

**OPTIONS PROPOSED BY SWITZERLAND FOR AMENDING THE ANNEX III
TO THE 1998 PROTOCOL ON HEAVY METALS**

Annex III

**BEST AVAILABLE TECHNIQUES FOR CONTROLLING EMISSIONS OF
HEAVY METALS AND THEIR COMPOUNDS FROM THE SOURCE
CATEGORIES LISTED IN ANNEX II**

1. not changed
2. changed - The up-to-date definition of the guidance document for the GP Protocol is used, new text:

The expression “Best available techniques” identifies the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing the basis for emission limit values (and other permit conditions) designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:

(a) “techniques” includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned,

(b) “available” techniques means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator,

(c) “best” means most effective in achieving a high general level of protection of the environment as a whole.

Criteria for determining BAT are as follows:

1. The use of low-waste technology;
2. The use of less hazardous substances;
3. The furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
4. Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
5. Technological advances and changes in scientific knowledge and understanding;

6. The nature, effects and volume of the emissions concerned;
7. The commissioning dates for new or existing installations;
8. The length of time needed to introduce the best available technique;
9. The consumption and nature of raw materials (including water) used in the process and energy efficiency;
10. The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
11. The need to prevent accidents and to minimize the consequences for the environment;
12. Information published by national and international organisations.

Not changed. The concept of best available techniques is not aimed at the prescription of any specific technique or technology, but at taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions.

3. The information regarding emission control performance and costs is based on official documentation of the Executive Body and its subsidiary bodies, in particular documents received and reviewed by the Task Force on Heavy Metal BAT reference documents from the European Integrated Pollution Prevention and Control Bureau (EIPPCB), the United Nations Environment Program (UNEP) 2002 Global Mercury Assessment, and various technical reports from United States Environmental Protection Agency (U.S. EPA), Environment Canada, and the European Commission and information provided directly by experts has been taken into consideration.

4. Not changed. Experience with new products and new plants incorporating low-emission techniques, as well as with the retrofitting of existing plants, is growing continuously; this annex may, therefore, need amending and updating.

5. Not changed. The annex lists a number of measures spanning a range of costs and efficiencies. The choice of measures for any particular case will depend on, and may be limited by, a number of factors, such as economic circumstances, technological infrastructure, any existing emission control device, safety, energy consumption and whether the source is a new or existing one.

6. Not changed. This annex takes into account the emissions of cadmium, lead and mercury and their compounds, in solid (particle-bound) and/or gaseous form. Speciation of these compounds is, in general, not considered here. Nevertheless, the efficiency of emission control devices with regard to the physical properties of the heavy metal, especially in the case of mercury, has been taken into account.

7. Not changed. Emission values expressed as mg/m³ refer to standard conditions (volume at 273.15 K, 101.3 kPa, dry gas) not corrected for oxygen content unless

otherwise specified, and are calculated in accordance with draft CEN (Comité Européen de Normalisation) and, in some cases, national sampling and monitoring techniques.

II. GENERAL OPTIONS FOR REDUCING EMISSIONS OF HEAVY METALS AND THEIR COMPOUNDS

Para 8 to 10 not changed

III. CONTROL TECHNIQUES

Para 11 and 12 not changed

13. In the case of particle-bound emissions of Cd, Pb and Hg, the metals can be captured by dust-cleaning devices. Typical dust concentrations after gas cleaning with selected techniques are given in table 1. Most of these measures have generally been applied across sectors. The minimum expected performance of selected techniques for capturing gaseous mercury is outlined in table 2. The application of these measures depends on the specific processes and is most relevant if concentrations of mercury in the flue gas are high.

Table 1: Performance of dust-cleaning devices expressed as hourly average dust concentrations

	Dust concentrations after cleaning (mg/m ³)
Fabric filters	1 - 5
Fabric filters, membrane type	< 1
Dry electrostatic precipitators	< 5 – 15
Wet electrostatic precipitators	< 1- 5
High-efficiency scrubbers	< 20
Ceramic filters	0.1 - 1

Note: Medium- and low-pressure scrubbers and cyclones generally show lower dust removal efficiencies.

Table 2: Minimum expected performance of mercury separators expressed as hourly average mercury concentrations

	Mercury content after cleaning (mg/m ³)
Selenium filter	< 0.01
Selenium scrubber	< 0.2
Carbon filter	< 0.01
Carbon injection + dust separator	< 0.05
Odda Norzink chloride process	< 0.1

Lead sulphide process	< 0.05
Bolkem (Thiosulphate) process	< 0.1
[Vosteen Process (Bromine)	0.001]

Para 14 to 18 not changed

IV. SECTORS

19. This chapter contains a table per relevant sector with the main emission sources, control measures based on the best available techniques, their specific reduction efficiency and the related costs, where available. Unless stated otherwise, the reduction efficiencies in the tables refer to direct stack gas emissions.

