the Rolling Process of the Iron and Steel Industry (on Trial) (MEE, 2010[7])
- Guidelines on Best Available Technologies of Pollution Prevention and Control for the Coking Process of the Iron and Steel Industry (on Trial) (MEE, 2010[8])
- Guidelines on Best Available Technologies of Pollution Prevention and Control for Mining and Mineral Processing of the Iron and Steel Industry (on Trial) (MEE, 2010[9])

2.2.2.2. The European Union

The European Union presents BAT and BAT-AELs information for the iron and steel sector in the Best Available Techniques (BAT) Reference Document (BREF) for Iron and Steel Production (EIPPCB, 2013[1]) and the corresponding BAT conclusions (Commission Implementing Decision 2012/135/EU).

Most steel production in the EU is almost exclusively produced by the BF-BOF and Electric Arc Furnace (EAF) processes. Therefore, the EU BREF does not include BAT conclusions and BAT-AELs for smelting and direct reduction processes (only general information on these processes is given in the BREF). The only direct reduction facility in Europe is located in Hamburg, Germany.

2.2.2.3. India

India presents BAT and BAT-AELs information in the Comprehensive Industry Documents (COINDs) and BAT-AELs in the Minimum National Standards (MINAS) for all industries. The following COINDs and MINAS are used to regulate pollution in the iron and steel sector:

- Minimum National Standards for Sponge Iron plants (rotary kilns) and Integrated iron and steel plants (CPCB, 2022[10]), for information on Blast Furnaces.
- Comprehensive Industry Document on Electric Arc & Induction Furnaces (COINDS/80/2009-10) (CPCB, 2010[11])

The MINAS set standards for the following pollutants from the integrated iron and steel plants in addition to Table 4:

- Water releases for pH, suspended solids, oil and grease and ammoniacal nitrogen as N.
- Air emissions for sulphur, benzo(a)pyrene (BaP) and carbon monoxide (CO).

No distinctions exist between AELs for new or existing iron and steel plants. The MINAS include other types of furnaces beyond those covered in Table 1: rolling mills, induction furnaces, cupola foundries, and refractory units.

2.2.2.4. Korea

Korea presents BAT and BAT-AELs for the iron and steel sector in the Korean Best Available Techniques Reference Document for Steel Production (NIER, 2017[12]). An updated version was published in December 2023 (NIER, 2023[13]). Korean Air Law provides AELs for certain air pollutants that are beyond the K-BREF, such as the BAT- AELs for dust (Particulate matter) emissions from Blast Furnaces in this report (MOE, 2024[14]).

2.2.2.5. United States

The US EPA regulates pollution through media-specific iron and steel sector regulations. The following regulations are used in the control and prevention of pollutants in the air and water:

- Air emissions:
    a. Taconite (pelletisation) (Air) (US EPA, 2024[15])
    b. Integrated iron & steel (Air) (US EPA, 2024[16]),
    c. Electric Arc (Air) (US EPA, 2007[17]), Electric arc (Air) (US EPA, 2022[18]),
    d. BOPF steel (Air) (US EPA, 1986[19]),
    e. Coke oven (Air) By-Product Recovery Plants (US EPA, 1999[20]), Batteries (US-EPA, 1999[21]), Pushing, Quenching and Battery Stacks (US-EPA, 2005[22]).
- Water releases:
    a. Iron and Steel (Water) (US EPA, 2005[23])

EPA develops limitations based on specific treatment technologies by using the performance of that technology at the time of rule writing to set numeric limitations. However, facilities may use whatever treatment and control technologies they choose to meet the limits set. In addition to the sector-specific regulations for stationary sources of air pollution, individual facilities may have site-specific limits set for NO_x, SO_2, CO, and PM under New Source Review permits.

The Integrated Iron and Steel Manufacturing NESHAP rule is currently being revised to include several fugitive and intermittent sources of pollution. The proposed rule closed its comment period in September 2023; a final rule is expected, possibly during 2024.

On January 31, 2024, the Environmental Protection Agency finalised amendments to the National Emission Standards for Hazardous Air Pollutants (NESHAP) for Taconite Iron Ore Processing Plants, strengthening existing emissions limits for harmful acid gases such as hydrogen chloride and hydrogen fluoride, and establishing new emission limits for mercury (US EPA, 2024[15]).

2.2.2.6. World Bank Group

The World Bank Group presents BAT and BAT-AELs information for the iron and steel sector in the Environmental, Health, and Safety Guidelines for Integrated Steel Mills (IFC, 2007[24]). It includes information relevant to manufacturing pig iron and raw or low-alloy steel from iron ore and iron-based alloys. This guideline applies to the following manufacturing processes:

- the manufacture of metallurgical coke;
- primary iron and steel production in Blast and Basic Oxygen furnaces (BF and BOF);
- scrap metal recycling in the electric arc furnace (EAF) process;
- the production of semi-finished products; and
- hot and cold rolling activities.

The EHS guideline for integrated steel mills does not include information on further processing of semi-finished products into finished products.

The general EHS guidelines are complementary and recommended to be used together with the industry-specific EHS guidelines. The General EHS guidelines provide information on the management of emissions from small combustion sources with a capacity of up to 50 megawatt thermal (MWth), including guidelines for exhaust emissions (IFC, 2007[25]). Guidance for facilities with power generating capacities over 50 MWth is provided in the EHS Guidelines for Thermal Power (IFC, 2008[26]).

2.2.3. Sub-Chapter Summary - Iron and Steel Production

Iron and steel production has been crucial for modern industrialised society, the economy, and infrastructure development for many decades. However, this sector has faced international scrutiny due to its various adverse environmental impacts, such as air emissions and releases of pollutants into water, as well as the consumption of large quantities of raw materials and energy. While steel production processes are diverse and well-established, industrial advancements and environmental pressures have led to innovation and new approaches.

Key observations from Chapter 1. and Chapter 2. concerning the iron and steel BREF information are summarised as follows:

- Production routes: Section 2.2 outlines the primary iron and steel production routes, highlighting the use of different raw materials. A primary differentiator is the raw material used, with steel being the resultant product (which may, for example, be made from scrap steel) and iron, an intermittent product made from iron ore requiring different technical approaches.
- Sector complexity: The iron and steel sector is evolving with new approaches, especially those aimed at decarbonisation. These may lead to variations in BREF approaches.

- Environmental concerns: While air emissions are commonly cited as the principal concern in iron and steel production, water releases, waste production, energy efficiency, and greenhouse gas emissions are also significant concerns highlighted in various BREFs.
- Controlled pollutants: A wide range of pollutants are identified in BREFs for control, and these vary depending on the production route, final product, and raw materials. Despite differences, there is a reasonable alignment among BREFs (see Table 4 Coverage of emissions in each Iron and Steel BREF).
- Scope of production methods: BREFs typically focus on prevalent production approaches within regions. For example, the EU BREF centred on Blast-Furnace -Basic Oxygen Furnace (BF-BOF) and Electric Arc Furnace (EAF) processes, which were almost solely used to make steel in the EU. Therefore, this focus excluded detailed BAT Conclusions and BAT-AELs for other processes like smelting and direct reduction (only general information on these processes is given in the BREF). The emergence of processes and techniques contributing to decarbonisation, such as hydrogen-based direct reduction of iron ore, as referred to in chapters 10 and 11 of the EU BREF, indicates a reshaping of the industry landscape.
- Future Scope Changes: In the future, strategic decisions such as closing blast furnaces in the UK and investing in new EAF are expected to change the focus of UK steel production towards scrap-based processes instead of traditional iron ore-based production. These decisions are likely to impact the future revisions of the BREF scopes. A UK BREF process to define UK BAT has now been introduced, and the first UK BREFs are going through the legislative process.

2.3. Paper and Pulp Production

The paper and pulp industry is essential for modern life but has a significant environmental impact. It is one of the most water-consuming sectors and uses large amounts of raw natural resources, such as wood fibres. Production processes, especially in pulping, result in the release of a significant number of chemicals, including chlorine-based compounds, due to the bleaching steps involved. Additionally, the pulp and paper production process is highly energy-intensive (e.g., the cooking process, recovery boilers, and drying process) and can lead to air emissions of pollutants. However, this sector has been making positive strides towards sustainability goals through advancements in applying value chain considerations, such as using better raw materials and recycled materials [7].

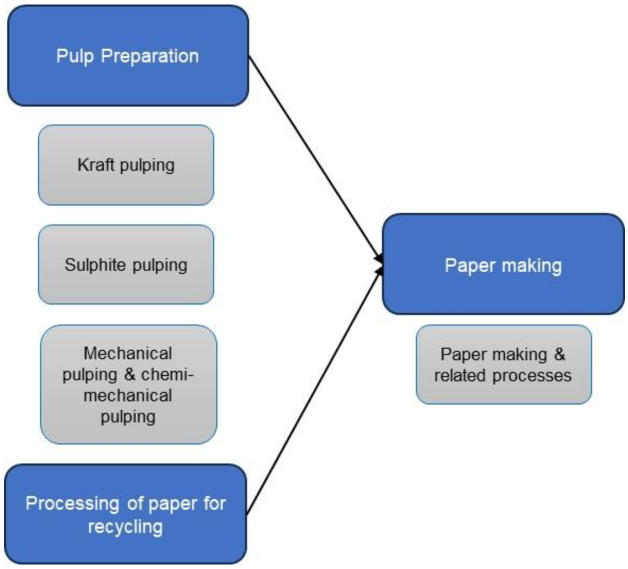
According to the EU BREF on the Production of Pulp, Paper, and Board, the emissions from pulp and paper production can be estimated with a combination of a product-orientated approach and a process-orientated approach (EIPPCB, 2015[27]). So, a combined procedure is followed to determine the emissions from pulp and paper mills:

- Assessing the whole pulp and paper mill
- Consider different products and product qualities manufactured.

The categorisation of production processes was based on the European Union BREF for the sector, which suggests the following five main sub-processes (Figure 2):

[7] The Activity 5 report on value chain approaches for determining BAT in industrial installations provides further information (OECD, 2021[64]).

Figure 2 Pulping and Paper-making processes (EU-BREF)



I. Kraft (Sulphate) Pulping Process – the most common chemical pulping process, accounting for around 80% of pulp production. The term 'sulphate pulping' derives from the make-up chemical sodium sulphate added in the recovery cycle to compensate for chemical losses. In the chemical pulping process, the fibres are liberated from the wood matrix as the lignin is removed by dissolving it into the cooking chemical solution at a high temperature. In the kraft pulp process, the active cooking chemicals (white liquor) are sodium hydroxide (NaOH) and sodium sulphide (Na_2S).

II. Sulphite pulping process - The importance of the sulphite process has steadily decreased, and today, only 10 % of world production is obtained by this method, with new installations not being constructed. The sulphite cooking process is based on aqueous sulphur dioxide (SO_2) and a base – magnesium, calcium, sodium or ammonium.

III. Mechanical pulping and chemi-mechanical pulping - In mechanical pulping, the wood fibres are separated from one another by mechanical energy applied to the wood matrix, causing the bonds between the fibres to break gradually and releasing fibre bundles, single fibres, and fibre fragments. The main processes and techniques are the production of groundwood pulp (GW), pressure groundwood pulp (PGW), thermomechanical pulp (TMP), chemi-mechanical pulp (CMP), or chemithermomechanical pulp (CTMP).

IV. Processing of paper for recycling – The system varies according to the paper grade and the type of furnishing used. Generally, the processing of recycled fibres (RCF) can be divided into two main categories:

   I. processes using exclusively mechanical cleaning, i.e. without deinking, comprising products like test liner, corrugating medium, uncoated board and carton board;

   II. mechanical cleaning and deinking processes, comprising products like newsprint, tissue, printing and copy paper, magazine papers (SC/LWC), coated board, carton board, or market deinked pulp (DIP).

- All process systems aim to defibrate, deflake, and remove impurities, i.e., efficiently separate fibrous material from impurities and contaminants. Recycled fibre plants have similar 'building blocks' designed for the specific task, involving various process stages.
- The EU BREF for the paper and pulp sector indicated that the pulp for papermaking may be produced from virgin fibre by chemical or mechanical means or by repulping paper for recycling (RCF). After primary use, most forest-based products can be considered valuable secondary raw materials. Recycling paper provides an essential secondary fibre source for paper production (EIPPCB, 2015[27]).

V. Papermaking and related processes – The paper and board production stage uses the prepared paper pulp as a raw material input to produce finished paper products.

2.3.1. Environmental Issues

Air and water emissions are often cited as major concerns for the industry, with water releases generally considered the top priority concern. Some BREFs highlight the impact of water consumption, waste production, energy efficiency, and greenhouse gases (GHGs). The substances identified vary between different BREFs.

The substances/parameters identified for air emissions differ between the BREFs but include nitrogen oxides (NO_x)[8], sulphur oxides (SO_x), dust (Particulate Matter, PM), total reduced sulphur (TRS), and dioxins and furans. The substances/parameters identified as concerns for water releases also differ between the documents but include chemical oxygen demand (COD), biochemical oxygen demand (BOD), adsorbable organic halides (AOX), heavy metals (nickel, copper and zinc), total nitrogen (tot-N), total phosphorus (tot-P), and total suspended solids (TSS), wastewater treatment (wastewater flow or wastewater sent to treatment). Table 5 provides a concise summary of the pollutants covered in each BREF, reflecting the comprehensive approach adopted by different regulatory authorities:

Table 5 Coverage of substances in each Paper and Pulp BREF

No	Substance	BREF
	Air emission	
1	Nitrogen Oxides (NO_x)	EU, World Bank
2	Sulphur Oxides (SO_x)	EU*, Korea, World Bank*
3	Dust/PM	EU, Korea, US EPA, India, World Bank
4	Carbon monoxide (CO)	-
5	Ammonia (NH_3), incl. slip	EU
6	Total reduced sulphur (TRS)	EU*, US EPA, India (only H_2S) World Bank
7	Hazardous Air Pollutant (HAPs)	US EPA
8	Dioxins and furans	China
	Water release	
9	Total suspended solids (TSS)	China, EU, Korea, US EPA
10	Chemical oxygen demand (COD)	China, EU, Korea, US EPA
11	Biochemical oxygen demand (BOD)	China, EU, US EPA, India
12	Adsorbable organic halides (AOX)	China, EU, US EPA, India

[8] The 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone targets nitrogen oxides (NO_x) is one of the international targets to reduce and limit to abate its emissions from recovery boilers of the pulp mills (UNECE, 2015[65]). In addition, there are efforts made such as the Guidance documents and other methodological materials for controlling and preventing the air emissions of sulphur dioxide (SO_2), nitrogen oxide (NO_x), ammonia (NH_3), volatile organic compounds (VOCs) and dust/PM (UNECE, n.d.[66]) .

13	Heavy Metals (zinc, nickel, copper)	Korea, US EPA
14	Total Nitrogen (TN)	EU, Korea
15	Total Phosphorus (tot-P)	China, EU
16	Ammonia	China
17	Wastewater treatment (wastewater sent to treatment)	China, EU
18	Water Consumption	China, EU, Korea
19	Hydrogen Chloride (HCl)	Korea

* The EU BREF and World Bank's EHS Guidelines also cover gaseous sulphur and sulphur dioxide (SO_2).

2.3.2. Country and Region BREF information

This report consists of BREFs or BREF-like documents from six countries or regions for the three selected sectors. The following section provides the full names of the BREFs analysed, including further information on specific details about the area (or country) represented in the BREF(s).

2.3.2.1. China (People's Republic of China)

China presents BAT and BAT-AELs for paper and pulp production in the Guidelines on Best Available Technologies of Pollution Prevention and Control (GATPPC) Pulp and Paper Industry (MEE, 2018[28]). It divides the pulping process into chemical pulp (including sulphate pulp, caustic soda pulp and sulphite pulp), chemical mechanical pulp, wastepaper pulp, and paper and paperboard manufacturing mechanisms. Usually, wood and bamboo are pulped using the sulphate pulping method. AELs are set for COD, BOD, SS, and ammonia under the wastewater treatment. However, there is no distinction in AELs for new or existing paper and pulp production plants.

A discharge standards document for water pollutants for the pulp and paper industry is available to limit AOX, total nitrogen, and total phosphorus releases. However, no BAT for any pollutant is included (MEE, 2008[29]). There is an AEL for ammonia release to water, but no standard is established for ammonia slip into the air.

2.3.2.2. The European Union

The European Union presents BAT and BAT-AELs information for the paper and pulp sector in the Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board (EIPPCB, 2015[27]) and the corresponding BAT conclusions (Commission Implementing Decision 2014/687/EU).

2.3.2.3. India

India presents BAT and BAT-AELs information in the MINAS standards for the Small Pulp and paper and Large Pulp and paper industries (CPCB, 2022[10]). A COIND document (1986) exists for plants with a production capacity of up to 10,000 tonnes and without chemical recovery; however, it is considered outdated. The MINAS set standards with a production capacity limit for small installations with a capacity below 24.000MT per year and large facilities. No differentiations are made in AELs for new or existing paper and pulp production plants.

In addition to Table 5 Coverage of substances in each Paper and Pulp BREF, the MINAS covers the following pollutants:

- Small installations have effluent standards for pH, suspended solids, sodium absorption ratio, and flow (total wastewater discharge). There are differences in these standards for discharges into inland surface water and disposal on land. The flow standards set vary between agro-based and recycled/waste papermaking.

- Large plants (paper and pulp, newsprints or rayon-grade paper) have effluent standards for pH, suspended solids and flow (total wastewater discharge), varying from large paper-pulp production plants to large rayon-grade plants.
- Air emissions standards are mentioned without differentiation for the pulping process for dust/PM and H_2S (MoEFCC, 2023[30]).

In 2023, the Ministry of Environment, Forest and Climate Change of India published a draft standards notification for the paper and pulp industry, which is expected to be approved as MINAS in the coming years. Key features of the new statement are:

I. There are different standards for mills that produce pulp (cooking of wood) and mills that use existing pulp (from recovered fibres, waste paper) or purchased pulp to produce paper. The production process for chemical pulp is much more polluting than that of paper production from existing pulp.

II. There are effluent standards for pH, TSS, BOD [3 days at 270c], COD, TDS, Colour, AOX, and SAR. Also, the standard for maximum TDS limit in treated effluent is now related to TDS in water intake (mg/l).

III. Process efficiency standards for freshwater consumption and effluent discharge standards are stated as volumes in m3/ton of product.

IV. The Key Parameter for Emissions Standards is H_2S, while Chemical Recovery Plant (CRP) boilers or limekilns are dust/PM and H_2S.

2.3.2.4. Korea

Korea presents BAT and BAT-AELs for the paper and pulp production sector in the Korean Best Available Techniques Reference Document for Pulp, Paper, and Cardboard Production (NIER, 2019[31]). Korean Air Law provides AELs for certain air pollutants beyond the K-BREF, such as the BAT- AELs for nitrogen oxides (NO_x) emissions from recovery boilers in kraft pulping mills in this report. (MOE, 2024[14]).

2.3.2.5. United States

The US EPA regulates pollution through media-specific regulations and the NESHAP and NSPS (US-EPA) related to paper and pulp production:

- Combustion (US EPA, 2020[32]), Non-combustion (US EPA, 2012[33]),
- Kraft pulp mills (US EPA, 2024[34]; US EPA, 2024[35]),
- Paper and pulp (Water) (US-EPA, 2021[36]; US EPA, 1997[37]).
- In addition, further supporting information may be found in the Greenhouse Gas Reporting Program (GHGRP) for paper and pulp sector (US-EPA, 2022[38]) and in the regulatory information available for paper, pulp, and lumber manufacturing (US EPA, 2023[39]).

The US-EPA develops limitations based on specific treatment technologies by using the performance of that technology at the time of rule writing to set numeric limitations. However, facilities may use whatever treatment and control technologies they choose to meet the limitations imposed. In addition to the sector-specific regulations for stationary sources of air pollution, individual facilities may have site-specific limits set for NO_x, SO_2, CO, and PM under New Source Review permits. The NSPS for kraft pulp mills sets standards for PM and TRS emissions from pulping and chemical recovery processes at kraft pulp mills constructed, reconstructed, or modified after 1976. NESHAP for pulp and paper (non-combustion) (2012) sets standards for hazardous air pollutants (HAP) for the pulping and bleaching systems at pulp and paper facilities. The main HAP of concern from pulping is methanol, and the main HAPs of concern from bleaching are Cl_2, HCl, and chloroform. NESHAP for pulp and paper (combustion) (2020) sets standards for HAP from combustion sources within the chemical recovery process area, focusing on gaseous organic HAP and metals.

2.3.2.6. World Bank Group

The World Bank Group presents BAT and BAT-AELs information for the paper and pulp sector in the Environmental, Health, and Safety Guidelines Pulp and Paper Mills (IFC, 2007[40]). This sector-specific EHS guideline is designed to be used with the General EHS Guidelines document, which guides users on common EHS issues that are potentially applicable to all industry sectors (IFC, 2007[25]).

2.3.3. Sub-chapter summary – Paper and Pulp production

The paper and pulp industry is crucial for modern life but has a significant environmental impact, with water releases being a primary concern. It is among the highest water-consuming sectors and relies heavily on raw natural resources, especially wood fibres. Production processes, such as pulping, result in significant chemical releases, particularly chlorine-based compounds, due to the bleaching steps involved. Additionally, energy-intensive operations like cooking, recovery boilers, and drying processes contribute to air emissions of pollutants. This report also considers additional impacts such as water consumption, waste generation and energy efficiency.

The following are the main findings from Chapter 1. and Chapter 2. concerning the paper and pulp BREFs information:

- Paper making and pulping may exist as separate processes, but they are often combined in integrated paper mills, and these may also incorporate energy generation plants. As a result, the range of environmental concerns and coverage in BREF documents is extensive and diverse due to variations in processes aimed at producing different types of paper. In other words, the diversity of paper types contributes to a broad spectrum of environmental issues addressed by BREFs.
- Kraft (sulphate) pulping stand out as the dominant global approach in chemical pulping, while other variants are described in Section 2.3.
- Air and water emissions are often described as key concerns for the sector, although water releases are typically deemed the priority concern. Some BREFs highlight the impact of water consumption, waste production and energy efficiency. The substances identified vary between different BREFs, see Table 5 Coverage of substances in each Paper and Pulp BREF.
- The BREFs cover various pollutants for air emissions, including nitrogen oxides (NOx), sulphur oxides (SOx), particulate matter (PM), total reduced sulphur (TRS), and dioxins and furans. However, the specific substances and parameters addressed differ among BREFs. For example, most BREFs cover NO_x and SO_x emissions, while only EU BREF mentions ammonia (NH_3), and US-EPA guidelines include hazardous air pollutants (HAPs).
- Similarly, water release concerns include a range of substances, including chemical oxygen demand (COD), biochemical oxygen demand (BOD), adsorbable organic halides (AOX), heavy metals (such as zinc, nickel, and copper), total nitrogen (tot-N), total phosphorus (tot-P), and total suspended solids (TSS), among others. The substances and parameters identified vary across the BREFs, reflecting regional priorities and considerations. While the EU BREF, GATPPC (China), and US EPA Effluent Guidelines address several water pollutants, others like K-BREF may focus on specific substances such as hydrogen chloride (HCl).
- BREF coverage exhibits variability based on geographical process preferences, as outlined in the description of common pulp and paper-making processes, reflecting the influence of process types prevalent in each region– see Section 2.3.2.

- The paper and pulp industry is making positive strides towards sustainability goals by implementing value chain considerations such as using alternative raw materials and recycled materials, as well as optimising water usage.

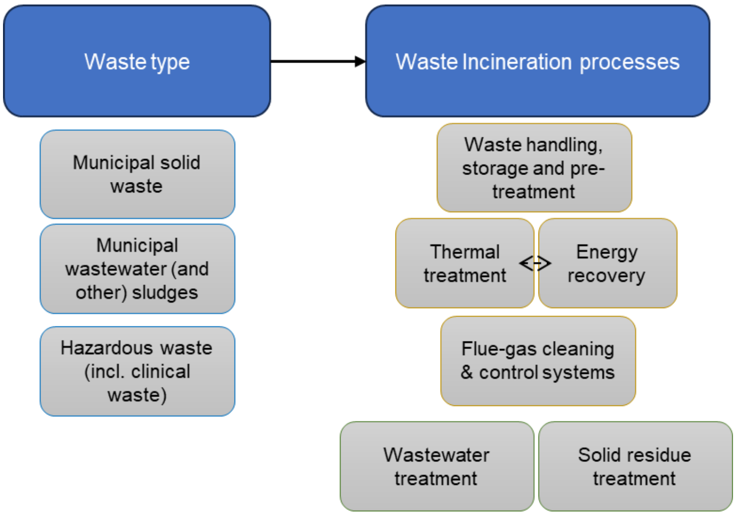
2.4. Waste Incineration

Incineration is a method used to manage a wide variety of wastes. It is often part of a waste treatment system that handles different types of waste, with specific processes developed and applied to treat different waste streams. The submitted BREFs covered various waste-specific sub-sectors, commonly addressing the following types. (Figure 3):

- municipal wastes (residual wastes - not pre-treated), pre-treated municipal wastes (e.g. selected fractions or refuse-derived fuel (RDF)) and non-hazardous industrial wastes and waste packaging
- hazardous wastes (including clinical waste and chemical wastes)
- municipal wastewater (and other) sludge types

Municipal solid waste is the most common type of waste globally, with variations in composition and management practices across countries and regions. It includes various materials generated from households, commercial establishments, institutions, and small businesses.

Figure 3 Common waste types and processes



The incineration processes consist of several stages, making up a complete installation. In most cases, the BREFs identify the primary process stages as follows and in Figure 3:

- waste handling, storage and pre-treatment
- thermal treatment (and energy recovery). Energy recovery is a process of recovering thermal energy from combustion for other uses, such as process heating.
- flue gas cleaning.

Additionally, the BREFs cover wastewater and solid residue treatment (except for COINDs) and may be integrated into the facility, depending on various factors, such as the type of waste processed and local environmental conditions.

2.4.1. Environmental Issues

All BREFs address various environmental issues, including emissions of multiple parameters to air and water, waste generation (e.g., ash residues and pollution control system residues), and energy efficiency (where energy is recovered).

Emissions into the air are usually identified as the most relevant environmental issue for waste incineration plants. The BREFs identify a range of substances of concern for air emissions, including nitrogen oxides (NO_x) and ammonia (NH_3), sulphur oxides (SO_x), dust (PM), total volatile organic compounds (TVOC), hydrogen chloride (HCl) and hydrogen fluoride (HF), heavy metals (mercury, cadmium, and total metals), and POPs (PCDD/F, PBDD/F, PCB).

Depending on the type of flue gas cleaning (dry or wet), wastewater may arise and require treatment before discharge. BAT approaches and emission levels, as addressed in the BREFs, depend on whether the discharge goes directly into the environment (typically after on-site wastewater treatment) or a collective or public wastewater treatment.

Table 6 summarises the substances covered in each municipal solid waste incineration (or similar) BREF, reflecting the comprehensive approach adopted by different regulatory authorities:

Table 6 Coverage of substances in each Waste incineration BREF

No	Substances	BREF
	Emissions to air	
1	Nitrogen Oxides (NOx)	China, EU, Korea, US EPA, India (expressed as NO and NO_2)
2	Ammonia (NH3)	EU
3	Sulphur Oxides (SO_x)	China, EU, Korea, US EPA, India (SO_2)
4	Dust/PM	China, EU, Korea, US EPA, India
5	Total volatile organic compounds (TVOC)	EU
6	Hydrogen Fluoride (HF) and hydrogen chloride (HCl)	China, EU, Korea, US EPA (HCl only, from hazardous waste incineration NESHAP), India
7	Heavy metals (mercury, cadmium and tot-metals)	China, EU, Korea, US EPA, India
8	POPs (PCDD/F, PBDD/F, PCB)	China, EU, US EPA, India (total dioxins and furans)
	Releases to water	
9	Total suspended solids (TSS)	China*, EU**, US EPA
10	Heavy metals (mercury, cadmium, As, Cr, Cu, Ni, Pb, Sb, Tl, Zn and tot-metals)	China*, EU**, US EPA
11	Total organic carbon (TOC)	EU**, US EPA
12	PCDD/F	EU**

* GATPPC generally does not provide standards for pollutant monitoring; standards for monitoring methods are typically covered in pollutant emission standards.

** The EU BREF provides a separate set of BAT-AELs for direct and indirect releases to water.

2.4.2. Country and Region BREF information

This report consists of BREFs or BREF-like documents from six countries or regions for the three selected sectors. The following section provides the full names of the BREFs analysed, including further information on specific details about the area (or country) represented in the BREF(s).

2.4.2.1. China (People's Republic of China)

China presents BAT and BAT-AELs for all industries in the Guidelines on Best Available Technologies of Pollution Prevention and Control (GATPPC) documents; however, there is no GATPPC document for municipal solid waste incineration. A standards document for pollution control on municipal solid waste (MSW) incineration issued in 2014 (revised in 2019) specifies pollutant emission limits (MEE, 2019[41]). The technical guideline for field supervision and inspection of municipal solid waste incineration plants with power generation (issued in 2023) specifies technical and equipment considerations. (MEE, 2023[42]).

Guideline on Best Available Technologies of Pollution Prevention and Control for Treatment and Disposal of Sludge from Municipal Wastewater Treatment Plant (On Trial) was used to extract standards for NO_x, dust/PM, and dioxins and furans (PCDD/F) emissions information (MEE, 2010[43]). In addition, data was compiled by direct supply by members of the Expert Group representing China.

2.4.2.2. The European Union

The European Union presents BAT and BAT-AELs information for the waste incineration sector in the Best Available Techniques (BAT) Reference Document for Waste Incineration (WI BREF) (EIPPCB, 2019[44]) and the corresponding BAT conclusions (Commission Implementing Decision (EU) 2019/2010), and in Directive 2010/75/EU on Industrial emissions, whose Chapter IV and Annex VI include special provisions for waste incineration (EU, 2010[45]).

The WI BREF covers all techniques and performances for the incineration of solid municipal waste, sewage sludges, clinical waste, and other types of hazardous waste. It is interlinked with other BREFs regarding energy efficiency and emissions from storage, for instance, but also with the BREF on waste treatment for the treatment of fly ashes and APC residues.

2.4.2.3. India

In India, domestic solid waste is regulated under the Solid Waste Management Rules, 2016, as amended and notified under the Environment (Protection) Act, 1986 (CPCB, 2016[46]). The rules specify emission norms for incinerators or thermal technologies in solid waste treatment and disposal facilities. Additionally, there is a technical guideline for the disposal of legacy waste (old municipal solid waste), which describes the treatment and disposal of legacy municipal solid waste by bio-remediation and bio-mining (CPCB, 2019[47]).

2.4.2.4. Korea

Korea presents BAT and BAT-AELs for the waste incineration sector in Korean Best Available Techniques Reference Document for Waste Incineration (I) (NIER, 2016[48]) and Korean Best Available Techniques Reference Document for Waste Incineration (II) (NIER, 2022[49]). The revised K-BREF for Waste Incineration (II) published in 2022 includes the revised BAT- AELs of heavy metals and hydrogen fluoride (HF).

2.4.2.5. United States

The US EPA regulates pollution through media-specific regulations for the waste incineration sector. The following regulations are used in the control and prevention of pollutants in the air and water:

- Large municipal waste combustors (US EPA, 2006[50])
- Small municipal waste combustors (US EPA, 2006[51])
- Other solid waste combustors (US EPA, 2006[52])
- Sewage treatment plant incineration (Air) (US EPA, 1994[53]),

- Waste combustors (Water) (US EPA, 2000[54]),
- Centralised waste treatment (Water) (US EPA, 2003[55])

The US EPA develops limitations based on specific treatment technologies – using the performance of that technology at the time of rule writing to set numeric limitations. However, facilities may use whatever treatment and control technologies they choose to meet the limitations set. In addition to the sector-specific regulations for municipal waste incineration, individual facilities may have site-specific limits set for NO_x, SO_2, CO, and PM under New Source Review permits or water pollutants under NPDES permits. The New Source Performance Standards (NSPS) for Large Municipal Waste Combustors (LMWC) mainly inform about energy recovery. Also, non-hazardous incinerators have been applied to a type of flue gas cleaning and control system.

2.4.2.6. World Bank Group

The World Bank Group presents BAT and BAT-AELs information for waste management in sector-specific and general Environment, Health and Safety Guidelines. As directly comparable “BREF equivalent” documents on municipal solid waste were not available, the following documents were referred to extract information for the pollutants covered by this report:

- Environmental, Health, and Safety Guidelines for Waste Management Facilities (IFC, 2007[56]).
- Environmental, Health, and Safety General Guidelines (IFC, 2007[25]).

The EHS Guidelines contain the performance levels and measures generally considered achievable in new facilities by existing technology at reasonable costs. Applying the EHS Guidelines to existing facilities may involve establishing site-specific targets and an appropriate timetable for achieving them.

The general EHS guidelines are complementary and recommended to be used together with the industry-specific EHS guidelines. The EHS Guideline for waste management facilities comprises the key environmental, health, and safety issues associated with the sector. It includes considerations for the operational and decommissioning phases and recommendations for mitigating these impacts.

The emissions (and effluent) standards for waste management facilities are sourced from AELs in the EU and the United States. Since this report collects the most updated AELs from the two BREFs, no further AELs from the EHS guidelines for this sector are reported in Chapter 4. of this cross-country analysis.

2.4.3. Sub-chapter summary – Waste Incineration

Incineration serves as a crucial method for treating a wide range of wastes within comprehensive waste management systems. Specific variant processes are being developed and applied to address diverse waste streams effectively. Following are the key observations from Chapters 1 and 2 on contextual matters surrounding the BREFs for municipal solid waste incineration:

- There are sectoral-specific BREF for municipal solid waste incineration available from the EU, Korea, and the US-EPA, while China (GATPPC) and India (CPCB and MINAS), alongside the EHS Guidelines provided by the World Bank, solely establish standards for pollution prevention and control. The EHS Guidelines, concentrating on waste management facilities, are incorporated in this report for informational purposes.
- BREF documents cover different types of waste to address the specific needs of various waste incineration sectors. They include clinical/medical/healthcare, hazardous chemicals, municipal solid (household and commercial), and industrial non-hazardous wastes. This broad coverage ensures that regulatory guidance provided in the BREFs suits different waste streams.
- BREFs are typically developed as a sector expands. For example, in India, there are only standards for municipal solid waste incineration, which has had limited application due to

alternative waste disposal methods, notably landfills. However, societal changes are expected to lead to a wider adoption of the technology in India for residual non-recyclable municipal waste.

- Technical processes covered in the BREFs vary but usually cover all stages of waste management, from waste reception and storage, pre-treatments (not always relevant), combustion, flue gas (and wastewater) treatment, energy recovery, residue handling, and monitoring.
- Air emissions have historically been prioritised as the most critical environmental concern in waste incineration. Consequently, all BREFs cover air emissions comprehensively, which are usually considered the most relevant environmental issue. BREFs identify various substances of concern for air emissions, such as nitrogen oxides (NO_x), ammonia (NH_3), sulphur oxides (SO_x), particulate matter (PM), total volatile organic compounds (TVOC), hydrogen chloride (HCl), hydrogen fluoride (HF), heavy metals (including mercury, cadmium, and total metals), and persistent organic pollutants (POPs) such as PCDD/F, PBDD/F and PCB. The type of flue gas cleaning (dry or wet) used in waste incineration processes may result in the production of wastewater, requiring treatment before being discharged. BREFs may describe BAT and BAT-AELs, specific to the type of discharge—whether directly to the environment (often after on-site treatment) or into a collective/public wastewater system.
- The BREFs cover a wide range of concerns beyond air emissions, but their approaches vary. For example, the EU BREF takes an integrated multi-media approach, addressing water releases, solid residues, energy efficiency, (and more) in one BREF. On the other hand, the US EPA regulates pollution in the waste incineration sector through media-specific regulations. Other BREFs may also refer to additional legislation and standards to address these aspects.
- There is reasonable consensus over the substances subject to control techniques and emission standards, possibly due to the maturity of regulation and technical approaches applied. However, it is important to consider that future revisions of this report may need to incorporate emerging issues and approaches, such as decarbonisation and carbon capture, to reflect evolving regulatory and technological landscapes.

Chapter 3. Best Available Techniques

3.1. Introduction

This section examines different techniques identified as the best available techniques (BAT) in the BREFs for the iron and steel, paper and pulp, and municipal solid waste incineration sectors. These BAT are used to prevent and/or control emissions or releases of specific pollutants resulting from industrial activities in the sector-specific BREFs. The identified BAT were analysed based on three categories:

I. General BAT are good practices to support sector-specific approaches.

II. Pollutant-specific or process-specific BAT approaches are often applied to prevent and control emissions or releases of sector-specific or process-specific pollutants.

III. Sub-sector differences are more detailed BAT used only in specific circumstances.

Pollutants and their associated BAT analysed in this Chapter were selected by the Expert Group members primarily on the availability of information across several BREFs to make valid cross-country analyses. As indicated in the earlier Chapters, the pollutants analysed for their BAT and BAT-AELs in the next chapter should not be taken as a suggestion of impact priority over other substances and key environmental issues not covered. The overall scope of the BREFs, including the environmental concerns specific to the country or region, is covered in Chapter 2. Many BAT commonly identified are technically described in the Activity 6 report on a Cross-country analysis of BREF for Thermal Power plants, Cement and Textile sectors (OECD, 2022[57]).

3.2. General BAT practices

General BAT includes versatile good environmental practices across diverse industries, transcending specific criteria and sectors required. It embodies a holistic approach that encourages the adoption of the most effective, efficient, and sustainable techniques applicable to industrial processes, waste management, and emissions control. These practices, by design, promote environmental responsibility by mitigating the potential adverse impacts of industrial activities on air, water, and soil.

Adopting general BAT allows for continuous improvement, emphasising the integration of cleaner production methods and resource efficiency and reducing every installation's overall environmental footprint. This inclusive approach underlines the universality of responsible environmental conduct and industrial pollution prevention and control.

General BAT conditions may apply to many sectors without specific criteria, i.e., largely regardless of input materials or processes used in the industry. By embracing cutting-edge approaches in resource management, energy efficiency, and waste reduction, the manufacturers may minimise their impact on air and water quality and enhance overall sustainability. Information regarding individual sectors is subject to the following paragraph No. 6. The following general BAT were observed in the BREFs for three industries:

- Environmental Management Systems (EMS)

    - A structured approach to environmental management and accredited/auditable systems is commonly described.
- Energy management and efficiency
    - While energy-specific issues are also identified within process-specific sections of the BREFs (e.g. BAT-AEELs for Energy Efficiency in European BREF for Waste Incineration), it is generally recognised that an overall energy management approach is beneficial, and various general techniques, such as energy consumption optimisation, are described in most BREFs.
- Material management and efficiency, waste prevention and waste management
    - Practices to prevent impacts from stockpiles of incoming raw materials and the storage and handling of residues are usually described.
    - careful selection and control of raw materials, process chemicals and additives
    - using recovered material, such as scrap metals.
    - separate collection of different waste fractions (including separation and classification of hazardous waste)
- Minimisation of diffuse dust emissions from materials storage, handling and transport
- Water and Wastewater Management
    - The BREFs commonly note the principle of good water management, which reduces freshwater consumption and ensures proper wastewater handling and treatment, including water recycling and closed-loop systems.
- Monitoring
    - Monitoring principles and methods for monitoring and compliance assessment of various processes and releases are described in general BAT sections of the BREFs. As part of the BAT-AELs analysis, monitoring conditions for all pollutants were included in Chapter 4.
- Noise reduction
    - Noise reduction, as a general BAT, employs techniques or strategies to control noise emissions in various industrial activities, such as optimising machinery and equipment to operate more quietly or soundproofing facilities.
- Odour control:
    - Odours from industrial processes are monitored under air emissions and, in some BREFs, managed with other pollutants, such as bioaerosols, dust, ammonia and volatile organic compounds (VOC) (IFC, 2007[58]).
    - In the EU, odour management is addressed differently across various BREFs:
        - In the EU BREF for iron and steel, in the BAT conclusions for the blast furnaces, BAT 69 indicates that BAT for minimising slag treatment emissions is to condense fume if odour reduction is required.
        - In the EU BREF for waste incineration, an odour management plan is foreseen as part of the Environmental Management system (BAT 1), which includes:
            a. A protocol for conducting odour monitoring. It may be complemented by measurement/estimation of odour exposure or estimation of odour impact.
            b. A protocol for response to identified odour incidents, e.g. complaints.
            c. An odour prevention and reduction programme designed to identify the source(s), to measure/estimate odour exposure, to characterise the contributions of the sources, and to implement prevention and/or reduction measures.
        a. In the EU BREF for pulp and paper, odour emissions are addressed in BAT 7 (techniques applicable for odours related to water systems closure as well as techniques applicable for

odours related to wastewater treatment and sludge handling, in order to avoid conditions where wastewater or sludge becomes anaerobic

- General Techniques to improve environmental and combustion performance, including on
  - Process design and control
  - Continuous (rather than intermittent) operations and reduction of non-standard operational event frequencies and periods
- Decommissioning
  - Environmentally responsible approaches for dismantling industrial facilities are described in some BREFs to consider their design for end-of-life plant decommissioning. It is usually described under the scope of the BREFs, such as done in the World Bank's EHS Guidelines for the three sectors.

In the same BREFs, there may be both the general BAT for all industries (e.g., Environmental Management Systems, EMS) and general BAT specific to the sub-sectors within an industry (e.g. wastewater treatment systems in the paper and pulp sector, collection systems for strong and weak malodorous gases, etc.). This practice is mainly noted for the EU BREFs and World Bank's EHS Guidelines. Other examples of sector-targeted general BAT identified are as below:

- General BAT for **iron and steel**:
  - As it is common for power plants to be integrated with steel works, they are sometimes briefly covered in the BREF and linked to other power plant-specific BREFs.
  - Integrated steelworks
    - optimisation of energy flows and optimised utilisation of the extracted process gases such as coke oven gas, blast furnace gas and basic oxygen gas
    - utilisation of waste heat, desulphurised and dedusted surplus coke oven gas, dedusted blast furnace gas and basic oxygen gas (mixed or separate) in boilers or in combined heat and power plants
    - minimisation of electrical energy consumption
    - online monitoring of the most critical energy flows and combustion processes
    - reporting and analysing tools to check the average energy consumption of each process
    - defining specific energy consumption levels for relevant processes.
  - Process integrated techniques in steel manufacturing
    - improved heat recovery, including combined heat and power production with the recovery of waste heat by heat exchangers and distribution either to other parts of the steelworks or to a district heating network
    - steam boilers or adequate systems in large reheating furnaces
    - preheating of the combustion air in furnaces and other burning systems
    - The use of top recovery turbines to convert the kinetic energy of the gas produced in the blast furnace into electric power;
  - Scrap-related processes/techniques (improved use of scrap)
    - acceptance criteria
    - having a good knowledge of scrap composition, in exceptional cases, a melt test might help characterise the composition of the scrap
    - adequate reception facilities and check deliveries
    - procedures to exclude scrap not suitable for use in installation

    - scrap sorting to minimise the risk of including hazardous or non-ferrous contaminants, particularly PCBs and oil or grease, and ensure the absence of mercury.

- General BAT for **paper and pulp**:
  - Boiler/steam system management
    - Rationalisation of driving management,
    - Utilisation of waste heat,
    - Application of high-efficiency facilities
  - Compressed air system management:
    - Rationalise operation management of compressed air system,
    - Waste heat utilisation of compressed air system,
    - Application of high-efficiency equipment to compressed air system
  - Pumping (Pump/Fan) System Management
  - Energy Diagnostics
  - Reducing the use of water
    - Change of river water intake water source,
    - Use heavy water
  - Utility Management
    - Improving heat transfer by installing several bars inside the dryer,
    - Adjusting exhaust air volume by measuring exhaust water volume and applying an automatic control device,
    - Using Airlift Pump,
    - Using turbo fans or blowers (EIPPCB, 2015[27]).
- General BAT for **waste incineration (municipal solid waste**):
  - In the World Bank's EHS Guidelines for waste management (IFC, 2007[58]), BAT applicable to MSW (and industrial non-hazardous waste) are categorised according to waste collection and transport, biological treatment, incineration, and landfilling. Air emissions from incineration depend on the specific waste composition and the presence and effectiveness of air pollution control systems. The following BAT are recommended to prevent, minimise, and control air for the MSW. In the EU, these BATs are included in the IED (EU, 2010[45]) and/or the BREF (EIPPCB, 2019[44]):
    - Follow applicable national requirements and internationally recognised standards for incinerator design and operating conditions,
    - Introduce wastes into the incinerator only after the optimum temperature reaches the final combustion chamber.
    - The waste charging system should be interlocked with the temperature monitoring and control system to prevent waste additions if the operating temperature falls below the required limits;
    - Minimise the uncontrolled ingress of air into the combustion chamber via waste loading or other routes;
    - Optimise furnace and boiler geometry, combustion air injection, and, if used, NO_X control devices using flow modelling;
    - Optimise and control combustion conditions by the control of air (oxygen) supply, distribution and temperature, including gas and oxidant mixing; the control of

combustion temperature level and distribution; and the control of raw gas residence time;

- Implement maintenance and other procedures to minimise planned and unplanned shutdowns;
- Avoid operating conditions over those that are required for efficient destruction of the waste;
- Use auxiliary burner(s) for start-up and shut-down and for maintaining the required operational combustion temperatures (according to the waste concerned) at all times when unburned waste is in the combustion chamber.
- Use a boiler to transfer the flue-gas energy for the production of electricity and/or supply of steam/heat, if practical;
- Consider the application of waste-to-energy or anaerobic digestion techniques to help offset emissions associated with fossil fuel-based power generation[9].

3.3. Iron and Steel Industry Specific BAT for the control of selected pollutants

Iron and steel production plants are known for emitting various polluting substances into the environment, many of which can have significant environmental and health impacts. Best available techniques (BAT) aim to minimise these emissions while maintaining the efficiency of the production process. The following parameters for the following plants in iron and steel production have been selected as examples for further analyses, and their BAT-AELs are compared in Chapter 4. :

- Sinter plants: Air emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x), dust (Particulate Matter), and heavy metals – mercury and dioxins.
- Blast Furnaces: Air emissions of dust and water releases of cyanides and heavy metals (lead and zinc).
- Electric Arc Furnaces (EAF): Air emissions of dust, heavy metals – mercury and dioxins and water releases of heavy metals (zinc).

3.3.1. Emissions to air

3.3.1.1. Nitrogen oxides (NO_x)

Table 7 BAT Approaches for control of NO_x emissions to air from Sinter plants

BREF	Techniques	Comments
China	• Activated carbon adsorption method synergistic desulphurisation, denitrification and dioxin removal technology.	Feasible process parameters: (1) The structure of activated carbon can be selected as cylindrical activated carbon with

[9]. The possibility of applying waste-to-energy techniques depends on several issues, including types of the MSW, the project design specifications established by the local government and laws applicable to the generation and sale of electricity produced. Also, it should be noted that recycling options may often save more energy than what is generated by incineration of mixed solid waste in a waste-to-energy facility.