I. Combustion of fossil fuels in utility and industrial boilers (annex II, category 1)

20. Following Paras are new: The combustion of coal in utility and industrial boilers is a major source of anthropogenic mercury emissions. The heavy metal content is normally several orders of magnitude higher in coal than in oil or natural gas.

21. Improved energy conversion efficiency and energy conservation measures will result in a decline in the emissions of heavy metals because of reduced fuel requirements. Combusting natural gas or alternative fuels with low heavy metal content instead of coal would also result in a significant reduction in heavy metal emissions such as mercury and can be regarded as BAT. Integrated gasification combined-cycle (IGCC) power plant technology is a high efficiency technology that reduces emissions from large scale power production based on solid fuels.

22. With the exception of mercury, heavy metals are mostly emitted in solid form in association with fly-ash particles. Therefore, BAT to reduce the emissions of heavy metals is generally the application of high performance dedusting devices such as electrostatic precipitators or fabric filters.

23. Beneficiation, e.g. "washing" or "bio-treatment", of coal reduces the heavy metal content associated with the inorganic matter in the coal but is connected with emissions of heavy metals to water. However, the degree of heavy metal removal with this technology varies widely.

24. For the combustion of coal and lignite, of liquid fuels and of biomass and peat a total dust removal of more than 99.5% can be obtained with electrostatic precipitators (ESP, dust reduction rate >99.5 %) or fabric filters (FF, dust reduction rate >99.95 %). ESP and FF are both considered as BAT with daily average values in the range of below 5 up to 20

mg/m³ (referred to a flue gas oxygen content of 6%); when operated with well and continuously maintained equipment large coal fired power plants fitted with ESP or FF can achieve yearly average values of < 5 mg/m³. With the exception of mercury, heavy metal emissions can be reduced by at least 90-99%, the lower figure for the more easily volatilized elements. Mercury is at least partly and up to 90 % present in the vapor phase and its collection by particulate matter control devices is highly variable. Low filter temperature helps to reduce the gaseous mercury off-gas content.

25. The application of techniques to reduce emissions of nitrogen oxides and sulphur dioxide from the flue gas can also remove heavy metals. For electrostatic precipitators (ESPs) or fabric filters (FFs) operated in combination with wet flue gas desulfurization (FGD) techniques, an average removal rate of 75 % and 90 % in the additional presence of high dust Selective Catalytic Reduction (SCR) devices can be obtained for Hg. The best levels of mercury control are generally achieved by emission control systems (e.g. FGD plus particulate control device) that use FFs. The capture of mercury can be enhanced by introducing carbon/activated carbon into the flue upstream of the ESP or FF or by distributing the flue gas throughout a carbon filter bed.

26. The least costly retrofit options for the control of Hg emissions from units with ESP or FF are believed to include:

- The modification of dry FGD systems by the use of appropriate sorbents for the capture of Hg is considered to be the easiest retrofit problem to solve.
- Injection of a sorbent upstream of the ESP or FF.
- Injection of a sorbent between the ESP and a pulse-jet FF retrofitted downstream of the ESP.
- Installation of a semi-dry circulating fluidized-bed absorber (CFA) upstream of an existing ESP used in conjunction with sorbent injection.

The wet scrubber efficiency for mercury removal can be increased by

- Adding lime or limestone
- Improving the Liquid-to-Gas Ratio
- Wet FGD Tower Design. Research has shown that tray tower or open spray tower designs can be effective in removing oxidized mercury from boiler flue gas.
- Injection of activated carbon impregnated with additives increasing adsorption capacity.

27. The most cost-effective approach to control mercury is probably an integrated multi-pollutant (SO₂, NO_x, PM, and mercury) control technology. A gas-phase oxidation process to simultaneously capture SO_x, NO_x and mercury (100 % reduction) is under demonstration.

28. Emissions of mercury can be reduced by using fuels with low mercury content. Fuel switch is an option if mercury free fuels are available e.g. natural gas or specific types of coal with low mercury content.