BREF	Techniques	Comments
		a diameter of 9 mm, a length of 10~15 mm, and a specific surface area of 150-300 m^2/g. (2) Temperature control range of activated carbon adsorption layer: 100°C~150°C. (3) Inlet flue gas dust concentration ≤ 100 mg/m^3. (4) Activated carbon heating resolution temperature control at 400°C~450°C. Pollutant reduction and emission (1) The efficiency of desulphurisation can reach 95%. (2) Denitrification efficiency can reach 30~40%. (3) Dioxin removal effect, from 1.5 ng-TEQ/Nm3 to 0.2 ng-TEQ/Nm^3. (4) Particle emission concentration is less than 20mg/m^3.
	• Selective catalytic reduction denitrification (decomposition of dioxins) technology (SCR).	Feasible process parameters: (1) Ammonia concentration should be controlled at 20~25 %. (2) The control temperature of the denitrification area should be greater than 280°C and controlled at 320°C~425°C. (3) The flue gas flow rate of the catalyst plane should be selected as 4~6 m/s. Pollutant reduction and emission: (1) Denitrification efficiency is not less than 80 %; (2) Ammonia escape concentration is less than 2.28 mg/m^3; (3) Dioxin emission concentration can be controlled at 0.1~0.3 ng-TEQ/Nm^3.
European Union	BAT for primary emissions from sinter strands is to reduce total nitrogen oxide (NO_X) emissions by using one or a combination of the following techniques: (1) Process-integrated measures can include (i) waste gas recirculation and (ii) other primary measures, such as the use of anthracite or the use of low-NOx burners for ignition.	• Waste gas recirculation: special attention needs to be paid to carbon monoxide in the recirculated waste gas; in existing plants, it may not be possible to install partial recycling due to space restrictions • Use of anthracites with lower nitrogen content compared to coke breeze • SCR: the gas must be low in dust and HM because they can make the surface of the

BREF	Techniques	Comments
	(2) End-of-pipe techniques, which can include regenerative active carbon (RAC) process SCR selective catalytic reduction.	catalyst ineffective; another prerequisite is a minimum off-gas temperature of about 300°C. Additionally, desulphurisation before the catalyst might be required. The high investment and operational costs, the need for catalyst revitalisation, NH_3 consumption and slip, the accumulation of explosive ammonium nitrate (NH_4NO_3), the formation of corrosive SO^3 and the additional energy required for reheating which can reduce the possibilities for recovery of sensible heat from the sintering process, all may constrain the applicability. This technique might be an option where environmental quality standards are unlikely to be met by applying other techniques. • Waste gas recirculation: The application of waste gas recirculation requires special efforts to ensure that the sinter quality and productivity are not affected negatively. Special attention needs to be paid to carbon monoxide (CO) in the recirculated waste gas to prevent employees' carbon monoxide poisoning. In existing plants, it may not be possible to install a partial recycling of waste gas due to space restrictions. • Use of anthracite: The use of anthracite depends on the availability of anthracites with a lower nitrogen content compared to Coke Breeze. • Regenerative activated carbon process (RAC): Dust abatement should be installed to reduce the inlet dust concentration before the RAC process. The layout of the plant and space requirements are generally essential factors when considering this technique, especially for a site with more than one sinter strand.
India	N/A	
Korea	• Emission gas recirculation • Use of low-nitrogen anthracite	

BREF	Techniques	Comments
	• Using low-NOx burners • Regenerated activated carbon • SCR	
United States	• There is no sector-specific BAT for NO_x emissions from sintering, although individual facilities may have site-specific NO_x limits in permits based on the New Source Review process.	
World Bank	• Application of waste gas recirculation; • Use of oven batteries with multi-stage air supply systems;	

3.3.1.2. Sulphur oxides (SO_x)

Table 8 BAT Approaches for control of SO_x emissions to air from Sinter plants

BREF	Techniques	Comments
China	Limestone-gypsum desulphurisation technology	Feasible process parameters (1) The design flow rate of the absorption tower should be less than 3.5 m/s. (2) The concentration of flue gas dust entering the desulphurisation system should be less than 100 mg/m^3. (3) Calcium-sulphur molar ratio of 1.03~1.05, pH value of absorption liquid is controlled at 5~6. (4) When limestone is used as a desulphurising agent, $CaCO_3$ content should be higher than 90%; for medium and low concentrations of sulphur, the particle size of desulphurising agent 250 mesh should be higher than 90 %; for high concentration of sulphur, the particle size of desulphurising agent 325 mesh should be higher than 90 %; when quicklime (CaO) is used, the purity should be higher than 85 %. Pollutant reduction and emission The efficiency of desulphurisation is generally more than 95 %, and the

BREF	Techniques	Comments
	• Ammonia desulphurisation technology • Spray drying desulphurisation technology	removal rate of fluoride and chloride is more than 95 %. Feasible process parameters: (1) The PH value of absorption liquid is controlled at 5~6. (2) The fly ash concentration in the flue gas at the entrance of the desulphurisation system is less than 100 mg/m^3. (3) Desulphurisation ammonia concentration should be 15~25 %. (4) The concentration of ammonia escaping from the flue gas after desulphurisation should be less than 10 mg/m^3, and the concentration of mist droplets in the flue gas at the exit of the mist eliminator should be less than 75 mg/m^3. Pollutant reduction and emission: The removal efficiency can be more than 95 %, and the fluoride and chloride removal rate is more than 95 %. Feasible process parameters (1) Lime slurry solids should be controlled at 20~25%, rotary atomiser slurry atomisation particle size 30~80 µm, two-fluid nozzle atomisation particle size particle size 70~200µm. (2) The resistance of the desulphurisation tower should be less than 1000 Pa, and the residence time of flue gas in the tower should be more than 18 seconds. (3) Under typical working conditions, the flue gas temperature at the outlet should be controlled at 15℃~20℃ above the dew point temperature. Pollutant reduction and emission:

BREF	Techniques	Comments
	• Circulating Fluidised Bed Desulphurisation technology	The sulphur dioxide removal rate can reach 90%; adding activated carbon or lignite can further remove dioxin and heavy metals such as mercury. Feasible process parameters (1) The particle size of desulphurising agent lime powder should be less than 2 mm, and the CaO content should be more than 80%. (2) Calcium-sulphur molar ratio can be selected as 1.2~1.35. (3) Under typical working conditions, the flue gas temperature at the outlet is controlled at 15°C~20°C above the dew point temperature. (4) The pressure drop of the desulphurisation tower should be controlled below 2500 Pa. (5) Dust concentration in the desulphurisation tower is kept at 800~1000 g/m^3 under standard conditions. Pollutant reduction and emission: The Sulphur dioxide (SO_2) removal rate is not less than 85%; adding activated carbon or lignite can further remove heavy metals such as dioxin and mercury. Adopting bag-type dust removal equipment, the particle emission concentration can be less than 30mg/m^3 or lower.
European Union	BAT for primary emissions from sinter strands is to reduce sulphur oxide (SO_X) emissions by using one or a combination of the following techniques: • Lowering the sulphur input by using Coke Breeze with a low sulphur content • Lowering the sulphur input by minimisation of coke breeze consumption	• RAC process: sulphuric acid is yielded as a by-product; RAC system can be developed as a single-stage or two-stage process; dust abatement should be installed before the RAC process. Dust abatement should be installed before the RAC process to reduce the inlet dust concentration. Generally, the layout of the plant and space requirements are important

BREF	Techniques	Comments
	• Lowering the sulphur input by using iron ore with a low sulphur content • Injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting by bag filter • Wet desulphurisation or regenerative activated carbon (RAC) process (with particular consideration for the prerequisites for application).	factors when considering this technique, but especially for a site with more than one sinter strand. High investment and operational costs. • Wet desulphurisation: The space requirements may be significant and restrict the applicability. High investment, operational costs, and significant cross-media effects such as slurry generation, disposal, and additional wastewater treatment measures must be considered. This technique was not used in Europe at the time of BREF's writing (BATc 2012) but might be an option where environmental quality standards are unlikely to be met by applying other techniques.
India	N/A	
Korea	• Use low-sulphuric powder coke • Use low- sulphuric iron ore • Dry desulphurisation or regenerative activated carbon (RAC)	
United States	There is no sector-specific BAT for SO_x emissions from sintering, although individual facilities may have site-specific NO_x limits in permits based on the New Source Review process.	
World Bank	• Selection of raw feedstocks with low sulphur content; • Minimising the sulphur content of the fuel; • Addition of absorbents such as hydrated lime [$Ca(OH)_2$], calcium oxide (CaO), or fly ashes with high CaO content injected into the exhaust gas outlet before filtration; • Installation of gas wet scrubbing systems in dedicated collecting and dedusting system; • Use of a wet-scrubber injection of a slurry mix containing calcium carbonate ($CaCO_3$), CaO, or $Ca(OH)_2$; • Use of a dry scrubber, if necessary	• Wet scrubber injection can commonly achieve a sulphur dioxide (SO_2) removal efficiency of up to 90 %. Its implementation also allows the reduction of hydrogen chloride (HCl), hydrogen fluoride (HF), ammonia (NH_3), and metals emissions. • The dry scrubber technique is more expensive and less commonly used than wet scrubbers.

3.3.1.3. Dust (Particulate matter)

Table 9 BAT approaches for control of dust (Particulate matter) emissions to air from Sinter plants

BREF	Techniques	Comments
China	• Bag filter technology	• A Low-resistance, high-efficiency bag dust collector is selected, and the ash cleaning method is low-pressure pulse type. The filter material can be selected with polyurethane needle felt, and if necessary, the coated filter material, needle filter materials with needle and calendered finishes, or PTFE impregnation treatment can be selected, and the single weight is not less than 520~540 g/m². When handling moist gases (batching dust removal), anti-condensation measures should be taken. When treating coal dust exhaust gas, anti-static filter material should be used. The flow rate in the dust removal duct is generally 16~18 m/s, not less than 15 m/s, to avoid dust accumulation in the tube. In addition to the sintering head, when the bag dust collector purifies other dust source points of the sintering process, the filter air speed is 1~1.1 m/min. The resistance of the dust collector equipment is less than 1300 Pa.
	• Electrostatic precipitator	• The dust removal efficiency can reach more than 99.9 %, and the particle emission concentration can be controlled within 30mg/m³ or even below 10 mg/m³. • A 400~500mm wide pole pitch electrostatic precipitator is selected for the head electrostatic precipitator. Mobile electrode technology can effectively remove the high specific resistance dust on the plate and reduce secondary dust. The number of electric fields of the electrostatic precipitator should not be less than 4, and the cross-sectional wind speed of the electrostatic precipitator should be 0.8~0.85m/s (for qualified enterprises,

BREF	Techniques	Comments
	• Electrostatic precipitator Combined bag filter technology • The sintered belt cooler adopts the fully enclosed hood method, and the waste hot gas is sent to the waste heat boiler for recovery through the pipeline.	the cross-sectional wind speed of the electrostatic precipitator can be lower) The number of electric fields of the tail electrostatic precipitator should not be less than 4, and the cross-sectional wind speed of the electrostatic precipitator can be slightly higher than that of the head, which is 0.9~1.0m/s (conditional enterprises, the cross-sectional wind speed of the electrostatic precipitator can be lower) • The pole spacing in the electric field area should be 400 mm. The filter air speed in the filter bag area should not be greater than 1.2 m/min. The dust concentration of imported flue gas in the standard state should be less than 1500 g/m^3 (standard, dry basis) • The fan or exhaust cylinder is arranged on the closed cover to discharge. /b10> The discharge point of the raw (burning) belt conveyor adopts the fully enclosed hood, and the dust production point of the receiving material adopts a double-layer closed cover. The vibrating screen adopts an integral sealing cover or a partial sealing cover. The pumping position of the closed hood should be set in the highest position of the pressure in the hood, consistent with the diffusion direction of harmful substances, and the wind speed of the closed hood mouth should be selected at 1~1.5 m/s.
European Union	• BAT for primary emissions from sinter plants is to reduce dust emissions from the sinter strand waste gas using a bag filter. • BAT for primary emissions for existing plants is to reduce dust emissions from the sinter strand waste gas by using advanced electrostatic precipitators when bag filters are not applicable.	• Bag filters used in sinter plants are usually applied downstream of an existing electrostatic precipitator or cyclone but can also be operated as a standalone device. • Applicability: Requirements such as space for a downstream installation to the electrostatic precipitator can be relevant for existing plants. Particular

BREF	Techniques	Comments
		regard should be given to the existing electrostatic precipitator's age and performance. • Advanced electrostatic precipitators are characterised by one or a combination of the following features: good process control; additional electrical fields; adapted strength of the electric field; adapted moisture content; conditioning with additives; higher or variably pulsed voltages; rapid reaction voltage; high energy pulse superimposition; moving electrodes; enlarging the electrode plate distance; or other features that improve the abatement efficiency.
India	N/A	
Korea	• Electrostatic precipitators and bag filters. • Controlling the amount of water in raw materials	
United States	• Baghouse • Venturi scrubber • Electrostatic precipitators • Operators using an air pollution control devices other than a baghouse, venturi scrubber, or electrostatic precipitator must submit a description of the device, test results collected to verify the performance of the device for reducing emissions of PM to the atmosphere to the AELs required, a copy of the operation and maintenance plant, and appropriate operating parameters	• The limits cover emissions from the wind box exhaust, discharge end, and sinter cooler. • Facilities must operate each capture system at or above the lowest value settings for operating limits.
World Bank	• Implement partial or total recirculation of waste gas in the sinter plant, according to sinter quality and productivity; • Use of electrostatic precipitator (ESP) pulse systems, ESP plus fabric filter, or adoption of pre-dedusting (ESP or cyclones) in addition to a high-pressure wet scrubbing system for waste gas de-dusting. The presence of fine dust, which consists mainly of alkali and lead chlorides, may limit the efficiency of ESPs	

Table 10 BAT Approaches for control of dust (Particulate matter) emissions to air from Blast Furnaces

BREF	Techniques	Comments
China		The GATPPCs mention the BAT for pollution prevention, which is common to the steel-making process, but they do not specify the furnace type. The GATPPC of the steel-making process in the steel and iron industry only specifically mention some BAT for EAFs
European Union	• BAT for displaced air during loading from the storage bunkers of the coal injection unit is to capture dust emissions and perform subsequent dry dedusting. • BAT for burden preparation (mixing, blending) and conveying is to minimise dust emissions and, where relevant, extraction with subsequent dedusting using an electrostatic precipitator or bag filter. • BAT for casting house (tap holes, runners, torpedo ladles charging points, skimmers) is to prevent or reduce diffuse dust emissions by using the following techniques: covering the runners, optimising the capture efficiency for diffuse dust emissions and fumes with subsequent off-gas cleaning using an electrostatic precipitator or bag filter, fume suppression using nitrogen while tapping, where applicable and where no collecting and dedusting system for tapping emissions is installed. • Dust emissions from blast furnace gas BAT is to reduce dust emissions from the blast furnace gas by using one or a combination of the following techniques: I. Using dry pre-dedusting devices such as deflectors, dust catchers, cyclones, and electrostatic precipitators. II. Subsequent dust abatement, such as hurdle-type scrubbers, venturi scrubbers, annular gap scrubbers, wet electrostatic precipitators, and disintegrators.	
India	N/A	
Korea	• The coal injection unit is used to capture dust emissions and subsequently perform dry dedusting, • Preparation (mixing, blending) and conveying are done to minimise dust emissions • Using bag filter.	

BREF	Techniques	Comments
United States	• Baghouse • Venturi scrubber • Electrostatic precipitators • Operators using an air pollution control devices other than a baghouse, venturi scrubber, or electrostatic precipitator must submit a description of the device, test results collected to verify the performance of the device for reducing emissions of PM to the atmosphere to the AELs required, a copy of the operation and maintenance plant, and appropriate operating parameters	• The limits cover emissions from the blast furnace cast house • Facilities must operate each capture system at or above the lowest value settings for operating limits
World Bank	• Use of dedusting systems, typically including scrubbers and • Electrostatic precipitators (ESP) before reuse of the off-gas.	

Table 11 BAT Approaches for control of dust (Particulate matter) emissions to air from EAF

BREF	Techniques	Comments
China	LT dry dedusting technology. • It converts the primary high-temperature flue gas through the evaporative cooler cooling, tempering and coarse de-dusting through the cylindrical electrostatic precipitator for fine de-dusting and, at the same time, recovers gas.	Feasible process parameters: • The flue gas temperature at the outlet of the vapour cooling flue is lower than 1000°C, the flue gas temperature at the outlet of the evaporative cooler is lower than 200°C, and the ratio of water spray in the evaporative cooler is 0.01～0.04 L/m^3. Pollutant reduction and emission • The dust removal efficiency is more than 99.9%, and the concentration of dust in the discharged waste gas is less than 20 mg/m^3.
	• Dedusting technology for OG systems	Feasible process parameters • The flue gas temperature at the outlet of the vapour cooling flue is lower than 1000℃, the water spray

BREF	Techniques	Comments
		ratio in the evaporative cooling tower is 3.0-3.5 L/m^3, and the water spray ratio in the secondary venturi of the RSW ring-gap adjustable throat is 2.0-2.5 L/m^3.
	• Long bag low-pressure pulse bag filter	Pollutant reduction and emission • The dust removal efficiency is more than 99.5%, and the concentration of dust in the discharged exhaust gas is less than 50 mg/m^3. • The filter material is mainly polyester needle felt. The filter air speed of the bag filter is 0.8~2 m/min, the resistance loss is less than 2000 Pa, the air leakage rate is less than 5%, and the operating temperature is not higher than 200 °C. The flue gas of the electric furnace of the new steelmaking enterprise adopts the fourth hole smoke exhaust, closed hood, roof cover and bag filter process. The flue gas of the electric furnace of the reconstruction and expansion of steelmaking enterprises adopts the process of deflector hood, top suction hood and bag filter; The converter secondary flue gas adopts the converter fire retaining door closed and belt dust collector process. The three-flue gas of the converter adopts the process of plant closure, roof exhaust and bag filter.
	• Flue gas quenching with high-efficiency filtration technology	• When the flue gas quenching technology is used, the flue gas of the electric furnace is rapidly cooled using a spray cooling device with biphasic nozzles, and the residence time required for the temperature of the flue gas in the flue to drop from about 650°C to less than 200°C is no more than 1 second. • This technology's flue gas capture rate is more than 95%, and the dust removal efficiency is more than

BREF	Techniques	Comments
		99.9%. However, flue gas waste heat cannot be recovered using this technology.
European Union	BAT is to achieve an efficient extraction of all emission sources by using one of the techniques listed below and to use subsequent dedusting using a bag filter: I. a combination of direct off-gas extraction (4th or 2nd hole) and hood systems II. direct gas extraction and doghouse systems III. direct gas extraction and total building evacuation (low-capacity electric arc furnaces (EAF) may not require direct gas extraction to achieve the same extraction efficiency).	
India	N/A	
Korea	• The techniques for reducing dust emissions from EAF • Hooded system • Doghouse system • Roof top dust collection	
United States	• Capture system including ducts, hoods, fans, and dampers used to transport captured particulate matter to the air pollution control device • Baghouse with bag leak detection system • Negative pressure fabric filter • Positive pressure fabric filter	NSPS and NESHAP do not prescribe specific air pollution control devices, although there are requirements for operating certain devices in service at a facility.
World Bank	• Quick cooling of gas followed by bag filters. The bag filters can be primed with absorbents (e.g. lime or carbon) to capture volatile impurities further; • Use of direct off-gas extraction and canopy hood enclosures and cleaning.	Baghouse filters and ESP have higher particulate collection efficiency, whereas wet scrubbers also allow the capture of water-soluble compounds (e.g., sulphur dioxide [SO^2] and chlorides). Bag filters are typically installed to control melting shop emissions. They are often preceded by cyclones, which are installed to act as spark separators. Adopting ESP or/and cyclones, as pre-treatments and bag filters, may typically achieve emissions levels from 10 to 20 mg/Nm^3.

3.3.1.4. Mercury (Hg)

Table 12 BAT Approaches for control of Hg emissions to air from Sinter plants

BREF	Techniques	Comments
China	• Spray drying desulphurisation with activated carbon or lignite, • Circulating Fluidised Bed Desulphurisation (CFBD) with activated carbon or lignite added	Adding activated carbon or lignite to dry (semi) desulphurisation methods synergistically treats heavy metals such as mercury.
European Union	• BAT for primary emissions from sinter strands is used to prevent or reduce mercury emissions by selecting raw materials with low mercury content or to treat waste gases in combination with activated carbon or activated lignite coke injection.	
India	N/A	
Korea	• Selecting raw materials with low mercury content. • Using a bag filter with activated carbon.	
United States	The US EPA does not have emission limits for mercury emissions from sintering.	In proposed updates to the NESHAP, EPA has proposed new emission limits for mercury from sintering.
World Bank	See Table 9, Table 10 and Table 11	PM may be generated in each steel production step and may contain varying concentrations of mineral oxides, metals (e.g. arsenic, cadmium, mercury, lead, nickel, chromium, zinc, manganese), and metal oxides.

Table 13 BAT Approaches for control of Hg emissions to air from EAF

BREF	Techniques	Comments
China	N/A	
European Union	BAT for the electric arc furnace (EAF) process is to prevent mercury emissions by avoiding, as much as possible, raw materials and auxiliaries which contain mercury	
India	N/A	
Korea	Avoid using mercury-containing raw materials and supplements.	

BREF	Techniques	Comments
United States	For scrap containing motor vehicle scrap, operators must procure scrap through one of three compliance options: • Operators must include a requirement in scrap specifications from motor vehicle scrap providers for removing mercury switches from vehicle bodies used to make the scrap. This includes a goal for each scrap provider to remove at least 80% of mercury switches. • Operators must participate in and only purchase motor vehicle scrap from providers participating in a mercury switch removal program that the EPA has approved. The program must aim to remove at least 80% of mercury switches from motor vehicles. • Operators must certify that the only scrap material from motor vehicles is scrap material recovered for their speciality alloy (including but not limited to chromium, nickel, molybdenum, or other alloys) and is not reasonably expected to contain mercury switches.	Operators must certify that scrap not subject to these requirements does not contain motor vehicle scrap.
World Bank	See Table 9, Table 10 and Table 11	PM may be generated in each steel production step and may contain varying concentrations of mineral oxides, metals (e.g. arsenic, cadmium, mercury, lead, nickel, chromium, zinc, manganese), and metal oxides.

3.3.1.5. Dioxins

Table 14 BAT Approaches for control of dioxin emissions to air from Sinter plants

BREF	Techniques	Comments
China	• Activated carbon adsorption with simultaneous desulphurisation, denitrification and dioxin removal technology.	The structure of activated carbon can choose cylindrical activated carbon with a diameter of 9mm and a length of 10~15mm, with a specific surface area of 150-300m2/g. Temperature control range of activated carbon adsorption layer: 100 °C ~ 150 °C. The dust concentration of the inlet flue gas ≤ 100mg/m3. The heating resolution

BREF	Techniques	Comments
	• Selective catalytic reduction (SCR) • Circulating Fluidised Bed Desulphurisation (CFBD) / Spray Drying Desulphurisation (SDD) adding lignite or activated carbon adsorption	temperature of activated carbon is controlled at 400 °C ~ 450 °C. The dioxin emission concentration of activated carbon adsorption technology can be controlled at 0.1~0.3 ng-TEQ/Nm³. One method is to add special catalysts (mostly composed of Ti, V, and W oxides) in the SCR denitrification process to catalyse the decomposition of PAHs, dioxins and other organic compounds while reducing NO_x. Another method is the catalytic filtration technology that combines "surface filtration" and "catalytic decomposition", where catalysts are added to the filter media or filled into the filter bags, which are designed to be the structure of a baghouse so that when the dioxin-containing gas passes through, the dioxin will be removed from the bag. When the dioxin-containing gas passes through, the dioxin is decomposed into CO_2, H_2O, and HCl. The catalytic filtration method has a high removal efficiency for both gas and solid dioxins, and the emission concentration can be lower than 0.1 ng-TEQ/Nm³. Lignite or activated carbon adsorbents are effective in adsorbing dioxins from flue gases.
European Union	BAT for prevention and reduction of PCDD/F and PCB by using one or a combination of the following techniques: • Avoid raw materials containing PCDD/F and PCB or their precursors as much as possible. • suppression of PCDD/F formation by the addition of nitrogen compounds • waste gas recirculation (particular attention to applicability restrictions to be considered) • injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting with a bag filter or advanced ESP when bag filters are not applicable	For the installation of bag filters in existing plants, requirements such as space for a downstream installation to the ESP can be relevant. Particular regard should be given to the age and the performance of the existing ESP.
India	N/A	
Korea	• Refrain from using precursor-containing raw materials.	

BREF	Techniques	Comments
	• Emission gas recirculation.	
United States	• The US EPA does not have emission limits for PCDD/PCDF emissions from sinter plants. • Operators are required to control the oil content in sinter plant feedstock to be no higher than 0.02%.	The EPA has proposed new emission limits for PCDD/PCDF from sinter plant wind boxes in proposed updates to the NESHAP.
World Bank	• Recirculation of waste gases may reduce pollutant emissions and reduce the amount of gas requiring end-of-pipe treatment; • Fine feed material (e.g. dust) should be agglomerated; • In sintering plants: minimising chloride input in the bed; use of additions such as burnt lime; and control of mill scale oil content (<1 percent); • Exclude the chlorine-rich fine fraction of filter dust from recycling in the sinter feed; • Use of clean scrap for melting; • Post-combustion of the EAF off-gas is used to achieve temperatures above 1200°C and maximise residence time at this temperature. The process is completed with a rapid quenching to minimise the time in the dioxin reformation temperature range; • Use of oxygen injection to ensure complete combustion; • Injection of additive powders (e.g. activated carbons) into the gas stream to adsorb dioxins before the dust removal by filtration (with subsequent treatment as a hazardous waste); • Installation of fabric filters with catalytic oxidation systems.	

Table 15 BAT Approaches for control of dioxin emissions to air from EAF

BREF	Techniques	Comments
China	• Scrap sorting pretreatment, flue gas quenching, high-efficiency filtration technology	Sorting the scrap minimises the amount of grease, paint, coatings, plastics, and other chlorine-containing organics and radioactive substances entering the furnace. Processing the sorted organic-containing scrap by degreasing, incineration, or pyrolysis reduces

BREF	Techniques	Comments
	• Bag dust removal, desulphurisation and other technologies can synergistically remove dioxins. • Flue gas quenching technology	the amount of dioxins generated in the EAF process at the source. Utilising the high-efficiency filtration of baghouses, most of the dioxins are trapped in the dust while the dust is removed. When using flue gas quenching technology, a spray cooling device quenches the electric furnace flue gas with a two-phase nozzle, and the flue gas temperature (in the flue) is reduced from about 650 °C to below 200 °C The residence time does not exceed 1 second.
European Union	BAT for the electric arc furnace (EAF) primary and secondary dedusting (including scrap preheating, charging, melting, tapping, ladle furnace and secondary metallurgy) is to prevent and reduce PCDD/F and PCB emissions by avoiding, as much as possible, raw materials which contain PCDD/F and PCB or their precursors and using one or a combination of the following techniques, in conjunction with an appropriate dust removal system: I. appropriate post-combustion II. appropriate rapid quenching III. injection of adequate adsorption agents into the duct before dedusting. In some cases, the BAT-AEL can only be achieved with primary measures.	Applicability of BAT I. Circumstances like available space, given off-gas duct system, etc., must be considered to assess applicability in existing plants.
India	N/A	
Korea	• Proper combustion and rapid cooling • Using Adsorption, • Bag filter, • Electrostatic precipitator (EP)	
United States	The US EPA does not have emission limits for PCDD/PCDF emissions from EAF.	Operators are required to control contaminants in scrap used in EAFs, including charging a furnace with metallic scrap free of oil filters, oily turnings, transformers or capacitors containing polychlorinated biphenyls, chlorinated plastics or free organic liquids.

BREF	Techniques	Comments
World Bank	N/A	

3.3.2. Releases to water

3.3.2.1. Cyanide

Table 16 BAT Approaches for control of CN– releases to water from Blast Furnaces

BREF	Techniques	Comments
China	• Pretreatment and O-A/O biochemical treatment technology. The biofilm method is used in the A section, the primary exposure with the biofilm method is used in the first O section, and the contact oxidation method is used in the second O section. • Pretreatment and A2/O biochemical treatment technology: the first A section adopts the hydrolysis acidification method, the second A section adopts the biofilm method, and the O section adopts the activated sludge method. • Pretreatment and A/O2 (biofilm anoxic-activated sludge aerobic-contact oxidation aerobic) biochemical treatment technology	• When cyanide is less than 70 mg/L, the cyanide removal rate is more than 99.8%. • When the influent COD is lower than 2000 mg/L, and ammonia nitrogen is lower than 150 mg/L, the cyanide removal rate is more than 99.8%. • When the influent COD≤2000 mg/L, NH^3-N≤ 150mg/L, the cyanide removal rate ＞99.8%.
European Union	BAT for treating wastewater from blast furnace gas treatment is to use flocculation (coagulation) and sedimentation and the reduction of easily released cyanide, if necessary.	
India	N/A	
Korea	N/A	
United States	The technologies used as the basis for determining cyanide effluent limits are high-rate recycling systems with a variety of system components and blowdown treatment, including alkaline or breakpoint chlorination for the destruction of cyanide.	The Effluent Guidelines for blast furnaces within the Iron and Steel Manufacturing Point Source category do not prescribe or describe the use of specific technologies, although the limits are derived based on the application of specific control technologies.
World Bank	N/A	

3.3.2.2. Heavy Metals (lead and zinc)

Table 17 BAT Approaches for control of Pb and Zn releases to water from Blast furnaces

BREF	Techniques	Comments
China	N/A	
European Union	BAT for treating wastewater from blast furnace gas treatment is flocculation (coagulation), sedimentation, and the reduction of easily released cyanide, if necessary.	
India	N/A	
Korea	N/A	
United States	The technologies used to determine the effluent guidelines for heavy metals from blast furnaces include high-rate recycle systems with clarifiers and cooling towers, blowdown treatment, metal precipitation, and multimedia filtration.	The Effluent Guidelines for blast furnaces within the Iron and Steel Manufacturing Point Source category do not prescribe or describe specific technologies. However, the limits are derived based on the application of specific control technologies.
World Bank	N/A	

Table 18 BAT Approaches for control of Zn releases to water from EAF

BREF	Techniques	Comments
China	BAT used for zinc, including electric arc dust: • Wet process • Fire-wet process	The GATPPCs of the iron and steel industry also cover BAT for solid waste utilisation (lead and zinc waste utilisation in EAF). The new technology of comprehensive utilisation of electric furnace dust includes a wet and fire-wet combined process. The wet process is used to recover the valuable substances in the electric furnace dust through leaching and electrolysis of acid, alkali, salt, and other solutions under non-high-temperature conditions. This method is usually used to treat electric furnace dust with a zinc content of more than 15 %; electric furnace dust

BREF	Techniques	Comments
		with a zinc content of less than 15 % needs to be enriched by centrifugal or magnetic separation and then processed by the wet process. The fire-wet process uses the rotary bottom furnace to carry out direct reduction roasting (fire process) on the electric furnace dust and other materials so that the iron is separated from zinc, lead and cadmium, and the directly reduced iron products obtained are returned to the electric furnace for recycling; the crude grade zinc oxide containing lead and other metals is purified and precipitated by hot ammonium chloride leaching (wet process), and the high-purity zinc oxide products are obtained after drying.
European Union	BAT is to minimise the wastewater discharge from continuous casting by using the following techniques in combination: I. The removal of solids by flocculation, sedimentation and/or filtration II. The removal of oil in skimming tanks or any other effective device III. the recirculation of cooling water and water from vacuum generation as much as possible.	
India	N/A	
Korea	N/A	
United States	N/A	
World Bank	N/A	

3.3.3. Subchapter conclusion

The subsequent section presents critical insights into specific Best Available Techniques (BAT) used for air emissions of NO_x, SO_x, dust/PM, Hg, dioxins and water releases of cyanide and heavy metals from BREFs for iron and steel production explored in Chapter 3:

- The European Union (EU), Korea, and China BREFs provide more comprehensive descriptions of techniques, explicitly indicating them as BAT, whereas India and the US-EPA documents offer less detailed specifications. Notably, China omits specific furnace types in its GATPPC document.

- Integrated facilities present opportunities for synergies within BREFs, particularly in addressing overall energy and materials efficiency concerns, which are not as feasible for individual process-specific installations.
- Emerging environmental issues are increasingly addressed alongside traditional process emission issues in BREFs, driven by decarbonisation initiatives. Recognising the potential contribution of modernised iron and steel industries, these BREFs highlight the importance of adapting to evolving environmental standards.
- There is a consensus on certain BAT across BREFs, notably end-of-pipe measures like Selective Catalytic Reduction (SCR) for NO_x reduction, flue gas desulphurisation for SO_2 abatement, and dust control using bag filters and Electrostatic Precipitators (ESPs). Additionally, process-integrated measures, which modify the production process to prevent emissions at their source, are also widely applied. These measures can be sector-specific; for example, installing low-NO_x burner systems in furnaces is a common technique.
- Advanced ESPs utilised for dust/PM emissions control from sinter plants characterised by a range of features, including good process control, additional electrical fields, adapted strength of the electric field, adapted moisture content, conditioning with additives, higher or variably pulsed voltages, rapid reaction voltage, high energy pulse superimposition, moving electrodes, enlarging the electrode plate distance, or other features aimed at enhancing abatement efficiency.
- Mercury (Hg) control strategies at sinter plants involve both preventative measures through material input control and abatement techniques like flue gas scrubbing, bag filters, and activated carbon injection.
- Dioxin controls include diverse strategies, including raw materials management, in-process control and optimisations, and various abatement approaches, such as activated carbon with fabric filters and SCR application.
- The management of wastewater emissions is generally aligned across the BREFs, although specific techniques vary. This reflects the evolving understanding and practices in wastewater treatment on a global scale.
- For cyanide release control from BF, in China, various pretreatment and biochemical treatment techniques are utilised, such as biofilms, hydrolysis acidification and activated sludge methods. These BAT demonstrate high cyanide removal rates, exceeding 99.8%, especially when influent chemical oxygen demand (COD) and ammonia-nitrogen levels are within certain thresholds. In the EU BREF, BAT includes flocculation (coagulation), sedimentation, and the reduction of easily reduced cyanide. The US EPA notes high-rate recycling systems with components like alkaline or breakpoint chlorination for cyanide destruction; however, specific BAT are not described in the Effluent Guidelines.
- Only the EU BREF and US-EPA Effluent Guidelines covered BAT for controlling heavy metals (lead and zinc). In the EU BREF, like cyanide control, BAT involved flocculation (coagulation), sedimentation, and reducing easily released cyanide. The US-EPA Effluent Guidelines focus on high-rate recycle systems with clarifiers, cooling towers, blowdown treatment, metal precipitation and multimedia filtration to address heavy metal discharge from blast furnaces. Again, specific techniques are not outlined in the Effluent Guidelines but are derived based on control technology applications. For the zinc control from the Electric Arc Furnaces (EAF), China emphasises comprehensive utilisation techniques for electric furnace dust, including wet and fire-wet combined processes. These BAT involve leaching, electrolysis, and direct reduction roasting to recover valuable substances and separate iron from zinc, lead and cadmium. In the EU BREF, BAT minimises wastewater discharge from continuous casting through techniques like solids removal, oil removal and water recirculation.

- These observations underline a common emphasis on BAT for water releases of these selected pollutants involving flocculation, sedimentation, and the utilisation of high-rate recycling systems across different regions. At the same time, specific approaches varied based on local conditions and industrial practices.

3.4. Paper and Pulp Industry Specific BAT for the control of selected pollutants

In paper and pulp production, BAT represents a set of practices and techniques that are continually refined and optimised to reduce the environmental footprint of this sector. Paper production involves a series of various types of pulping techniques; for this cross-country analysis, kraft pulping, including its recovery boilers, and paper manufacture from recycled paper were examined for their emissions and releases of several pollutants, including water consumption in these two processes. The following selected pollutants for the two processes are analysed for their associated BAT and their BAT-AELs in 4.3. Paper and Pulp Production:

- Kraft Pulping: Air emissions of total reduced sulphur (TRS), dust (Particulate Matter, PM) and nitrogen oxides (NO_x) from recovery boilers. The total suspended solids (TSS), chemical oxygen demand (COD) and adsorbable organic halides (AOX) release into water.
- Paper manufacture from recycled paper: Water releases of total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halides (AOX), total nitrogen (tot-N) and total phosphorus (tot-P).
- Water consumption per tonne of production is analysed as a process efficiency measure for kraft pulping and paper production.

3.4.1. Emissions to air

3.4.1.1. Nitrogen oxides (NO_x)

Table 19 BAT Approaches for control of NO_x emissions from Recovery Boilers in Kraft Pulping

BREF	Techniques	Comments
China	SNCR	For all pulping processes
European Union	BAT is to use an optimised firing system including all of the techniques: a) Computerized combustion control b) Good mixing of fuel and air c) Staged air feed systems (using different air registers and air inlet ports)	BAT 22. The technique (c) applies to new recovery boilers and, in the case of a significant refurbishment of recovery boilers, as this technique requires considerable changes to the air feed systems and the furnace.
India	N/A	
Korea	Multi-stage combustion system (Quaternary air)	BAT 31: an appropriate combination of these techniques
United States	N/A	While the EPA does not have sector-specific emission limits for NO_x from kraft pulping, individual facilities may have site-specific limits in permits based on the New Source Review process.

BREF	Techniques	Comments
World Bank	Primary emissions management strategies for Kraft and sulphite mills include the following: a) Oxidation of black liquor before direct contact evaporation b) Reduced emissions of nitrogen oxides (NO_x) by control of firing conditions, such as excess air;	(a) Applicable to existing facilities, as direct contact evaporators should not be used in new facilities.

3.4.1.2. Dust (Particulate matter)

Table 20 BAT Approaches for control of dust (Particulate matter) emissions from Recovery Boilers in Kraft Pulping

BREF	Techniques	Comments
China	• Electrostatic precipitator (ESP) • Bag filter	The ESP and bag filter are considered generally applicable BAT for all pulping processes.
European Union	To reduce dust emissions from a recovery boiler, BAT is using an electrostatic precipitator (ESP) or a combination of ESP and wet scrubber.	BAT 23.
India	N/A	
Korea	N/A	
United States	• The technology basis for the original NSPS PM standard was an electrostatic precipitator (ESP). • Recovery furnaces are equipped with either a dry-bottom or wet-bottom ESP. • Wet scrubbers or ESP-scrubber combinations are used to a lesser extent.	NESHAP and NSPS do not prescribe the use of specific control technologies, although requirements for the operation of certain control devices may be outlined in the regulations.
World Bank	See Table 20.	

3.4.1.3. Total reduced sulphur (TRS)

Table 21 BAT Approaches for control of TRS and SO_x emissions from Recovery Boilers in Kraft Pulping

BREF	Techniques	Comments
China	White clay washing and filtration technology	After washing and filtering the white mud using a filter press, it can effectively reduce the content of sodium sulphide in the white mud, reduce the TRS emission from the lime kiln during the calcination of the white mud, and also make the operation of the lime kiln more stable. This method can only be used in enterprises preparing wood pulp using the sulphate method.
European Union	General BAT (for paper and pulp production): a. Collection systems for strong and weak malodorous gases comprising the following features: - covers, suction hoods, ducts, and extraction system with sufficient capacity; - continuous leak detection system; - safety measures and equipment. b. Incineration of strong and weak non-condensable gases, e.g. in the recovery boiler, the lime kiln or dedicated TRS burner or power boiler c. Recording unavailability of the incineration system and any resulting emissions To reduce SO_2 and TRS emissions from a recovery boiler, BAT is to use a combination of the techniques given below: • Increasing the dry solids (DS) content of black liquor • Optimized firing • wet scrubber	BAT 20 Back-up systems are installed to ensure the constant availability of incineration for odorous strong gases. Lime kilns can serve as backup for recovery boilers; further backup types of equipment are flares and package boilers. • An evaporation process can concentrate the black liquor before burning. • Firing conditions can be improved, e.g., by mixing air and fuel, control of furnace load, etc. BAT 21
India	N/A	Only standards for H_2S are set in the MINAS for the sector.

BREF	Techniques	Comments
Korea	N/A	
United States	The original technology basis for direct contact evaporator (DCE) recovery furnaces was two or more stages of black liquor oxidation before evaporation. For non-direct contact evaporator (NDCE) recovery furnaces, the basis was that excellent combustion control within the furnace is needed.	NESHAP and NSPS do not prescribe the use of specific control technologies, although requirements for the operation of certain control devices may be outlined in the regulations

World Bank	Kraft pulping processes typically emit highly malodorous reduced sulphur compounds denoted as total reduced sulphur (TRS), which include hydrogen sulphide, methyl mercaptan, dimethyl sulphide, and dimethyl disulphide.
	
	Recommended emissions management strategies include the following:
	• For bleached and unbleached Kraft mills, malodorous gases from vents at all points in the process handling black liquor, unwashed brown pulp, partially washed brown pulp, unbleached pulp, and condensates should be collected and incinerated to oxidise all reduced sulphur compounds completely,
	• In the case of high-concentration gases (generally from condensates and digester vents), a stand-by system for incineration should be provided, designed to take over from the main system, as required, thus minimising venting of TRS gases to the atmosphere,
	• In sensitive situations (e.g., proximity to residential areas), a standby incinerator or other alternative incineration point for the low-concentration should be considered.
	• Specific to recovery boilers:
	  ○ Reducing sulphur emissions by concentrating black liquor in the evaporator (Kraft mills) above 75% dry solids before incineration in the recovery boiler;
	  ○ Reducing sulphur emissions by controlling combustion process	

BREF	Techniques	Comments
	parameters in the recovery boiler, including temperature, air supply, and distribution of black liquor in the furnace and furnace load (Kraft mills).	

3.4.2. Releases to water

3.4.2.1. Total suspended solids (TSS)

Table 22 BAT Approaches for control of TSS releases from Kraft Pulping

BREF	Techniques	Comments
China	• Coagulation and sedimentation • Activated sludge method • Fenton oxidation/coagulation and • Sedimentation/air flotation	These BAT are used to treat COD, BOD, SS, and ammonia.
European Union	BAT13 • To reduce nutrient (nitrogen and phosphorus) emissions into receiving waters, BAT is to substitute chemical additives with high nitrogen and phosphorus contents with additives containing low nitrogen and phosphorus contents BAT 14 • Primary (physico-chemical) treatment • Secondary (physico-chemical) treatment BAT 15 • Tertiary treatment when further removal of organic substances, nitrogen or phosphorus is needed. BAT 16 • Proper design and operation of the biological treatment plant • Regularly controlling the active biomass • Adjustment of nutrition supply (nitrogen and phosphorus) to the actual need of the active biomass	General BAT 13 - 16 apply to most pulp, paper and board mills Specific BAT 19 applies to kraft pulp mills in addition to BAT 13-16

BREF	Techniques	Comments
	• Specific BAT for kraft pulp mills. BAT 19 • To reduce emissions of pollutants into receiving waters from the whole mill, BAT is to use TCF or modern ECF bleaching and a suitable combination of the techniques given below: • modified cooking before bleaching • oxygen delignification before bleaching • closed brown stock screening and efficient brown stock washing • partial process water recycling in the bleach plant • effective spill monitoring and containment with a suitable recovery system • maintaining sufficient black liquor evaporation and recovery boiler capacity to cope with peak loads • stripping the contaminated (foul) condensates and reusing the condensates in the process.	
India	N/A	
Korea	N/A	
United States	While no technologies are specified in EPA regulations, the effluent limits are based on applying chemical coagulation followed by granular filtration and applying best management practices for spill prevention and control of spent pulping liquor.	
World Bank	N/A	

Table 23 BAT Approaches for control of TSS releases from Paper Production (recycled)

BREF	Techniques	Comments
China	• Coagulation and sedimentation • Activated sludge method	These BAT are used for treating COD, BOD, SS and ammonia.

<table>
<tr><th>BREF</th><th>Techniques</th><th>Comments</th></tr>
<tr><td></td><td>Fenton oxidation/coagulation and
Sedimentation/air flotation</td><td></td></tr>
<tr><td>European Union</td><td>To prevent and reduce the pollution load of wastewater into receiving waters from the whole mill, BAT is to use a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15, BAT 16, BAT 43 and BAT 44:
BAT 13
To reduce nutrient (nitrogen and phosphorus) emissions into receiving waters, BAT is to substitute chemical additives with high nitrogen and phosphorus contents with additives containing low nitrogen and phosphorus contents.
BAT 14
Primary (physicochemical) treatment
Secondary (biological) treatment
BAT 15
Tertiary treatment when further removal of organic substances, nitrogen or phosphorus is needed
BAT 16
Proper design and operation of the biological treatment plant
Regularly controlling the active biomass
Adjustment of nutrition supply (nitrogen and phosphorus) to the actual need of the active biomass
BAT 43
Separation of the water systems
Counter-current flow of process water and water recirculation
Partial recycling of treated wastewater after biological treatment
Clarification of white water
BAT 44
Monitoring and continuous control of the process water quality</td><td>General BAT 13 - 16 apply to most pulp, paper and board mills.
Specific BAT 43 and 44 apply to paper mills processing recovered fibres in addition to BAT 13-16.</td></tr>
</table>

BREF	Techniques	Comments
	• Prevention and elimination of biofilms by using methods that minimise emissions of biocides • Removal of calcium from process water by controlled precipitation of calcium carbonate	
India	N/A	
Korea	• Fibre Disc filter • Auto Strainer • DAF (Dissolved Air Flotation) • Sand Filter	BAT 49 and BAT 50 are to use an appropriate combination of these techniques.
United States	While no technologies are specified in EPA regulations, the effluent limits are based on applying chemical coagulation followed by granular filtration.	
World Bank	N/A	

3.4.2.2. Chemical oxygen demand (COD)

Table 24 BAT Approaches for control of COD releases from Kraft Pulping

BREF	Techniques	Comments
China	• Coagulation and sedimentation • Activated sludge method • Fenton oxidation/coagulation and • Sedimentation/air flotation	These BAT are used for treating COD, BOD, SS and ammonia.
European Union	Table 22 contains relevant BAT, which also applies to COD releases from Kraft Pulping.	
India	N/A	
Korea	N/A	
United States	N/A	
World Bank	N/A	

Table 25 BAT Approaches for control of COD releases from paper production (recycled)

BREF	Techniques	Comments
China	• Coagulation and sedimentation • Activated sludge method • Fenton oxidation/coagulation and • Sedimentation/air flotation	These BAT are used for treating COD, BOD, SS and ammonia.
European Union	Table 23 contains relevant BATs, which also apply to COD releases from paper production.	
India	N/A	
Korea	• Activated Carbon Absorption Facilities • Ozonation	• BAT 50 is to use an appropriate combination of these techniques • BAT 54 is to use an appropriate combination of these techniques (In the case of wastewater containing non-degradable organic substances)
United States	N/A	
World Bank	N/A	

3.4.2.3. Adsorbable organic halides (AOX)

Table 26 BAT Approaches for control of AOX releases from Kraft Pulping

BREF	Techniques	Comments
China	N/A	China has only a discharge standard for water pollutants for the pulp and paper industry to limit AOX releases.
European Union	Table 22 contains relevant BAT, which also applies to AOX releases from Kraft Pulping.	
India	N/A	
Korea	N/A	

BREF	Techniques	Comments
United States	The US EPA has different standards for facilities using exclusively TCF (totally chlorine-free) bleaching.	
World Bank	N/A	

Table 27 BAT Approaches for control of AOX releases from paper production (recycled)

BREF	Techniques	Comments
China	N/A	China has only a discharge standard for water pollutants for the pulp and paper industry to limit AOX releases.
European Union	Relevant BATs can be found in Table 23, which apply to AOX releases from paper production.	
India	N/A	
Korea	N/A	
United States	N/A	The US EPA has different standards for facilities that exclusively use TCF (totally chlorine-free) bleaching.
World Bank	N/A	

3.4.2.4. Total Nitrogen (tot-N) and Total Phosphorus (tot-P)

Table 28 BAT Approaches for control of tot-N and tot-P releases from paper production (recycled)

BREF	Techniques	Comments
China	N/A	China has a discharge standard for water pollutants for the pulp and paper industry to limit tot-N and tot-P releases.

BREF	Techniques	Comments
European Union	Relevant BAT can be found in Table 23, which also applies to tot-N and tot-P releases from paper production.	
India	N/A	
Korea	N/A	
United States	N/A	
World Bank	N/A	

3.4.2.5. Process Efficiency BAT

The paper and pulp production relying heavily on freshwater use upholds optimising water management to indicate process efficiency in the sector. To reduce freshwater use and generation of wastewater, BAT targets closing the water system to the degree technically feasible in line with the pulp and paper grade manufactured. A closed-loop water system would recycle the water used during the production processes and reuse it within the system rather than being discharged as wastewater. This system helps minimise water consumption, reduce environmental impact, and improve the overall efficiency of paper and pulp production.

In this cross-country analysis, water consumption efficiency practices are examined for the kraft pulping process and paper-making from recycled paper, as follows:

Table 29 BAT Approaches for Water Consumption Efficiency in Kraft Pulping

BREF	Techniques	Comments
China	Dry peeling technology	Water saving of 3-10 t per tonne of pulp
European Union	BAT 5 To reduce freshwater use and generation of wastewater, BAT is to close the water system to the degree technically feasible in line with the pulp and paper grade manufactured by using a combination of the techniques given below: a. Monitoring and optimising water usage b. Evaluation of water recirculation options	General BAT 5 applies to all pulp and paper mills. It applies to new plants and major refurbishments. Applicability may be limited due to water quality and product quality requirements or due to technical constraints (such as precipitation/incrustation in the water system) or increased odour nuisance. In the EU BAT Conclusions, BAT-associated wastewater flow is available (at the point of discharge after waste treatment as a yearly

BREF	Techniques	Comments
	c. Balancing the degree of closure of water circuits and potential drawbacks; adding additional equipment if necessary d. Separating less contaminated sealing water from pumps for vacuum generation and reuse, e. Separation of clean cooling water from contaminated process water and reuse f. Reusing process water to substitute for freshwater (water recirculation and closing of water loops) g. In-line treatment of (parts of) process water to improve water quality to allow for recirculation or reuse BAT 19 To reduce emissions of pollutants into receiving waters from the whole mill, BAT is to use TCF or modern ECF bleaching and a suitable combination of the techniques given below: • modified cooking before bleaching • oxygen delignification before bleaching • closed brown stock screening and efficient brown stock washing • partial process water recycling in the bleach plant • effective spill monitoring and containment with a suitable recovery system • maintaining sufficient black liquor evaporation and recovery boiler capacity to cope with peak loads • stripping the contaminated (foul) condensates and reusing the condensates in the process.	average), as reported in Chapter 4 - Table 59 BAT- AEPLs for water consumption in Kraft pulping.
India	N/A	
Korea	Pulp and Paper Integrated Mill	BAT 30 is to use an appropriate combination of these techniques (A vertically integrated system starting from the plantation)
United States	N/A	

BREF	Techniques	Comments
World Bank	Separation of the pulp mill and paper mill water systems as well as the use of counter-current water systems from paper to pulp mill to reduce overall water consumption, TSS and dissolved organics.	

Table 30 BAT Approaches for water consumption efficiency in Paper Production (recycled)

BREF	Techniques	Comments
China	N/A	
European Union	BAT 5 general BAT, please refer to Table 30 BAT 43 To reduce freshwater use, wastewater flow, and the pollution load, BAT is to use a combination of the techniques given below: • separation of the water systems • counter-current flow of process water and water recirculation • partial recycling of treated wastewater after biological treatment clarification of white water BAT 44 To maintain advanced water circuit closure in mills processing paper for recycling and to avoid possible adverse effects from the increased recycling of process water, BAT is to use one or a combination of the techniques given below: a) Monitoring and continuous control of the process water quality, b) Prevention and elimination of biofilms by using methods that minimise emissions of biocides, c) Removal of calcium from process water by a controlled precipitation of calcium carbonate.	
India	N/A	
Korea	• Individual treatment of non-degradable high-concentration wastewater • MBBR (Moving Bed Biofilm Reactor)	• BAT 42 is to use an appropriate combination of these techniques • BAT 47 is to use an appropriate combination of these techniques

BREF	Techniques	Comments
	• High concentration inorganic coagulants	(Molecular/Polymeric Inorganic Coagulant)
United States	N/A	The US EPA does not promulgate regulations related to water consumption for manufacturing paper from recycled materials.
World Bank	Anaerobic biological pretreatment is favoured for certain types of effluents that are high in BOD/COD and low in toxic substances, such as sulphite pulping condensates and mechanical pulping and RCF (Recycled Fiber Pulping) effluents, with reuse of the remaining purified condensates to reduce overall water consumption and effluent volumes.	

3.4.3. Subchapter conclusion

The subsequent section presents critical insights into specific Best Available Techniques (BAT) used for air emissions of NO_x, dust/PM, and total reduced sulphur (TRS) and water releases of total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halides (AOX), total nitrogen (tot-N) and total phosphorus (tot-P), and water consumption efficiency methods from BREFs for paper and pulp production explored in Chapter 3:

- There is a consensus on certain BAT across BREFs, notably end-of-pipe measures like Selective Non-Catalytic Reduction (SNCR) for NO_x reduction and dust control from kraft recovery boilers using bag filters and Electrostatic Precipitators (ESPs).
- Strategies for controlling NO_X emissions in Kraft recovery boilers vary across different BREFs, encompassing staged and controlled combustion methods as well as Selective Non-Catalytic Reduction (SNCR). China notes SNCR across all processes. In the EU BREF, an optimised firing system incorporating computerised combustion control, fuel and air mixing, and staged air feed systems (BAT 22) is recommended, which apply to new or refurbished recovery boilers. The K-BREF includes a multi-stage combustion system (BAT 31) and highlights the importance of using a combination of BAT. The US EPA notes that the individual facilities may have site-specific limits in permits based on the New Source Review process for NO_x emissions from kraft pulping. The World Bank's EHS guidelines emphasise primary strategies such as oxidation of black liquor before direct contact evaporation and controlling firing conditions to reduce NO_x emissions.
- BAT approaches for TRS emissions show variety between BREFs. The GATPPC (China) recommend white clay washing and filtration technology to reduce TRS emissions, which is particularly effective for installations using the sulphate method. The EU BREF recommends collection systems for malodorous gases, incineration of gases and optimising firing conditions (BAT 20 and BAT 21). In the US, there are standards for H_2S are set, with BAT focused on combustion control within the furnace for non-direct evaporator (NDCE) recovery furnaces. The World Bank's EHS guidelines note collecting and incinerating malodorous gases from various points in the process, standby incineration systems for high-concentration gases and control measures to reduce sulphur emissions specific to recovery boilers.

- Control of TSS releases reflects a typical range of industrial wastewater management techniques, including flocculation, sedimentation, and biological methods.
- BAT for the COD reduction in water is primarily limited to China and the European Union (EU), with the EU noting similar approaches to TSS reduction methods. Notable BAT include coagulation, sedimentation, activated sludge, and Fenton oxidation methods applied across regions. While specific BAT for AOX varies, general strategies for water treatment align with those for TSS and COD, with emphasis on effective removal techniques.
- In addressing tot-N and tot-P releases, similar BAT as those for TSS and COD are applied, focusing on nutrient substitution, physicochemical and biological treatments, and water system management.
- Efforts to enhance water consumption efficiency are prioritised across regions, with BAT emphasising the closure of water systems and the use of advanced treatment methods, such as dry peeling technology for waster saving in China, individual treatment methods and moving bed biofilm reactors for high-concentration wastewater in Korea, anaerobic biological pre-treatment and condensate reuse for reducing water consumption and effluent volumes in EHS guidelines.

3.5. Waste Incineration specific BAT for the control of selected pollutants

BAT consist of a comprehensive set of advanced practices and techniques essential in mitigating the environmental impacts of waste treatment through incineration. By utilising BAT, incineration facilities can significantly reduce harmful emissions of air pollutants while increasing energy recovery from the waste stream.

For the waste incineration sector, the sub-group of experts agreed to focus on the incineration of municipal solid waste. The air emissions of dust (Particulate Matter, PM), nitrogen oxides (NO_x), ammonia (NH_3), heavy metals (mercury, cadmium and total metals), hydrogen chloride (HCl) and hydrogen fluoride (HF) and dioxins and furans (PCDD/F) were examined across the different BREFs.

3.5.1. Emissions to air

3.5.1.1. Nitrogen Oxides (NO_x)

Table 31 BAT Approaches for control of NO_x, including NH_3 emissions from MSWI

BREF	Techniques	Comments
China (Sludge from wastewater treatment plant)	SNCR	The selective non-catalytic reduction (SNCR) method after the baghouse can achieve a denitrification [10]efficiency of 3070%. Under standard conditions, the dry flue gas contains no more than 450 mg/m^3 of NO_x at 6% oxygen.
European Union	• Optimisation of the incineration process • Flue-gas recirculation • Selective non-catalytic reduction (SNCR) • Selective catalytic reduction (SCR) • Catalytic filter bags • Optimisation of the SNCR/SCR design and operation • Wet scrubber (ammonia)	• BAT 29. To reduce channelled NO_x emissions to the air while limiting the emissions of CO and N_2O from waste incineration and the emissions of NH_3 from the use of SNCR and/or SCR, BAT is to use an appropriate combination of these techniques. • Flue-gas recirculation: This method's applicability for existing plants may be limited due to technical constraints (e.g., pollutant load in the flue gas, incineration conditions). • SNCR: Selective reduction of nitrogen oxides to nitrogen with ammonia or urea at high temperatures and without a catalyst. The operating temperature window is maintained between 800 °C and 1 000 °C for optimal reaction. The performance of the SNCR system can be increased by

[10] Denitrification is the microbial process of reducing nitrate and nitrite to gaseous forms of nitrogen, principally nitrous oxide (N_2O) and nitrogen (N_2) (Skiba, 2008[69]).

BREF	Techniques	Comments
		controlling the injection of the reagent from multiple lances with the support of a (fast-reacting) acoustic or infrared temperature measurement system to ensure that the reagent is injected in the optimum temperature zone at all times. • SCR: Selective reduction of nitrogen oxides with ammonia or urea in the presence of a catalyst. The technique is based on reducing NO_X to nitrogen in a catalytic bed by reaction with ammonia at an optimum operating temperature typically around 200–450 °C for the high-dust type and 170–250 °C for the tail-end type. Ammonia is generally injected as an aqueous solution; the ammonia source can also be anhydrous ammonia or a urea solution. Several layers of catalyst may be applied. A larger catalyst surface installed as one or more layers achieves a higher NO_X reduction. 'In-duct' or 'slip' SCR combines SNCR with downstream SCR, which reduces the ammonia slip from SNCR. In the case of existing plants, the applicability may be limited by a lack of space. • Catalytic filter bags: Filter bags are either impregnated with a catalyst (or the catalyst) directly mixed with organic material to produce the fibres used for the filter medium. Such filters can reduce PCDD/ F emissions and, in combination with a source of NH_3, NO_X emissions. This is only applicable to plants fitted with a bag filter. • Optimisation of the SNCR/SCR design and operation: Optimisation of the reagent to NO_X ratio over the cross-section of the furnace or duct, the size of the reagent drops, and the temperature window in which the reagent is injected. • Wet scrubber: When a wet scrubber is used for acid gas reduction, particularly with SNCR, unreacted ammonia is absorbed by the scrubbing liquor and, once stripped, can be recycled as SNCR or SCR reagent. However, there may be applicability

BREF	Techniques	Comments
		restrictions due to low water availability, e.g. in arid areas.
India	N/A	
Korea	• Low-temperature multistage combustion method • Selective non-catalytic reduction (SNCR) • Selective catalytic reduction (SCR) • Wet scrubber	BAT is to use an appropriate combination of these techniques
United States	Emission limits for NO_x from municipal solid waste combustion are based on selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR).	Numeric emission limits are based on performance test data from controls, but sources may use whatever means they deem necessary to meet the standards.
World Bank	• Use primary (combustion-related) NO_X control measures and/or selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR) systems, depending on the emissions levels required; • Use a flue gas treatment system for control of acid gases, dust/PM, and other air pollutants;	

3.5.1.2. Dust (Particulate matter)

Table 32 BAT Approaches for control of dust (Particulate matter) emissions from MSWI

BREF	Techniques	Comments
China (Sludge from wastewater treatment plant)	N/A	China has a discharge standard for dust emissions for sludge from wastewater plants.
European Union	• Bag filter • Electrostatic precipitator • dry sorbent injection • wet scrubber • fixed- or moving bed adsorption	BAT 25. To reduce channelled emissions to the air of dust, metals, and metalloids from waste incineration, BAT is to use one or a combination of these techniques.
India	N/A	

BREF	Techniques	Comments
Korea	• Bag filter, • Cyclone, • Electric precipitation, • Scrubber	BAT is to use an appropriate combination of these techniques
United States	Emission limits for PM from MSWI are based on the use of fabric filters (baghouses) and ESP.	Numeric emission limits are based on performance test data from controls, but sources may use whatever means they deem necessary to meet the standards.
World Bank	N/A	

3.5.1.3. Heavy metals (Mercury, Cadmium and total metals)

Table 33 BAT Approaches for control of heavy metal (Hg, Cd and tot-metals) emissions from MSWI

BREF	Techniques	Comments
China	N/A	China has a discharge standard for emissions of heavy metals (mercury, cadmium and total metals).
European Union	• Bag filter • Electrostatic precipitator • Dry sorbent injection • Wet scrubber • Fixed- or moving bed adsorption BAT 31 for Hg emissions control, in addition to the above: • Injection of special, highly reactive activated carbon • Boiler bromine addition (to furnace)	• BAT 25. To reduce channelled emissions to air of dust, metals and metalloids from the incineration of waste, BAT is to use one or a combination of these techniques. • BAT 31 for mercury emissions: In order to reduce channelled Hg emissions to air (including Hg emission peaks) from the incineration of waste, BAT is to use one or a combination of these techniques.
India	N/A	
Korea	• Bag filter, • Cyclone, • Electric precipitation	BAT is to use an appropriate combination of these techniques

BREF	Techniques	Comments
United States	• Metal emissions from MSWI are generally controlled through the control of PM emissions. • Limits for PM emissions are based on the use of fabric filters (baghouses) or ESP • Limits for mercury emissions also consider the use of activated carbon injection	Numeric emission limits are based on performance test data from controls, but sources may use whatever means they deem necessary to meet the standards.
World Bank	• Conduct waste segregation and/or pre-sorting to avoid incineration of wastes containing metals and metalloids that may volatilise during combustion and be difficult to control through air emission technology (e.g., mercury and arsenic).	

3.5.1.4. Dioxins and Furans (PCDD/F)

Table 34 BAT Approaches for control of PCDD/F emissions from MSWI

BREF	Techniques	Comments
China (Sludge from wastewater treatment plant)	N/A	China has a discharge standard for PCDD/F emissions for sludge from wastewater plants.
European Union	a. Optimization of the incineration process b. Control of the waste feed c. On-line and off-line boiler cleaning d. Rapid flue gas cooling e. Dry sorbent injection f. Fixed or moving bed adsorption g. SCR h. Catalytic filter bags i. Carbon sorbent in a wet scrubber	• BAT 30. To reduce channelled emissions to air of organic compounds, including PCDD/F and PCBs from the incineration of waste, BAT is to use techniques (a), (b), (c), (d), and one or a combination of techniques (e) to (i). • Control of waste does not apply to MSW • Fixed- or moving-bed adsorption and SCR: A lack of space in existing plants may limit their applicability.
India	N/A	

BREF	Techniques	Comments
Korea	• Waste quality management • Maintain appropriate combustion temperature • Avoiding PCDD/F resynthesis temperature during heat recover	BAT is to use an appropriate combination of these techniques.
United States	Limits for dioxins and furans are based on the use of activated carbon injection.	Numeric emission limits are based on performance test data from controls, but sources may use whatever means they deem necessary to meet the standards.
World Bank	• Standards for stationary incinerators, which include temperature and afterburner exit gas quenching (i.e. rapid temperature reduction) requirements, are preferred to eliminate dioxins and furans nearly; • Minimise the formation of dioxins and furans by ensuring that particulate control systems do not operate in the 200 to 400 degrees Celsius temperature range; identifying and controlling incoming waste composition; using primary (combustion-related) controls; using designs and operation conditions that limit the formation of dioxins, furans, and their precursors; and using flue gas controls;	

3.5.1.5. Hydrogen fluoride (HF) and hydrogen chloride (HCl)

Table 35 BAT Approaches for control of HF and HCl emissions from MSWI

BREF	Techniques	Comments
China	N/A	China has a discharge standard for HCl emissions.
European Union	BAT 27. To reduce channelled emissions of HCl, HF and SO_2 BAT is to use one or a combination of the techniques given below: (a) wet scrubber (b) Semi-wet absorber (c) Dry sorbent injection	BAT 27 (a) may have applicability restrictions due to low water availability, e.g., in arid areas. The technique (d) is only applicable to fluidised bed furnaces.

BREF	Techniques	Comments
	(d) Direct desulphurisation (e) Boiler sorbent injection BAT 28. To reduce channelled peak emissions of HCl, HF and SO_2 to air from the incineration of waste while limiting the consumption of reagents and the amount of residues generated from dry sorbent injection and semi-wet absorbers, BAT is to use technique (a) or both of the techniques given below: (a) Optimised and automated reagent dosage (b) Recirculation of reagents	BAT 28 (a) is generally applicable to all, but (b) is generally applicable to new plants. It is only applicable to existing plants within the constraints of the size of the bag filter.
India	N/A	
Korea	N/A	
United States	N/A	
World Bank	N/A	

3.5.2. Subchapter conclusion

The subsequent section presents critical insights into specific Best Available Techniques (BAT) used for air emissions of NOx, dust/PM, heavy metals (mercury, cadmium and total metals), dioxins and furans (PCDD/F), hydrogen fluoride (HF) and hydrogen chloride (HCl) from BREFs for the municipal solid waste incineration explored in Chapter 3:

- The sector BREFs focus on regulating installation emissions rather than dealing with more comprehensive strategic waste management and contextual decisions. For example, the BREFs deal with situations when waste is treated in incineration plants rather than whether particular wastes should be incinerated or recycled. In the field of waste management, targeted BREFs are available for governments and regions with BREFs for waste incineration. These BREFs provide a valuable resource for ensuring proper waste management and reducing the environmental impact of waste disposal.
- As directly comparable "BREF equivalent" documents on municipal solid waste were not available for the GATPPC from China (only standards available) and World Bank's EHS guidelines, the GATPPC for sludge from wastewater treatment and EHS guidelines for waste management were referred to extract information for the pollutants covered by this report.
- The BREFs tend to recognise different technical approaches (and hence, different BAT) that apply to other waste streams or focus solely upon a specific waste stream. Although specific approaches are applied to suit particular challenges (e.g. chemical hazardous wastes), there is a broad alignment of the techniques applied to control emissions of pollutants, e.g. SNCR and SCR for NOx emission, bag filters and/or electrostatic precipitators for dust control. Combinations of combustion/process monitoring and abatement systems are noted as BAT for various pollutants, such as combinations of dry sorbent injection, fixed- or moving-bed adsorption, SCR, and catalytic

filter bags for PCDD/F control. The choice of technique depends on factors such as emission regulations, technical feasibility, and environmental conditions.

Chapter 4. BAT- Associated Emission or Environmental Performance levels

4.1. Introduction

Industrial activities are integral to modern life but generate a substantial share of environmental pollution that threatens ecosystems and human health. In this critical context, technology based BAT and BAT-associated emission levels (BAT-AELs) or environmental performance levels (BAT-AEPLs) can be considered indispensable tools for striking a balance between industrial progress and environmental protection. Setting and enforcing BAT-AELs are critical steps in mitigating the adverse effects of industrial pollution on human health and the environment. They serve as a roadmap for industries to minimise their environmental footprint while maintaining competitiveness in a rapidly evolving world.

This chapter compares the emission and other quantitative performance standards specified (or considered equivalent to) to be BAT-associated for the selected environmental issues in the six BREFs for the iron and steel, paper and pulp and waste incineration sectors.

4.2. Iron and Steel Production

4.2.1. Emissions to air

Nitrogen Oxides (NO_x)

Table 36 BAT- AELs for NO_x emissions to air from Sinter plants

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	The denitrification efficiency can reach 30~40%. The denitrification efficiency is not less than 80%. 300	The denitrification efficiency can reach 30~40%. The denitrification efficiency is not less than 80%. 300	mg/Nm3			HJ/T 42 HJ/T 43	• Activated carbon adsorption method synergistic desulphurisation, denitrification and dioxin removal technology. • Selective catalytic reduction denitrification (decomposition of dioxins) technology (SCR). • Emission standard of air pollutants for sintering and pelletising of iron and steel industry (GB 28662-2012:)
European Union	Primary emissions from sinter strands: <500 (process integrated measures 1) <250 (RAC 2) <120 (SCR 3)	Primary emissions from sinter strands: <500 (process integrated measures 1) <250 (RAC 2) <120 (SCR 3)	mg/Nm3	Daily mean value	15 % O2 dry volume, standard conditions (273.15 K, 101.3 kPa), after deduction of water vapour content	the following generic EN standards apply: EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181.	1. Process-integrated measures can include (i) waste gas recirculation; (ii) other primary measures, such as the use of anthracite or the use of low-NOx burners for ignition;

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
						continuous monitoring	End of pipe techniques: 2. RAC Regenerative active carbon process 3. SCR selective catalytic reduction
India	N/A						
Korea		55-170 (before 2007)	ppm				
United States	N/A	N/A					
World Bank	500 0.4-0.65	500 0.4-0.65	mg/Nm^3 Kg/T product		For combustion gases: dry, temperature 273.15 K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273.15		

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
					K (0°C), pressure 101.3 kPa (1 atmosphere)		

Sulphur Oxides (SO_x)

Table 37 BAT- AELs for SO_x emissions to air from Sinter plants

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	200	200	mg/Nm³			HJ/T 56 HJ/T 57 HJ 629 GB 28662-2012	• Limestone-gypsum desulphurisation technology (The desulphurisation efficiency can generally reach more than 95%.) • Ammonia desulphurisation technology (The desulphurisation efficiency can generally reach more than 95%.) • Spray drying desulphurisation technology (The desulphurisation efficiency can generally reach more than 90%.)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
							• Circulating fluidised bed desulphurisation technology (The desulphurisation efficiency can generally reach more than 85%.)
European Union	Primary (sinter strand): <350-500 (1) <100 (2)	Primary (sinter strand): <350-500 (1) <100 (2)	mg/Nm³	Daily mean	No correction for the oxygen level Expressed as SO_2 standard conditions (273.15 K, 101.3 kPa), after deduction of water vapour content	EN 14791 If measurements are continuous, the following generic EN standards apply: EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181. Continuous monitoring	(1) one or combination of • lowering the sulphur input by using Coke Breeze with a low sulphur content • lowering the sulphur input by minimisation of coke breeze consumption • lowering the sulphur input by using iron ore with a low sulphur content • injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting by bag filter (2) wet desulphurisation or regenerative activated carbon (RAC) process (with particular consideration for the prerequisites for application).
India	N/A						
Korea		30 -100 (before 2007)	ppm				
United States	N/A	N/A					

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
World Bank (Sulphur dioxide, SO_2)	500	500	mg/Nm³		For combustion gases: dry, temperature 273 K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273 K (0°C), pressure 101.3 kPa (1 atmosphere)		

Dust (Particulate matter)

Table 38 BAT- AELs for dust (Particulate matter) emissions to air from Sinter plants

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	30 (Bag filter) 50 (Electrostatic precipitator) 30 (Electric bag dust collector) 10 (dust source sealing)	30 (Bag filter) 50 (Electrostatic precipitator) 30 (Electric bag dust collector) 10 (dust source sealing)	mg/m³			GB/T16157 GB/T 15432 GB 28662-2012	• Bag dust removal technology • Electrostatic precipitator technology • Electric bag composite dust removal technology • Dust source sealing technology
European Union	**Primary** (sinter strand waste gas): <1-15 **Secondary** (sinter strand discharge, sinter crushing, cooling, screening and conveyor transfer points) <10 (1)	**Primary** (sinter strand waste gas): <1-15 (1) <20-40 (2) **Secondary** (sinter strand discharge, sinter crushing, cooling, screening and conveyor transfer points)	mg/m³	Daily mean	No correction for the oxygen level standard conditions (273,15 K, 101,3 kPa), after deduction of water vapour content	EN 13284-1 If measurements are continuous, EN 13284-2 also applies and the following generic ones: EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181 Continuous monitoring	(1) Bag filter (new and existing installations for primary and secondary emissions) (2) Advanced electrostatic precipitator (ESP) (existing installations for primary emissions when bag filters are not applicable; new and existing installations for secondary emissions) Hooding and/or enclosure (for secondary emissions)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	<30 (2)	<10 (1) <30 (2)					
India	150	150	mg/m³				
Korea		4-16 (before 2014)	mg/Sm³				
United States	Windbox exhaust: 0.3 Discharge end: 0.01 gr/dscf, opacity <10% Sinter cooler: 0.01 gr/dscf	Windbox exhaust: 0.4 Discharge end: 0.02 gr/dscf, opacity <20% Sinter cooler: opacity <10%	lbs/ton (pounds per ton of product) gr/dscf (grains per dry standard cubic foot)	Opacity: 6-minute average		Continuous opacity monitoring systems or bag leak detection, inspection and monitoring for pressure drop, dust removal, cleaning cycles, and other operating conditions Continuous parameter monitoring systems and monitoring for hourly average pressure drop and water flow rate. Continuous opacity monitoring and hourly average opacity monitoring	**Baghouses** **Venturi scrubber**

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
							ESP
World Bank	20-50* 0.04-0.4	20-50* 0.04-0.4	mg/Nm³ Kg/T product		For combustion gases: dry, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273K (0°C), pressure		*Lower value where toxic metals are present

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
					101.3 kPa (1 atmosphere)		

Table 39 BAT- AELs for dust (Particulate matter) emissions from Blast Furnaces

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	20 (1) 50 (2) 20 (3) 20 (4)	20 (1) 50 (2) 20 (3) 20 (4)	mg/m³			GB/T16157 GB/T 15432 GB 28662-2012	(1) LT dry de-dusting technology (2) OG system de-dusting technology (3) Converter flap door closure with bag filter (4) Plant closure, roof extraction with bag filter
European Union	Displaced air during loading from the storage bunkers of the coal injection unit:	Displaced air during loading from the storage bunkers of the coal injection unit:	mg/Nm³	(1) average over the sampling period (discontinuous measurement, spot samples for at least half an hour).	(7) No correction for the oxygen level (8) Reference oxygen level:3 dry vol-%	EN 13284-1 If measurements are continuous, EN 13284-2 also applies and the following generic ones: EN 15267-1,	(3) dry dedusting (4) ESP or bag filter (5) - using dry pre-dedusting devices such as deflectors, dust catchers, cyclones, ESP

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	<20 (1) (7) Casting house (tap holes, runners, torpedo ladles charging points, skimmers): <1 – 15 (2) (7) Cleaned blast furnace (BF) gas: <10 (1) (5) (7) Hot blast stoves: <10 (2) (6) (8)	<20 (1) (7) Casting house (tap holes, runners, torpedo ladles charging points, skimmers): <1 – 15 (2) (7) Cleaned blast furnace (BF) gas: <10 (1) (5) (7) Hot blast stoves: <10 (2) (6) (8)		(2) daily mean value.	- standard conditions (273,15 K, 101,3 kPa), after deduction of water vapour content	EN 15267-2, EN 15267-3 and EN 14181	- subsequent dust abatement such as hurdle-type scrubbers, venturi scrubbers, annular gap scrubbers, wet ESP, and disintegrators. (6) dedusted surplus COG, BFG, BOG and NG, individually or in combination.
India	30	50	mg/Nm^3				
Korea	10	25 (after 2007)	mg/Sm^3				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	(before 2015)	15 (before 2007)					
United States	Casthouse: 0.003 gr/dscf, opacity <15%	Casthouse: 0.01 gr/dscf, opacity <20%	lbs/ton (pounds per ton of product) gr/dscf (grains per dry standard cubic foot)	Opacity: 6-minute average		Continuous opacity monitoring systems or bag leak detection, inspection and monitoring for pressure drop, dust removal, cleaning cycles, and other operating conditions Continuous parameter monitoring systems and monitoring for hourly average pressure drop and water flow rate Continuous opacity monitoring and hourly average opacity monitoring	**Baghouses** **Venturi scrubber** **ESP**
World Bank	20-50*	20-50*	mg/Nm^3		For combustion gases: dry, temperature 273		

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	0.005	0.005	Kg/T product		K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere)		

*Lower value where toxic metals are present.

Table 40 BAT- AELs for dust (Particulate matter) emissions to air from EAF

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	The flue gas capture rate is greater than 95%, the dust	The flue gas capture rate is greater than 95%, the dust	mg/Nm^3				• 4th hole smoke extraction, airtight hood, roof hood and bag filter

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	removal efficiency is greater than 99%, and the dust concentration of the exhaust gas is less than 20.	removal efficiency is greater than 99%, and the dust concentration of the exhaust gas is less than 20.					• Deflector hood, roof hood and bag filter • Flue gas capture and bag dust removal technology
European Union	primary and secondary dedusting (including scrap preheating, charging, melting, tapping, ladle furnace and secondary metallurgy): <5 (1) (3)	primary and secondary dedusting (including scrap preheating, charging, melting, tapping, ladle furnace and secondary metallurgy): <5 (1) (3)	mg/Nm³	daily mean value (1)	No correction for the oxygen level standard conditions (273,15 K, 101,3 kPa), after deduction of water vapour content	EN 13284-1 If measurements are continuous, EN 13284-2 also applies and the following generic ones: EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181	(3) Bag filter
India	150	150	mg/Nm³				
Korea		1-10 (before 2014)	mg/Sm³				
United States	12 (mg/dscm)	Opacity limits from shops	Milligrams per dry standard				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	OR 0.0052 (gr/dscf)		cubic meter (mg/dscm) Or Grains per dry standard cubic foot				
World Bank	20-50* 0.02	20-50* 0.02	mg/Nm^3 Kg/T product		For combustion gases: dry, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere).		

*Lower value where toxic metals are present.

Mercury (Hg)

Table 41 BAT- AELs for Hg emissions to air from Sinter plants

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	N/A	N/A					• Bag dust removal, desulphurisation and other technologies can remove heavy metals synergistically. • Bag dust removal, desulphurisation and other technologies can remove heavy metals synergistically.
European Union	<0.03 – 0.05	<0.03 – 0.05	mg/Nm^3	Average over the sampling period (discontinuous measurement, spot samples for at least half an hour).	There is no correction for the oxygen level. Standard conditions (273.15 K, 101.3 kPa), after deduction of water vapour content.	EN standards for long-term sampling are being developed by the European Committee for Standardisation (CEN). EN 13211 Generic EN standards and EN 14884"	Select raw materials with a low mercury content or treat waste gases in combination with activated carbon or activated lignite coke injection.
India	N/A	N/A					
Korea	N/A	N/A					

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
United States	<0.000081	<0.00026	lb/ton of steel scrap input to the BOPF				Plants are required to control the scrap input into the associated BOPF.
World Bank	N/A	N/A					See Table 38, Table 39 and *Lower value where toxic metals are present. Table 40

Table 42 BAT- AELs for Hg emissions to air from EAF

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	N/A	N/A					Bag dust removal, desulphurisation and other technologies can remove heavy metals synergistically.
European Union	Primary and secondary dedusting:	Primary and secondary dedusting:	mg/Nm^3	Average over the sampling period (discontinuous measurement, spot	There is no correction for the oxygen level.	EN standards for long-term sampling are being developed by the European	Prevent mercury emissions by avoiding raw materials and auxiliaries that contain

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	For mercury <0,05	For mercury <0,05		samples for at least four hours).	Standard conditions (273,15 K, 101,3 kPa), after deduction of water vapour content	Committee for Standardisation (CEN). EN 13211 Generic EN standards and EN 14884	mercury as much as possible.
India	N/A	N/A					
Korea	N/A	N/A					
United States	Facilities must certify that they participate in a program to remove mercury switches from motor vehicle scrap. For more details, see Table 13.						
World Bank	N/A	N/A					See Table 38, Table 39 and *Lower value where toxic metals are present. Table 40

Dioxins

Table 43 BAT- AELs for dioxins emissions to air from Sinter plants

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	0.2 (Activated carbon) 0.1-0.3 (SCR)	0.2 (Activated carbon) 0.1-0.3 (SCR)	ng-TEQ/Nm³			HJ/T 77.2 GB 28662-2012	• Activated carbon adsorption method synergistic desulphurisation, denitrification and dioxin removal technology. • Selective catalytic reduction denitrification (decomposition of dioxins) technology (SCR).
European Union	<0.05 – 0.2 (bag filter 1)	<0.05 – 0.2 (bag filter 1) <0.2 – 0.4 (ESP 2)	ng I-TEQ/Nm³ I-TEQ International toxic equivalent – derived by using the equivalence factors in Part 2 of Annex VI	6-8 hour random sample under steady-state conditions	No correction for the oxygen level standard conditions (273.15 K, 101.3 kPa), after deduction of water vapour content	EN standards for long-term sampling are being developed by the European Committee for Standardisation (CEN). EN 1948-1, EN 1948-2, EN 1948-3"	• Injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting with a bag filter (1) or advanced ESP when bag filters are not applicable (2) • Avoidance of raw materials which contain PCDD/F and PCB or their precursors as much as possible • Suppression of PCDD/F formation by addition of nitrogen compounds • Waste gas recirculation

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
India	N/A	N/A					
Korea	N/A	N/A					
United States	Average oil content in feedstock less than 0.02 % or Average volatile organic compound emissions from wind box exhaust stream below 0.2	lbs per ton of sinter	30-day rolling average				
World Bank	0.1 1-10	0.1 1-10	ng TEQ/ Nm^3 Kg/T product		For combustion gases: dry, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere)		

Table 44 BAT- AELs for dioxins emissions to air from EAF

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	≤0.5	≤0.5.	ng-TEQ/m^3		.	HJ/T 77.2 GB 28662-2012	• Scrap sorting pretreatment, • Flue gas quenching, • High-efficiency filtration technology.
European Union	Primary and secondary dedusting (including scrap preheating, charging, melting, tapping, ladle furnace and secondary metallurgy): <0.1	Primary and secondary dedusting (including scrap preheating, charging, melting, tapping, ladle furnace and secondary metallurgy): <0.1	ng I-TEQ/Nm^3 I-TEQ International toxic equivalent – derived by using the equivalence factors in Part 2 of Annex VI	6 – 8 hour random sample during steady-state conditions	No correction for the oxygen level standard conditions (273,15 K, 101,3 kPa), after deduction of water vapour content	EN standards for long-term sampling are being developed by the European Committee for Standardisation (CEN). EN 1948-1, EN 1948-2, EN 1948-3	• Appropriate post-combustion • Appropriate rapid quenching • Injection of adequate adsorption agents into the duct before dedusting
India	N/A	N/A					
Korea	N/A	N/A					
United States	Facilities must select and inspect scrap to minimise the amount of chlorinated plastics, oil, and free organic liquids charged into the furnace.						
World Bank	0.1	0.1	ng TEQ/ Nm^3		For combustion gases: dry, temperature 273 K (0°C),		

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	0.07-9	0.07-9	Kg/T product		pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapour or oxygen content, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere)		

4.2.2. Releases to water

Cyanides

Table 45 BAT- AELs for CN^- releases to water from Blast Furnaces

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China (Coking process)	0.5	0.5	mg/L			HJ 484 GB 16171	• Pre-treatment + O-A/O biochemical treatment technology. • Pretreatment+A2/O biochemical treatment technology

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
							• Pre-treatment + A/O2 biochemical treatment technology
European Union	Easily released cyanides: <0.4	Easily released cyanides: <0.4	mg/L	Based on a qualified random sample or 24-hour composite sample.		Based on the use of the DIN 38405 D 13-2 or any other national or international standard that ensures the provision of data of an equivalent scientific quality	use of flocculation (coagulation) and sedimentation and reduction of easily released cyanide, if necessary
India	0.2	0.2	mg/L				
Korea	N/A	N/A					
United States	0.000584 0.000292 (0.03)*	0.00175 0.000876 (0.03)*	kilograms per 1000 kg output (mg/l)	Daily Monthly		**Standard methods** 4500–CN^- B–2016 through 4500–CN^- F–2016 and 4500–CN^- N–2016; **ASTM** D7511–12(17). D2036–09(15)(A), D7284–13(17)	Existing plants: chemical precipitation, alkaline chlorination, dechlorination New plants: Chemical precipitation, alkaline chlorination, dechlorination, granular media filtration
World Bank	(free) 0.1	(free) 0.1	mg/L				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
	(total) 0.5	(total) 0.5					

*The conversion to a long-term average (LTA)[11] concentration for the US cyanide standards is 0.03 mg/L for blast furnaces.

Heavy metals (Lead)

Table 46 BAT- AELs for Pb releases to water from Blast Furnaces

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	1.0	1.0	mg/L			GB/T 7485	
European Union	<0.5	<0.5	mg/L	based on a qualified random sample or 24-hour composite sample		The following generic EN standards apply: EN ISO 11885, EN ISO 15586, EN ISO 17294-2	Use flocculation (coagulation) and sedimentation and reduce easily released cyanide, if necessary.
India	N/A						
Korea	N/A						

[11] The US-EPA defines a long-term average (LTA) as the average pollutant concentration that is achieved over a period of time. It is the mean of the underlying statistical distribution of the daily effluent values used to calculate numeric pollutant limitations .

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
United States	0.000263 0.0000876 (0.08)*	0.000263 0.0000876 (0.08)*	kilograms per 1000 kilograms output (mg/l)*	Daily Monthly		**Standard methods:** 3111 B–2011 or 3111 C–2011 3113 B–2010 3120 B–2011 3125 B–2011 3500–Pb B–2011. **ASTM** D4190–15\ D3559–15 (C).	Existing plants: chemical precipitation, alkaline chlorination, dechlorination New plants: Chemical precipitation, alkaline chlorination, dechlorination, granular media filtration
World Bank	0.2	0.2	mg/L				

* The conversion to an LTA for the US lead standards is 0.08 mg/L for new and existing plants.

Heavy Metals (Zinc)

Table 47 BAT- AELs for Zn releases to water from Blast Furnaces

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	N/A						
European Union	Zinc: <2	Zinc: <2	mg/L	Based on a qualified random sample or 24-hour composite sample		The following generic EN standards apply: EN ISO 11885, EN ISO 15586, EN ISO 17294-2	Use of flocculation (coagulation) and sedimentation and reduction of easily released cyanide, if necessary
India	N/A	N/A					
Korea	N/A	N/A					
United States	0.000394 0.000131 (0.08)*	0.000394 0.000131 (0.08)*	kilograms per 1000 kilograms output (mg/l)*	Daily Monthly		**Standard methods** 3111 B–2011 or 3111 C–2011 3120 B–2011 3125 B–2011 3500 Zn B–2011 **ASTM** D4190–15	Existing plants: chemical precipitation, alkaline chlorination, dechlorination New plants: Chemical precipitation, alkaline chlorination, dechlorination, granular media filtration

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
World Bank	2	2	mg/L				

*The conversion to a long-term average concentration for the US zinc standards for blast furnaces is 0.08 mg/L.

Table 48: BAT- AELs for Zn releases to water from EAF

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
China	N/A	N/A					
European Union	<2	<2	mg/L	Based on a qualified random sample or 24-hour composite sample.		The following generic EN standards apply: EN ISO 11885, EN ISO 15586, EN ISO 17294-2	• Removal of solids by flocculation, sedimentation and/or filtration, • Removal of oil in skimming tanks or in any other effective device • Recirculation of cooling water and water from vacuum generation as much as possible
India	N/A	N/A					
Korea	N/A	N/A					

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.3)
	New Plant	Existing Plant					
United States	0.00062 0.000207 (0.4)*	0.00062 0.000207 (0.4)*	kg/kkg[12] (mg/l)*	Daily Monthly		**Standard methods** 3111 B–2011 or 3111 C–2011 3120 B–2011 3125 B–2011 3500 Zn B–2011 **ASTM** D4190–15	New and existing plants: • Coagulation/Flocculation, Chemical Precipitation
World Bank	2	2	mg/L				

*The conversion to a long-term average concentration for the US zinc standards is 0.4 mg/L for EAF.

[12] In US EPA documents, the unit "kg/kkg" stands for kilograms per kilokilogram. This unit is simplified to grams per kilogram (g/kg) because a kilokilogram is equivalent to 1,000 kilograms.

4.2.3. Subchapter conclusion

This section summarises the BAT-AELs noted for emissions of nitrogen oxides (NO_x), sulphur oxides (SOx), dust/Particulate Matter, mercury (Hg) and dioxins and releases of cyanides and heavy metals (zinc and lead) from various types of iron and steel plants across different BREFs. It considers monitoring standards, reference conditions, and averaging periods of the BAT-AELs presented whenever available. Key observations on the BAT-AELs reported for a selected number of pollutants are as follows:

- Nitrogen Oxides (NO_x) emissions from sinter plants: In GATPPC documents (China), new sintering plants are required to achieve a denitrification efficiency of not less than 80%, with a specified standard of 300 mg/Nm^3. Various techniques are employed, such as activated carbon adsorption and SCR. The EU-BREF indicates different BAT-AELs that vary based on primary emissions from sinter stands, with AELs ranging from <120 mg/Nm^3 when SCR is applied to 500 mg/Nm^3 (process integrated measures). Continuous monitoring of NO_x is mandated, following the EN standards. The K-BREF has a range of 55 to 170 parts per million (ppm) that apply to plants before 2007. There are no specific BAT-AELs covered in the US-EPA documents. However, monitoring standards include continuous monitoring of combustion gases and non-combustion gases. The EHS Guidelines for the World Bank Group recommends AELs of 500 mg/Nm^3, with variations based on product type and different averaging periods.
- Sulphur Oxides (SO_x) emissions from sinter plants: Broadly, AELs are set within the same range. In the GATPPC document, the BAT-AELs are set at 200 mg/Nm^3 for both new and existing plants without any averaging periods. The EU has established a range of 350-500 mg/Nm^3. When wet desulphurisation and RAC techniques are implemented, a lower limit of 100 mg/Nm^3 is required. However, it's worth noting that these techniques were not yet in use in the EU at the time when the BREF was written. The K-BREF has a range of 30 to 100 parts per million (ppm) that apply to plants before 2007. The EHS Guidelines for the World Bank Group recommends the same AEL of 500 mg/Nm^3 for SO_x.
- Dust/Particulate matter AELs were analysed for sinter plants, blast furnaces and electric furnaces (EAF). Most AELs for sinter plants are set below 50 mg/Nm^3, dropping to 10 mg/Nm^3 when bag filters are applied. For the EU, references to AELs <10 mg/Nm^3 relate to specific local conditions. India sets a higher AEL of 150 mg/Nm^3. From blast furnaces, the AELs for dust emissions are broadly aligned around 10-50 mg/Nm^3. From the EAF, AELs are generally similar or lower than others, with the EU setting a <5 mg/Nm^3 daily mean average, which may reflect the EAF's relative novelty and differences in its processes.
- Mercury (Hg) and dioxins AELs were analysed from sinter plants and EAF. Limited AELs were available; only the EU BREF for both plant types and US-EPA guidelines for only sinter plants specified BAT-AELs for Hg emissions. For dioxins, TEQ approaches facilitate comparison with aligned AELs across China, the EU, and the World Bank for both sinter plants and EAF.
- Cyanides and heavy metals (lead and zinc) AELs were analysed for their releases to water from blast furnaces. The AELs for cyanides given in the different BREFs are reasonably well aligned in the range of 0.2 – 0.5 mg/L. The conversion to a long-term average (LTA) concentration for the US cyanide standards is 0.03 mg/L for blast furnaces. Similar observations are noted for the lead AELs, with a range of 0.2 – 1.0 mg/L. The conversion to an LTA for the US lead standards is 0.08 mg/L for new and existing plants. For zinc, EAF and Blast furnace AELs are aligned at 2 mg/L for the EU and World Bank. The conversion to a long-term average concentration for the US zinc standards is 0.08 mg/L for blast furnaces and 0.4 mg/L for EAF.

While AELs vary based on plant types and countries/regions, the similarities in approaches may encourage efforts to align standards for pollutants emitted from sinter plants, blast furnaces, and EAFs. The monitoring standards and averaging periods also vary, with BAT ranging from qualified random or continuous sampling to specific standard methods such as ASTM D4190–15. Collectively, these regulations highlight the global efforts within the iron and steel industry to reduce air and water pollution, with considerations for regional variations and technological advancements in plants.

4.3. Paper and Pulp Production

4.3.1. Emissions to air

Nitrogen Oxides (NO_x)

Table 49 BAT- AELs for NO_x emissions from Recovery boilers (Kraft Pulping)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	The denitrification efficiency can reach 30~40%.	The denitrification efficiency can reach 30~40%.				HJ/T 42 HJ/T 43	Please refer to Table 19
European Union	120 – 200 (softwood and hardwood) Softwood: DS < 75 %: 0,8 – 1,4 DS 75-83 %: 1,0 – 1,6 Hardwood: DS < 75 %: 0,8 – 1,4	120 – 200 (softwood and hardwood) Softwood: DS < 75 %: 0,8 – 1,4 DS 75-83 %: 1,0 – 1,6	mg/Nm³	Yearly average	Standard conditions: 273.15 K, 101.3 kPA, dry gas Concentration value at 6 % O_2	Continuous	Computerised combustion control Good mixing of fuel and air Staged air feed systems (using different air registers and air inlet ports).

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
	DS 75- 83 %: 1,0 – 1,7	Hardwood: DS < 75 %: 0,8 – 1,4 DS 75- 83 %: 1,0 – 1,7	Load-values: Kg NO_x/ADt				
India	N/A	N/A					
Korea	150	150	ppm				
United States	N/A	N/A					
World Bank	1.5 for hardwood pulp 2.0 for softwood pulp	As new plant	Kg/ADt[13]				

[13] "kg/Adt" stands for "kilograms per air-dried ton." Adt solely stands for air-dried ton, which is a measure of pulp that has been dried to a specific moisture content, usually around 10% moisture. This unit is used to measure the amount of a substance (typically a pollutant or chemical) per ton of air-dried pulp.

Dust (Particulate matter)

Table 50 BAT- AELs for dust/PM emissions from Recovery Boiler (Kraft Pulping)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	30 (Bag filter) 50 (Electrostatic precipitator)	30 (Bag filter) 50 (Electrostatic precipitator)	mg/m³			GB/T16157 GB/T 15432 GB 28662-2012	Please refer to Table 20
European Union	10-25 0.02 -0.20	10 – 40 0.02 – 0.3	mg/Nm³ kg dust/ADt	Yearly average Yearly average	Concentration value at 6 % O_2.	Periodic or continuous	Please refer to Table 20
India	<100 For Large Plants (More than 24000 MT/Annum)	<100 For Large Plants (More than 24000 MT/Annum)	mg/l				
Korea		(Prior to 2014 - Less than two tons/h)	mg/Sm³	3 years			

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
		1-18 (Prior to 2014- more than two tons/h) 3-1					
United States	0.034 g/dscm 20% opacity (if ESP is used, unless in combination with a wet scrubber)	0.10 g/dscm 20% opacity (if ESP is used, unless in combination with a wet scrubber)	grams per dry standard cubic meter	Filterable PM: > 60- minute sampling time Opacity: 6-minute averaging	Corrected to 8% O_2	Continuous opacity monitoring systems are required for kraft and soda recovery furnaces equipped with ESP	ESP or ESP- wet scrubber combination
World Bank	N/A	N/A					

Total Reduced Sulphur (TRS)

Table 51 BAT- AELs for TRS emission from Recovery Boiler (Kraft Pulping)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	N/A	N/A					Please refer to Table 21.

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
European Union	1-10 (Daily average) 1-5 (Yearly average)	1-10 (Daily average) 1-5 (Yearly average)	mg/Nm³ TRS	Daily average and yearly average	6% O_2	Continuous	Please refer to Table 21.
India (Chemical Recovery Plant (CRP) boilers/ Limekilns)	H_2S *: <10	H_2S *: <10	mg/Nm³				
Korea	N/A						
United States	Straight kraft recovery furnace: 5 Cross recovery furnace: 25		Parts per million by dry volume ppm	12-hour averaging for TRS and oxygen concentrations by averaging 12 1-hour average measurements	Per dry volume, corrected to 8% O_2	Continuous monitoring systems to monitor and record the concentration of TRS emissions on a dry basis and the per cent of oxygen by volume on a dry basis in the gases discharged into the atmosphere; For any recovery furnace, lime kiln, or smelt dissolving tank using a wet scrubber emission control device: continuous measurement of the pressure drop of the gas stream through the control equipment OR measurement of fan amperage or PRM (for	For recovery furnaces with direct contact evaporators (DCE): black liquor oxidation. For recovery furnaces with non-direct contact evaporators (NDCE): good combustion control.

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
						smelt tank scrubbers), measurement of the scrubbing liquid flow rate OR measurement of scrubbing liquid supply pressure. For ESP control on any recovery furnace or lime kiln, monitor the secondary voltage and secondary current of the ESP collection field or total secondary power.	
World Bank	N/A	N/A					

* Hydrogen sulphide (H_2S) is measured as part of an odour control assessment to identify and analyse the emission source of odorous gases. It does not include pulping mills operating on a soda process and those with sulphur-free operations.

4.3.2. Releases to water

Total suspended solids (TSS)

Table 52 BAT- AELs for TSS release from Kraft pulping

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	30	30	mg/L			GB/T 11091	Table 22 BAT Approaches for control of TSS releases from Kraft Pulping

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
European Union[14]	Bleached kraft pulp (direct discharge) 0.3-1.5 Unbleached kraft pulp (direct discharge) 0.3-1.0	Bleached kraft pulp (direct discharge) 0.3-1.5 Unbleached kraft pulp (direct discharge) 0.3-1.0	kg/ADt[15]	Yearly average	Average of all daily averages taken within a year, weighted according to the daily production, and expressed as mass of emitted substances per unit of mass of products/materials generated or processed	Daily - Rapid test methods can also be used. The results of rapid tests should be checked regularly (e.g. monthly) against EN standards or, if EN standards are not available, against ISO, national or other international standards which ensure the provision of data of equivalent scientific quality. For mills operating less than seven days a week, the monitoring frequency for COD and TSS may be reduced to cover the days the mill is in operation or to extend the sampling period to 48 or 72 hours.	Table 22 BAT Approaches for control of TSS releases from Kraft Pulping
India	500 For Large Plants (More than 24000 MT/Annum)	500 For Large Plants (More than 24000 MT/Annum)	mg/L				

[14] The EU BREF adds that at well-designed and operated plants, TSS emissions are between 10 mg/l and 20 mg/l, and BOD between 5 mg/l and 15 mg/l (close to the detection limit) both as an annual average value (see Table 5.21).

[15] "kg/Adt" stands for kilograms per air-dried ton.

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
Korea		More than 2,000 m^3 – 'Na' area : 5~50 mg/L	mg/L				
United States	**Dissolving kraft** Monthly: 14.3 Daily max: 27.3 **Bleached kraft:** Monthly: 4.8 – 9.5 New source fibre line: 3.86 Daily max: 9.1 - 18.2 New source fibre line: 8.47**Unbleached kraft**: Monthly: 3.0 – 4.8 kg/kkg Daily max: 5.8 – 9.1	**Dissolving kraft** Monthly: 20.05 + 3.75 (wet barking) + 0.4 (log/chip washing) + 0.8 (log flume/pond) Daily max: 37.3 + 6.9 (wet barking) + 0.7 (log/chip washing) + 1.45 (log flume/pond) **Bleached kraft:** Monthly: 11.9 - 16.4 + 2.8 – 3.1 (wet barking) + 0.25 – 0.35 (log/chip washing)	kg/kkg[16] kg per 1 ton product	The monthly average is the average of daily values for 30 consecutive days.	Production is defined as the annual off-the-machine production divided by the number of operating days in the year; Paper and paperboard production is measured at the off-the-machine moisture content except for unbleached kraft and market pulp, which is measured in air-dry-tons (10% moisture content)		BAT value depends on process /product (range provided)

[16] Kilograms per kilokilogram (equivalent to grams per kilogram [g/kg]).

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
		+ 0.55 – 0.7 (log flume/pond) Daily max: 22.5 - 30.4 + 5.3 – 5.75 (wet barking) + 0.55 – 0.65 (log/chip washing) + 1.15 – 1.25 (log flume/pond)**Unbleached kraft**: Monthly: 6.0 -6.25 Daily max: 12.0 – 12.5					
World Bank	Bleached kraft pulp: 1.5 Unbleached kraft pulp: 1	Bleached kraft pulp: 1.5 Unbleached kraft pulp: 1	Kg/Adt				

Table 53 BAT- AELs for TSS release from paper manufacturing (recycled)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	10 30	10 30	mg/L			GB/T 11091	Coagulation and sedimentation, activated sludge method, Fenton oxidation Coagulation and sedimentation with activated sludge method Coagulation and sedimentation/air flotation
European Union[17]	With deinking 0.08-0.3 0.1-0.4 for tissue paper Without deinking 0.02-0.2	With deinking 0.08-0.3 0.1-0.4 for tissue paper Without deinking 0.02-0.2 (For existing plants, levels up to 0,45 kg/t may occur due to the continuous decline in the quality of waste paper and the difficulty of	kg/t	Yearly average	The average of all daily averages taken within a year is weighted according to daily production and expressed as the mass of emitted substances per unit of mass of products/materials generated or processed.	Daily - Rapid test methods can also be used. The results of rapid tests should be checked regularly (e.g. monthly) against EN standards or, if EN standards are not available, against ISO, national or other international standards which ensure the provision of data of equivalent scientific quality.	Please refer to Table 23

[17] The EU BREF adds that at well-designed and operated plants, TSS emissions are between 10 mg/l and 20 mg/l, and BOD between 5 mg/l and 15 mg/l (close to the detection limit) both as an annual average value (see Table 5.21).

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
		continuously upgrading the effluent treatment plant).				For mills operating less than seven days a week, the monitoring frequency for COD and TSS may be reduced to cover the days the mill is in operation or to extend the sampling period to 48 or 72 hours.	
India	500 Large Plants (More than 24000 MT/Annum)	500 Large Plants (More than 24000 MT/Annum)	mg/l				
Korea		More than 2,000 m3 – Clean area: 8~25 More than 2,000 m3 – 'Ga' area: 4~50 More than 2,000 m3 'Na' area :3~50 More than 2,000m3 – Special area:5~25 Less than 2,000 m3 – Clean area:9~35	mg/L				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
		Less than 2,000 m3 – 'Na' area: 12~90					
United States	Fiber Deink Monthly: 4.6 – 6.8 Daily max: 8.7 – 13.1 Fiber Non-Deink: Monthly: 1.40 – 5.3 Daily max: 2.7 – 10.2	Fiber Deink Monthly: 12.95 Daily max: 24.05 Fiber Non-Deink: Monthly: 2.5 – 5.1 Daily max: 5.0 – 17.05	kg/kkg	Average of daily values for 30 days	Production is defined as the annual off-the-machine production divided by the number of operating days in the year; Paper and paperboard production is measured at the off-the-machine moisture content except for secondary fibre deink and, which is measured in air-dry-tons (10% moisture content)		
World Bank	Recycled fibre without deinking: 0.15 kg/Adt Recycled fibre with deinking: 0.3 kg/Adt	Recycled fibre without deinking: 0.15 kg/Adt Recycled fibre with deinking: 0.3 kg/Adt	kg/Adt				

Chemical oxygen demand (COD)

Table 54 BAT- AELs for COD releases from Kraft pulping

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	60/90 (Chemical methods, Chemi- chemi-mechanical pulping) 50/80 (mechanical pulping methods)	60/90 (Chemical methods, Chemi- chemi-mechanical pulping) 50/80 (mechanical pulping methods)	mg/L			GB/T 11914	Please refer to Table 24
European Union	Bleached kraft pulp: 7-20 Unbleached kraft pulp: 2.5-8	Bleached kraft pulp: 7-20 Unbleached kraft pulp: 2.5-8	Kg/ADt	Yearly average	The average of all daily averages taken within a year is weighted according to daily production and expressed as the mass of emitted substances per unit of mass of products/materials generated or processed.	COD: ISO 15705 EN 38409	Please refer to Table 24
India	350	350	mg/L				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
	Large Plants (More than 24000 MT/Annum)	Large Plants (More than 24000 MT/Annum)					
Korea		More than 2,000 m³ – 'Na' area: 35-70	mg/L				
United States	N/A						
World Bank	Bleached kraft pulp, integrated: 20 Unbleached kraft pulp, integrated: 10	Bleached kraft pulp, integrated: 20 Unbleached kraft pulp, integrated: 10	kg/Adt				

Table 55 BAT- AELs for COD releases from paper manufacturing (recycled)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	60 (Coagulation and sedimentation +Activated sludge	60 (Coagulation and sedimentation +Activated sludge	mg/L			GB/T 11914	Please refer to Table 22

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
	+Fenton oxidation) 90 (Coagulation and sedimentation +Activated sludge + Coagulation and sedimentation)	+Fenton oxidation) 90 (Coagulation and sedimentation +Activated sludge + Coagulation and sedimentation)					
European Union	With deinking: 0.9-3.0 0.9-4.0 for tissue Without deinking: 0.4-1.4	With deinking: 0.9-3.0 0.9-4.0 for tissue Without deinking: 0.4-1.4	kg/Adt	Yearly average	Average of all daily averages taken within a year, weighted according to the daily production, and expressed as mass of emitted substances per unit of mass of products/materials generated or processed		
India	350 Large Plants (More than 24000 MT/Annum)	350 Large Plants (More than 24000 MT/Annum)	mg/L				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
Korea		More than 2,000 m3 – 'Na' area:15-70 Less than 2,000 m3 – 'Na' area:38-90	mg/L				
United States	N/A	N/A					
World Bank	Recycled fibre without deinking: 1.5 Recycled fibre with deinking: 4	Recycled fibre without deinking: 1.5 Recycled fibre with deinking: 4	kg/Adt				

Adsorbable organic halides (AOX)

Table 56 BAT- AELs for AOX releases from Kraft pulping

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	12		mg/L			GB 3544-2008	

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
European Union	0 -0.2 Applicable for mills using chlorine-containing bleaching chemicals For mills producing pulp with high strength, stiffness and high purity properties (e.g. for liquid packaging board and LWC), emissions of AOX up to 0.25 may occur.	0 -0.2 Applicable for mills using chlorine-containing bleaching chemicals For mills producing pulp with high strength, stiffness and high purity properties (e.g. for liquid packaging board and LWC), emissions of AOX up to 0.25 may occur.	kg/ADt	Yearly average		EN ISO 9562:2004	Please refer to Table 26
India	Large plants: 1 Small Plants: 2	Large plants: 1 Small Plants: 2	kg/ton of paper produced				
Korea	N/A	N/A					

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
United States	**Bleached kraft:** Direct discharge: Monthly: 0.272 Daily max: 0.476 Indirect discharge: Monthly: 0.814 Daily max: 1.16	**Bleached kraft:** Direct discharge: Monthly: 0.623 Daily max: 0.951 Indirect discharge: Monthly: 1.41 Daily max: 2.64	kg/kkg	Average of daily values for 30 days	Fox AOX, specifically, production, is defined as the annual bleached pulp production entering the first stage of the bleach plant divided by the number of operating days during that year. Unbleached pulp production is measured in air-dried-metric tons (10% moisture) of Brownstock pulp entering the bleach plant.	AOX ML = 20 µg/L (EPA Method 1653) The minimum monitoring frequency for AOX at non-TCF plants is a daily measurement.	
World Bank	N/A	N/A					

Table 57 BAT- AELs for AOX releases from paper manufacturing (recycled)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	12		mg/L			GB 3544-2008	
European Union	With deinking: 0.05 for wet-strength paper Without deinking 0.05 for wet strength paper	With deinking: 0.05 for wet-strength paper Without deinking 0.05 for wet strength paper	kg/t	Yearly average		EN ISO 9562:2004	Please refer to Table 27
India	Large plants: 1 Small Plants: 2	Large plants: 1 Small Plants: 2	kg/ton of paper produced				
Korea	N/A	N/A					
United States	N/A	N/A					
World Bank	Recycled fibre without deinking: 0.005 Recycled fibre with deinking: 0.005	Recycled fibre without deinking: 0.005 Recycled fibre with deinking: 0.005	Kg/Adt				

Total Nitrogen (tot-N) and Total Phosphorus (tot-P)

Table 58 BAT- AELs for total N and/or total P release from paper manufacturing (recycled)

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	N/A	N/A					
European Union	**Total Nitrogen:** Without deinking: 0.008-0.09 With deinking: 0.01-0.1 0.01-0.15 for tissue paper **Total phosphorus:** Without deinking: 0.001-0.05 With deinking: 0.002-0.01 0.002-0.015 for tissue paper.	**Total Nitrogen:** Without deinking: 0.008-0.09 With deinking: 0.01-0.1 0.01-0.15 for tissue paper **Total phosphorus:** Without deinking: 0.001-0.05 With deinking: 0.002-0.01 0.002-0.015 for tissue paper.	kg/t	Yearly average		Weekly (once a week) Total-N: ISO 11905-1, ISO 10048, ISO 11732 Total P: ISO 6878, EN 6878, EN 1189	See Table 28 and Table 29
India	N/A	N/A					
Korea		**Total Nitrogen:** More than 2,000m^3 – Clean area:3~25 More than 2,000 m^3 – outside of clean areas:5~50	mg/L				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
		Less than 2,000 m³ – Clean area:5~25 Less than 2,000 m³ – outside of clean areas:7~50 **Total Phosphorus:** More than 2,000m³ – Clean area:1~3 More than 2,000 m³ – outside of Clean areas:1~6 Less than 2,000 m³ – Clean area:1~3 Less than 2,000 m³ – outside of clean areas:1~6					
United States	N/A						
World Bank	**Total Nitrogen:** Recycled fibre without deinking: 0.05 Recycled fibre with deinking: 0.1 **Total Phosphorus:** Recycled fibre without deinking: 0.005	**Total Nitrogen:** Recycled fibre without deinking: 0.05 Recycled fibre with deinking: 0.1 **Total Phosphorus:** Recycled fibre without deinking: 0.005	kg/ADt				

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
	Recycled fibre with deinking: 0.01	Recycled fibre with deinking: 0.01					

Process efficiency

The water consumption per tonne of production indicates the process efficiency measures covered and are shown in the BREFs as BAT-associated environmental performance levels (BAT-AEPLs).

Table 59 BAT- AEPLs for water consumption in Kraft pulping

BREF	BAT AE(P)L specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	N/A						
European Union	**Wastewater flow:** Bleached kraft: 25-50 Unbleached kraft: 15-40	**Wastewater flow:** Bleached kraft: 25-50 Unbleached kraft: 15-40	m^3/ADt	Yearly average			Please refer to Table 30
India	N/A						

BREF	BAT AE(P)L specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
Korea	N/A						
United States	N/A						
World Bank	Bleached kraft pulp : 10-20	Bleached kraft pulp : 10-20	m^3/t				

Table 60 BAT- AEPLs for water consumption in paper making (recycled)

BREF	BAT AE(P)L specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
China	N/A						
European Union	**Wastewater flow:** RCF paper mills without deining: 1.5-10 RCF paper mills with deinking: 8-15	**Wastewater flow:** RCF paper mills without deining: 1.5-10 RCF paper mills with deinking: 8-15	m^3/t	Yearly average			Please refer to Table 31

BREF	BAT AE(P)L specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of Associated BAT (See also Sections 3.2 and 3.4)
	New Plant	Existing Plant					
	RCF-based tissue paper mills with deinking: 10-25	RCF-based tissue paper mills with deinking: 10-25					
India	N/A	N/A					
Korea	N/A	N/A					
United States	N/A	N/A					
World Bank*	Uncoated Folding Boxboard: 2-10 Coated Folding Boxboard: 7-15 Corrugated Medium and Packaging Paper: 1.5-10 Newsprint: 10-20 Tissue: 5-100 Writing and printing paper: 7-20		m^3/t				

*Clean cooling water is generally not reported as part of the water consumption.

4.3.3. Subchapter conclusion

This section summarises the BAT-AELs noted for emissions of nitrogen oxides (NO_x), dust/Particulate Matter, total reduced sulphur (TRS) and releases of total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halides (AOX), total-nitrogen (tot-N) and total phosphorus (tot-P) from kraft pulping, recovery boiler in kraft pulp mills, and paper production from recycled paper across different BREFs. Water consumption, regardless of the pulping process, as part of analysing process efficiency was included. It considers monitoring standards, reference conditions, and averaging periods of the BAT-AELs presented whenever available. Key observations on the BAT-AELs reported for a selected number of pollutants are as follows:

- Nitrogen Oxides (NO_x) from kraft pulping recovery boilers are reported in the EU-BREF with a range of 120-200 mg/Nm^3, World Bank's EHS guidelines with 1.502.0 Kg/ADt, and in K-BREF as 150 ppm for both new and existing mills.
    - The EU BREF noted that the actual NO_x emission level of a recovery boiler depends on the DS (dry solid content of black liquor) content and the nitrogen content of the black liquor, and the amount and combination of non-condensable gases (NCG) and other nitrogen-containing flows (e.g. dissolving tank vent gas, methanol separated from the condensate, bio-sludge) burnt. The higher the DS content, the nitrogen content in the black liquor, and the amount of NCG and other nitrogen-containing flows burnt, the closer the emissions will be to the upper end of the BAT-AEL range. If a recovery boiler were to burn black liquor with a DS > 83 %, then NO_x emission levels should be reconsidered on a case-by-case basis. Increasing the DS content of the black liquor results in lower SO_2 emissions and higher NO_x emissions. Due to this, a recovery boiler with low emission levels for SO_2 may be on the higher end of the range for NO_x and vice versa.
    - While the EPA does not have sector-specific emission limits for NO_x from kraft recovery furnaces, individual facilities may have site-specific limits in permits based on the New Source Review process.
- Dust/Particulate matter emissions had AELs set for recovery boilers in all BREFs except the EHS guidelines. The EU sets a range for new plants of 10-25 mg/Nm^3 and 10 – 40 mg/Nm^3 for existing plants, and Korea sets AELs with a range of 1-18 mg/Sm^3, both as long-term averages. India provides a higher level of <100 mg/l for Large Plants (more than 24000 MT/Annum) without any averaging period. The US report a range of 0.034 – 0.1 g/dscm (grams per dry standard cubic meter, which reflects potential variation in the regulatory framework from others in dust pollution control. Furthermore, the EU BREF notes potential emission increases up to 50 mg/Nm^3 (corresponding to 0,4 kg/ADt) over time for existing recovery boilers equipped with ESP nearing the end of their operational life. The K-BREF notes that the AELs for dust/PM emissions from the recovery boiler as part of the kraft pulping mills are only available for paper and cardboard incineration.
- Total reduced sulphur (TRS) is a malodourous gas made up of hydrogen sulphide (H_2S), methyl mercaptan, dimethyl sulphide, and dimethyl disulphide (IFC, 2007[40]). BAT-AELs for TRS emissions from recovery boilers are outlined across different regions, focusing on daily and yearly averages. For example, the EU BREF suggests 1-10 mg/Nm^3 (daily average) and 1-5 mg/Nm^3 (annual average). India only controls H_2S emissions with an AEL of <10 mg/Nm^3 from chemical recovery plant (CRP) boilers/ limekilns).
- Total Suspended Solids (TSS) releases to water from kraft pulping appear to have significant variations in AELs across the BREFs, including differences in units and AEL setting approaches. For example, China sets an AEL of 30mg/Nm^3, Korea 5-50 mg/L, India 500 mg/L and the US provides various AELs in kg per tonne of product for a variety of processes. Similar to the AELs from kraft pulping, TSS releases from recycled paper manufacturing show differences between

AELs provided and are further complicated by the variant units and reporting approaches across countries/regions.

- The chemical oxygen demand (COD) discharge limits from kraft pulping and recycled paper manufacturing appear to be region-specific. In both cases, AELs have significant differences between the BREFs, with variant units and reporting approaches.
  - The EU BAT-AELs notes that there are no BAT-AELs for TOC in the EU BAT conclusions (BATc). However, there is a monitoring requirement in the EU BATc with the following footnote: There is a trend to replace COD with TOC for economic and environmental reasons. If TOC is already measured as a key process parameter, there is no need to measure COD; however, a correlation between the two parameters should be established for the specific emission source and wastewater treatment step.
- The adsorbable organic halides (AOX) discharge limits from kraft pulping and recycled paper manufacturing appear to be region-specific, like COD. China sets an AEL of 12mg/L, EU AEL ranges 0-0.2 kg/ADt, India 1 or 2 kg/ton of paper produced for large and small plants. The US provides kg/tonne figures in the range of 0.27 to 2.64 depending on the averaging period. Similar AELs and approaches are applicable to AOX from recycled paper manufacturing.
- Total nitrogen and total phosphorus release from paper manufacturing (recycled paper) show diversity in AELs depending on factors such as the presence of the deinking process and the paper type produced. For example, in the EU, the range for tot-N without deinking is 0.008-0.09 kg/t, while with deinking, it is slightly higher at 0.01-0.1 kg/t. Similarly, for tot-P, the range varies with and without deinking, and it is also influenced by the paper type manufactured. Monitoring standards for either tot-N or tot-P were presented only by the EU BREF, which included ISO and EN standards and averaging periods ranging from yearly averages to weekly measurements.
- Water consumption per tonne of production was used to indicate process efficiency in kraft pulping and recycled paper making. Only the EU BREF and World Bank EHS guidelines included BAT-associated environmental performance levels (BAT-AEPLs) for water consumption. The BAT-AEPLs for kraft pulping vary depending on whether the plant is new or existing. In the EU BREF, wastewater flow for bleached kraft ranges from 25 to 50 m^3/ADt annually, while for unbleached kraft, it ranges from 15 to 40 m^3/ADt. The World Bank sets a narrower range of 10-20 m^3/t for bleached kraft pulp. Paper-making efficiency AEPLs also vary based on the final paper type produced. In the EU BREF, wastewater flow for RCF paper mills without deinking ranges from 1.5 to 10 m^3/t, while for RCF-based tissue paper mills with deinking, it ranges from 10 to 25 m^3/t. The EHS guidelines have a wider range of water consumption standards for different papers, such as tissue paper (5-100 m^3/t) and newsprint (10-20 m^3/t). The US EPA did not report any standards for water consumption but noted that the facilities in the bleached kraft subcategory are allowed to participate in the Voluntary Advanced Technology Incentives Program, which establishes three tiers of performance requirements with unique limits and standards. As part of the second implementation stage, facilities in tiers II and III must meet requirements of 10 m^3/kkg product and 5 m^3/kkg product for total pulping area condensate, evaporator condensate, and bleach plant wastewater flow.

4.4. Waste Incineration

4.4.1. Emissions to air

Nitrogen Oxides (NO_x)

Table 61 BAT- AELs for NO_x emissions (including NH_3) from MSW (non-hazardous waste) incineration

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
China (Sludge from municipal wastewater treatment plant)	50-200	50-200	mg/Nm³			HJ/T 42, HJ/T 43, HJ 693	
European Union	50-120 (lower end of range with SCR*)	50—150 (lower end of range with SCR*) 180 (upper end where SCR is not applicable)	mg/Nm³	Daily average	Standard conditions: Dry gas, 273.15 K, pressure of 101.3 kPa Oxygen 11 dry vol-%	Continuous: Generic EN standards for continuous measurements are EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181. (DIN EN 14792)	• Optimisation of the incineration process • Flue-gas recirculation • SNCR • SCR • Catalytic filter bags • Optimisation of the SNCR/SCR design and operation • Wet scrubber

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
	(Ammonia slip) 2-10	(Ammonia slip) 2-10 2-15 (for existing plants fitted with SNCR without wet abatement)	mg/Nm³	Daily	Standard conditions: dry gas, 273.15 K, pressure of 101.3 kPa Oxygen 11 dry vol-%	Continuous, Generic EN standards for continuous measurements are EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181. (DIN EN ISO 21877)	• Applicable to SCR and/or SNCR use. The lower end of the range is achievable when using SCR. The lower end of the BAT-AEL range may not be achievable when incinerating waste with a high nitrogen content.
India	400	400	mg/Nm³	30 minutes sampling duration			NO and NO_2 expressed as NO_2.
Korea		19-50 33-90	ppm, more than 2 tons/hr ppm, less than 2 tons/hr		12% O_2		
United States	**Large MSWI:**150 **Small MSWI:**	**Large MSWI:** 180-250	ppmvd[18]	24-hour daily block arithmetic average	7% O_2 dry basis	CEMs for large plants above 250 tons per day (tpd)	

[18] The unit ppmvd stands for "parts per million by volume, dry." It is commonly used to express the concentration of a pollutant in a gas stream, measured on a dry basis (i.e., excluding water vapour).

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
	>250 tons/day 150 <250 tons/day 500	**Small MSWI:** >250 tons/day 170-380				Stack test for small plants below 250 tpd	
World Bank	N/A						

*The lower end of the BAT-AEL range may not be achievable when incinerating waste with a high nitrogen content (e.g. residues from the production of organic nitrogen compounds).

Dust (Particulate matter)

Table 62 BAT- AELs for dust (Particulate matter) emission from MSW (non-hazardous waste) incineration

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
China (Sludge from municipal wastewater treatment plant)	0.6~30	0.6~30	mg/Nm³			GB/T 16157	

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	**Existing Plant**					
European Union	<2 to 5	<2 to 5	mg/Nm³	Daily	Standard conditions: dry gas, 273.15 K, pressure of 101.3 kPa Oxygen 11 dry vol-%	Continuous, Generic EN standards for continuous measurements are EN 15267-1, EN 15267-2, EN 15267-3 and, EN 14181 and EN 13284-2.	• Bag filter • Electrostatic precipitator • Dry sorbent injection • Wet scrubber • Fixed or moving bed adsorption • Applicability comments provided for several techniques See also Section 3.5.1
India	50	50	mg/Nm³	30 minutes sampling duration			
Korea		2-30	mg/Sm³				
United States	**Large MSWI:** 20 **Small MSWI:** >250 tons/day: 24	**Large MSWI:** 25 **Small MSWI:** >250 tons/day: 27	mg/dscm	Annual 3 run average	Corrected to 7% O_2	Stack testing	Baghouse or ESP

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
	<250 tons/day: 24	<250 tons/day: 70					
World Bank	N/A						

Heavy metals (mercury)

Table 63 BAT- AELs for Hg emission from MSW incineration

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
China	0.05	0.05	mg/Nm³			Hg: HJ 543	
European Union	<5-20 (daily average or average over the sampling period) or 1-10 (long-term sampling period)	<5-20 (daily average or average over the sampling period) or 1-10 (long-term sampling period)	ug/Nm³	daily average or 2 to 4-week average	dry gas, 273.15 K, pressure of 101.3 kPa Oxygen 11 dry vol-%	Continuous, Generic EN standards for continuous measurements are EN 15267-1, EN 15267-2, EN 15267-3, EN 14181, and EN 13284-2. EN 14884	• Wet scrubber (low pH) • Dry sorbent injection • Injection of special, highly reactive activated carbon • Boiler bromine addition • Fixed or moving-bed adsorption • Various applicability notes See also Section 3.5.1

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
India	0.05	0.05	mg/Nm^3	Standard refers to sampling time anywhere between 30 minutes and 8 hours.			
Korea	N/A						
United States	**Large MSWI:** 50 **Small MSWI:** >250 tons/day 80 <250 tons/day 80	**Large MSWI:** 50	ug/dscm (micrograms per dry standard cubic meter)	Annual 3 run average	Corrected to 7% O_2	Stack testing	
World Bank	N/A						

Heavy metals (cadmium)

Table 64 BAT- AELs for Cd emission from MSW incineration

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
China	(Cd + Tl) 0.1		mg/Nm³			HJ 657	
European Union (Cd + Tl)	0.005 – 0.02	0.005 – 0.02	mg/Nm³	Average over the sampling period	Standard conditions: Dry gas, 273.15 K, pressure of 101.3 kPa Oxygen 11 dry vol-%	Once every six months EN 14385	• Bag filter • Electrostatic precipitator • Dry sorbent injection • Wet scrubber • Fixed or moving bed adsorption • Applicability comments provided for several techniques
India (Cd + Th + their compounds)	0.05	0.05	mg/Nm³	Standard refers to sampling time anywhere between 30 minutes and 8 hours.			
Korea	N/A						
United States	**Large MSWI:** 10	**Large MSWI:** 35	ug/dscm	Annual 3 run average	Corrected to 7% O_2	Stack testing	

BREF	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
	New Plant	Existing Plant					
	Small MSWI: >250 tons/day 20 <250 tons/day 20	**Small MSWI:** >250 tons/day 40 <250 tons/day 100	(micrograms per dry standard cubic meter)				
World Bank	N/A						

Heavy metals (total metals)

Table 65 BAT- AELs for total metals emission from MSW incineration

BREF	Metals in total group	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
China	Sb+As+Pb+Cr+ Co+Cu+Mn+Ni	1.0		mg/Nm^3				

BREF	Metals in total group	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
European Union	Sb+As+Pb+Cr+ Co+Cu+Mn+Ni+ V	0.01-0.3	0.01-0.3	mg/Nm3	Average over the sampling period	Standard conditions: dry gas, 273.15 K, pressure of 101.3 kPa Oxygen 11 dry vol-%	Once every six months EN 14385	• Bag filter • Electrostatic precipitator • Dry sorbent injection • Wet scrubber • Fixed or moving-bed adsorption • Various applicability notes See also Section 3.5.1
India	Sb + As + Co + Cr + Cu + Mn + Ni + V + their compounds	0.05	0.05	mg/Nm3	2 hours sampling duration			
Korea	Chromium, Cr Lead, Pb	0.1- 0.15, more than 2 tons/hr 0.05 – 0.16, more than 2 ton/hr 0.05 – 0.36, for 200 kg/hr ~ 2 ton/hr		mg/Nm3				
United States	N/A							
World Bank	N/A							

Dioxins and Furans (PCDD/F)

Table 66 BAT- AELs for PCDD/F emission from MSW incineration

BREF	Substance grouping	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
GATPPC (Sludge from municipal wastewater treatment plant)	PCDD/Fs	0.1	0.1	ng I-TEQ/Nm³			HJ 77.2	
European Union	PCDD/F	< 0.01–0.04 (average over the sampling period) < 0.01–0.06 (long-term sampling period) < 0.01–0.06 (average over the sampling period)	< 0.01–0.06 (average over the sampling period) < 0.01–0.08 (long-term sampling period) < 0.01–0.08 (average over the sampling period)	ng I-TEQ/Nm³ (for PCDD/F) ng WHO-TEQ/Nm3 (for	Average over the sampling period Long-term sampling period Average over the sampling period	Standard conditions: Dry gas, 273,15 K, pressure of 101,3 kPa Oxygen 11 dry vol-%	EN 1948-1, EN 1948-2, EN 1948-3 for short-term sampling No EN standard available for long-term sampling, EN 1948-2, EN 1948- 3	• Optimisation of the incineration process • Control of the waste feed • On-line and off-line boiler cleaning • Rapid flue gas cooling • Dry sorbent injection • Fixed or moving bed adsorption • SCR • Catalytic filter bags • Carbon sorbent in a wet scrubber

BREF	Substance grouping	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
	PCDD/F + dioxin-like PCBs	< 0.01–0.08 (long-term sampling period)	< 0.01–0.1 (long-term sampling period)	PCDD/F + dioxin-like PCBs)	Long-term sampling period			
India	Total Dioxins and Furans	0.1	0.1	ngTEQ/Nm³	6-8 hours sampling duration			
Korea	N/A							
United States	Dioxins/furans	**Large MSWI:** 13 **Small MSWI:** >250 tons/day 13	**Large MSWI:** 30 (without ESP) 35 (with ESP) **Small MSWI:** >250 tons/day 30 (without ESP) 60 (with ESP) <250 tons/day 125	Ng/dscm (Nanograms per dry standard cubic meter) Total mass basis	Annual 3 run average Runs must be at least 4 hours	Corrected to 7% O_2	Stack test	• Carbon injection • ESP

BREF	Substance grouping	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
		<250 tons/day 13						
World Bank	N/A	N/A						

Hydrogen fluoride (HF) and hydrogen chloride (HCl)

Table 67 BAT- AELs for HF and HCl emission from MSW incineration

BREF	Substance grouping	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
China	HCl	60 50		mg/m^3	(1 h average) (24 hr average)		HJ/T 27, HJ 548, HJ 549	
European Union	HCl	<2-6 (1)	<2-8 (1)	mg/Nm^3	Daily average (HCl) Daily average or average over	Standard conditions: Dry gas, 273.15 K, pressure of 101.3	EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181.	• Wet scrubber • Semi-wet absorber • Dry sorbent injection

BREF	Substance grouping	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
	HF	<1	<1		sampling period (HF)	kPa Oxygen 11 dry vol-%	HCl: DIN EN 1911 HF: DIN CEN/TS 17340	• Direct desulphurisation • Boiler sorbent injection A wet scrubber can achieve the lower end of the BAT-AEL, and a dry sorbent injection may be associated with the higher end.
India	HCl HF	50 4	50 4	mg/Nm³	30 minutes sampling duration			
Korea	HCl HF		1-15, more than 2 ton/hr 1-20, less than 2 ton/hr 0.05-1.7, more than 200 kg/hr	ppm				

BREF	Substance grouping	BAT AEL specified		Units	Averaging periods	Reference Conditions	Monitoring standards	Summary of associated BAT techniques (See also Sections 3.2 and 3.5)
		New Plant	Existing Plant					
United States	HCl		15	ppmvd[19]		Corrected to 7% O2		
World Bank	N/A	N/A						

[19] Parts per million by volume, dry.

4.4.2. Subchapter conclusion

This section summarises the BAT-AELs noted for emissions of nitrogen oxides (NO_x), dust/Particulate Matter, heavy metals (mercury, cadmium and total metals), and dioxins and furans (PCDD/F), and hydrogen fluoride (HF) and hydrogen chloride (HCl) from municipal solid waste incineration plants across different BREFs. It considers monitoring standards, reference conditions, and averaging periods of the BAT-AELs presented whenever available. Key observations on the BAT-AELs reported for a selected number of pollutants are as follows:

- Nitrogen oxide (NO_x) emissions have a wide range of AELs described across the BREFs (total range 50 to 400 mg/Nm^3), which also differ between new and existing facilities. Variations in AEL ranges between new and existing facilities may be explained by design optimisation approaches that are available when developing new facilities, whereas older/existing facilities' performance is constrained by earlier design optimisation decisions. Most BREFs describe BAT AELs in a range of 50 to 200 mg/Nm^3; India suggests a level of 400 mg/Nm^3.
    - Ammonia (NH_3) is only covered by the EU-BREF due to efforts to control “ammonia slip” when abatement systems (i.e. SNCR and/or SCR) are applied to achieve lower NO_x levels.
    - K-BREF notes that commercial and industrial non-hazardous waste AELs are 36 – 70 ppm for more than 2 ton/hr and 47-90 ppm for less than 2 ton/hr. There are various AELs set for different waste and plant design types. Plant type is based on the capacity of less than 200 kg, 200kg to less than 2 tons and more than 2 tons, which can be incinerated in an hour.
- Dust (Particulate Matter) emission standards also show considerable variation across the BREFs. In the EU BREF, the AELs are set as less than 2 to 5 mg/Nm^3 for both new and existing plants, with daily averaging periods. Monitoring standards include continuous measurements according to various EN standards. Whilst the EU defines one set of emission levels, the US establishes different levels for new and existing plants based on waste throughput capacity thresholds. The AELs have generally been set (for many years) based on continuous online emission monitoring, but it is noted that the US uses spot sampling methods.
- Mercury emissions from MSWI have a reasonable alignment of AELs across the BREFs with mostly around 50 ug/Nm^3; only the EU BREF provides an AEL range of 5-20 ug/Nm^3. China and India have similar BAT AELs for mercury emissions, indicating potential for international harmonisation of standards. However, the absence of specified AELs from K-BREF and the World Bank’s EHS guidelines suggests a different regulatory approach in many countries/regions. The EU-BREF further notes on BAT-AELs for mercury emissions as below:
    - Monitoring standards: For plants incinerating wastes with a proven low and stable mercury content (e.g. mono-streams of waste of a controlled composition), the continuous monitoring of emissions may be replaced by long-term sampling (no EN standard is available for long-term sampling of Hg) or periodic measurements with a minimum frequency of once every six months. In the latter case, the relevant standard is EN 13211.
    - Either the BAT-AEL for daily average or average over the sampling period or the BAT-AEL for long-term sampling period applies. The BAT-AEL for long-term sampling may apply in the case of plants incinerating waste with a proven low and stable mercury content (e.g. mono-streams of waste of a controlled composition).
    - The lower end of the BAT-AEL ranges may be achieved when incinerating wastes with a proven low and stable mercury content (e.g., mono-streams of waste of a controlled composition) or using specific techniques to prevent or reduce the occurrence of mercury peak emissions while incinerating non-hazardous waste. The higher end of the BAT-AEL ranges may be associated with the use of dry sorbent injection.

- Heavy Metals (cadmium and total metals) were collectively analysed for their AELs presented in the BREFs. The total metals groupings, including the AELs set across the BREFs, show significant diversities. Across all, the EU BREF provides the strictest range of AELs for both cadmium (0.005 – 0.02 mg/Nm^3) and total metals (0.01-0.3 mg/Nm^3) emissions. Following EU-BREF, the MINAS (India) set an AEL of 0.05 mg/Nm^3 and in K-BREF, the AELs provided for chromium (Cr) and lead (Pb) in different ranges depending on the hourly incineration rate. Monitoring standards and reference conditions for both heavy metals are specified in most regions, ensuring consistency in their measurement.
- Dioxins and furans emissions were only analysed based on the AELs set for the polychlorinated dibenzodioxins and furans (PCDD/F) across the BREFs. There is some degree of alignment regarding a numerical level of 0.1ng/Nm^3. Still, there are major differences in reporting substance groupings, monitoring conditions, and correction factors, which may undermine this remark across BREFs. The EU-BREF further notes on BAT-AELs for dioxins emissions to air from municipal solid waste (non-hazardous waste) incineration as below:
    - There are BAT-AEL for PCDD/F and BAT-AEL for PCDD/F and dioxin-like PCBs. The BAT-AEL does not apply if the emission levels are proven sufficiently stable (by a long-term sampling period).
- Hydrogen fluoride (HF) and hydrogen chloride (HCI) emissions from MSWI have a significant variation in reported AEL ranges, with only HCL standards in China (60 mg/m3, with a 24-hr average) and India (50 mg/Nm3, with a 30-minute sampling duration) reporting a close range. Similarly to other pollutants, there are distinct variations in units, sampling, and other reporting conditions of the AELs.

Chapter 5. Conclusion

The cross-country analysis of BAT and associated environmental levels (BAT-AELs) in (OECD, 2022[59]) and this report provides comprehensive insights into the regulatory frameworks and environmental control measures across different regions and industrial sectors. By analysing air and water emissions of various pollutants, the activities highlight both commonalities and differences in approaches to managing industrial pollution (see Annex A).

(OECD, 2022[59]) and this report analysed BREFs-like documents from a diverse set of jurisdictions, namely China, the EC, Flanders (Belgium), India, Korea and the US, including guidelines from the World Bank, offering a broad perspective on global regulatory practices. The studies identified multiple common techniques used to mitigate air and water pollution, reflecting a shared recognition of effective BAT across jurisdictions.

Major pollutants targeted for air emissions include dust/particulate matter (PM), sulphur oxides (SO_x), nitrogen oxides (NO_x), and carbon dioxide (CO_2). For example, in (OECD, 2022[59]), coal and gas-fuelled thermal power plants focused on reducing emissions of PM, SO_x, NO_x and mercury (Hg). Similarly, in this report, iron and steel production and municipal solid waste incineration facilities aimed to control emissions of NO_x, SO_x, PM and heavy metals (including Hg) and dioxins. Common end-of-pipe techniques (such as selective catalytic reduction [SCR], electrostatic precipitators [ESP], fabric filters and activated carbon adsorption) for NO_x and PM were frequently identified across these sectors. Differences in pollutants analysed in both activities arise from the nature of the processes and the end-products. For example, dioxins are specific to iron and steel production and waste incineration due to high-temperature processes (and the use of scrap metals containing organic compounds in the case of the iron and steel sector), which can form dioxins (EIPPCB, 2013[1]). In contrast, thermal power plants burning coal and/or gas mainly emit PM, SO_x, NO_x and Hg (IFC, 2008[26]). Process-integrated measures were also commonly noted for air emissions, such as the use of low NO_x burners to reduce NO_x emissions during combustion processes in nearly all sectors.

The analysis of water pollutants also revealed common approaches. Examination of the textile industry highlighted key water pollutants such as pH, AOX, BOD, COD, various metals (chromium, copper, nickel, and zinc) as well as water consumption. In this report, the paper and pulp industry focused on similar parameters, including TSS, COD, AOX, total nitrogen, total phosphorus, and water consumption per tonne of production. These similarities suggest that sectors with significant water usage and wastewater discharge issues are adopting comparable BAT, including end-of-pipe techniques like activated sludge, adsorption and coagulation, and process-integrated methods like recycling and reusing process water within the facility to address their environmental impacts.

While end-of-pipe techniques are indispensable for addressing specific pollutants, process-integrated measures, such as materials/chemicals substitutions, the use of high-quality raw materials and process optimisation (e.g. water consumption per tonne production) are becoming more common due to their long-term sustainability and efficiency benefits. The most effective air and water pollution control strategies typically involve a combination of both approaches, tailored to the specific needs and circumstances of the industry and the pollutants being managed.

Despite these commonalities, the studies also revealed significant differences in regulatory approaches and the implementation of BAT influenced by various factors. One of the primary reasons for this is the legal status of the BREFs, which may be either guidance documents or legally binding standards. This difference affects the level of compliance and enforcement across different jurisdictions. For example, where BREFs are legally binding, industries are required to strictly comply with the specified BAT and BAT-AELs, leading to more uniform implementation. In contrast, where BREFs serve only as guidelines, there may be greater flexibility but also greater variation in their application. The technical-economic status of a jurisdiction, including its history of BREF production and environmental protection policies, also plays a critical role. For example, (OECD, 2022[59]) noted variations in BAT and BAT-AELs, possibly due to differences in legal and institutional frameworks noted above. This report found similar variations attributable to the specific characteristics of industrial installations and differing environmental concerns of governments.

Another major challenge identified in both studies was the lack of measurement and assessment conditions for the BAT-AELs set, which hampered direct comparability. This report made notable improvements by gathering detailed information on measurement and assessment conditions, providing a more robust dataset (of BAT-AELs) for valid comparison. In contrast, (OECD, 2022[59])outlined difficulties due to inconsistencies in the supplied measurements, highlighting the need for standardised referencing/monitoring practices in environmental assessments.

The findings from these comparative analyses underscore the importance of international collaboration and the harmonisation of environmental regulations. By identifying common BAT and understanding the reasons behind regulatory and technical differences, policymakers and industry leaders can work towards aligning standards and improving the environmental performance of installations globally.

In conclusion, while both cross-country analysis studies highlight similarities and differences in regulatory approaches and techniques, they collectively emphasise the benefits of shared knowledge and cooperation in advancing global environmental protection standards. By leveraging these insights, national authorities responsible for BAT policies can enhance their regulatory frameworks and contribute to more sustainable industrial practices worldwide.

Annex A. Parameters covered in Activity 6 and this report

Activity	Sectors	BREFs selected	Process or end-products	Air emissions	Water releases
Activity 6 (OECD, 2022[57])	Thermal Power Plants	• China (GATPPC), • the EC (EU-BREFs), • India (MINAS and COINDs), • Korea (K-BREFs), • US-EPA (NESHAP and NSPS), • World Bank (EHS guidelines), • Flanders region (VITO studies)	• Coal-fired • Gas-fuelled	• For coal-fired plants,: PM/dust, SO_x, NO_x, Hg and CO_2. • For the gas-fuelled plants, NO_x and CO_2. • Energy efficiency BAT for both coal and gas-fuelled installations.	
	Cement Production		Portland cement	PM/dust, SO_x, NO_x, and CO_2.	
	Textile Manufacturing		Pre-treatment (desizing, bleaching and mercerizing) and dyeing processes.		pH, AOX, BOD, COD, heavy metals (chromium, copper, nickel and zinc), Water consumption per tonne production
This report	Iron and Steel Production	• China (GATPPC), • the EC (EU-BREFs), • India (MINAS and COINDs), • Korea (K-BREFs), • US-EPA (NESHAP and NSPS), • World Bank (EHS guidelines)	• Sinter plants • Blast Furnaces • Electric Arc Furnaces (EAF)	PM/dust, SO_x, NO_x, heavy metals (mercury), dioxins and CO_2.	Cyanides and heavy metals (lead and zinc).
	Paper and Pulp Production		• Kraft Pulping and recovery boilers. • Paper manufactured from recycled paper	TRS, dust/PM, NO_x, and CO_2	TSS, COD, AOX, total nitrogen, total phosphorus, water consumption per tonne production.
	Waste Incineration		Municipal solid waste incineration	dust/PM, NO_x, ammonia (from NO_x reduction), heavy metals (mercury, cadmium and total metals), dioxins and furans (PCDD/F), HF and HCl, and CO_2.	

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Industrial facilities have a significant impact on the environment due to their use of large amounts of raw materials and energy, resulting in the release of pollutants into the air, water, and soil. These facilities are obligated to adhere to various regulatory requirements, including emission levels and environmental quality objectives at the local level. This report provides a cross-country analysis of Best Available Techniques Reference Documents (BREFs) for three industrial sectors: iron and steel, paper and pulp, and waste incineration. It examines six BREFs from different countries and organisations, such as China, India, South Korea, the US, the EU, and the World Bank. The information gathered from various jurisdictions may help and support countries in developing sector-specific BREFs. Furthermore, this comparative analysis can identify areas for potential harmonisation between countries and highlight aspects of the BREFs that may require expansion or updating to better address environmental impact considerations.