Table 3: Control measures, reduction efficiencies and costs for fossil-fuel combustion emissions

Emission source	Control measure(s)	Reduction efficiency (%)	Abatement costs (total costs US\$)
All fuels	ESP or FF, and FGD	Hg: 75 (average)	
	ESP or FF, and FGD and SCR	Hg: 90 (average)	
	Switch to fuels with lower heavy metals emissions	Dust 70 – 100	Highly case-specific
	ESP (cold-side)	Cd, Pb: > 90; Hg: 10 – 40 PM: > 99.5 – 99.8	Specific investment US\$ 5-10/m ³ waste gas per hour (> 200,000 m ³ /h)
	(Wet) flue-gas desulphurization (FGD) ^{a/}	Cd, Pb: > 90; Hg: 20 – 80 ^{b/}	15-30/Mg waste gas
	Fabric filters (FF)	Cd: >95; Pb: > 99; Hg: 10 – 60 PM > 99.95 (< 5 mg/m ³)	Specific investment US\$8-15/m ³ waste gas per hour (> 200,000 m ³ /h)
	ESP or FF, and FGD	Hg: 75 (average)	
	ESP or FF, and sorbent injection	Hg: 50 – >95	90 % control: US\$ 35,000 – 70,000 per pound Hg removed / 0.03 – 0.2 US cent/kWh
	ESP or FF, and carbon filter bed	Hg: 80 – 90	US\$ 33,000 – 38,000 per pound Hg removed
	Coal cleaning	Cd, Pb: up to 80; Hg: 10 – 50	
^{a/} Hg removal efficiencies increase with the proportion of ionic mercury. High-dust selective catalytic reduction (SCR) installations facilitate Hg(II) formation.			
^{b/} This is primarily for SO ₂ reduction. Reduction in heavy metal emissions is a side benefit. (Specific investment US\$ 60-250/kW _{el}). Wet scrubbers installed primarily for mercury cost between \$76,000 and \$174,000 per pound of mercury removed.			

II. Primary iron and steel industry (annex II, category 2)

27. This section deals with emissions from sinter plants, pellet plants, blast furnaces, and steelworks with a basic oxygen furnace (BOF) with subsequent casting. In integrated steelworks, sinter plants and steelworks dominate the overall emissions for most atmospheric pollutants including heavy metals. Emissions of Cd, Pb and Hg occur in

association with particulates. The content of the heavy metals of concern in the emitted dust depends on the composition of the raw materials and the types of alloying metals added in steel-making. The reduction and capture of fugitive emissions is important. The most relevant emission reduction measures are outlined in table 4. Fabric filters should be used whenever possible; if conditions make this impossible, electrostatic precipitators and/or high-efficiency scrubbers may be used.

28. The following techniques are considered as BAT:

- For sinter plants, waste gas dedusting by advanced ESP or ESP plus FF or pre-dedusting (e.g. ESP or cyclones) plus high pressure wet scrubbing, and minimisation of heavy metal emissions by fine wet scrubbing systems or a bag filter with lime addition and the exclusion of dust from last ESP field from recycling to the sinter strand. Waste gas should be recirculated if possible.
- For pelletisation plants, efficient removal of particulate matter from the induration strand waste gas by means of scrubbing or semi-dry desulphurisation and subsequent de-dusting.
- For blast furnaces, blast furnace gas treatment with efficient de-dusting (e.g. dry separation plus scrubber or wet ESP), and the efficient capture of fugitive emissions and purification by FF or ESP
- For hot metal pre-treatment, the efficient capture and exhaust and subsequent purification by means of FF or ESP.
- For oxygen steelmaking, BOF gas recovery and primary de-dusting by dry ESP or scrubbing and secondary de-dusting by means of FF or ESP. Efficient capture and exhaust during charging and tapping, hot metal handling and reladling is important. It is recommended that an environmental performance indicator for PM for the BOF steelmaking process would be a maximum of 60 grams per tonne of molten steel.

Table 4: Emission sources, control measures, dust reduction efficiencies and costs for the primary iron and steel industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Dust emission levels (mg/Nm ³)	Abatement costs
Sinter plants	Emission optimized sintering	ca. 50		..
	Fabric filters	> 99	10 – 20	3,000 – 16,000 €/a
	Advanced ESP (Moving Electrode ESP, ESP pulse system, high voltage ESP...)		< 50	
	Pre-dedusting (e.g. ESP or cyclones) + high performance wet scrubbing system		< 50	
Pellet plants	ESP + lime reactor + fabric filters	> 99		..
	Scrubbers or semi-dry desulphurisation and subsequent de-dusting	> 95	< 10	..
Blast furnaces gas cleaning	FF / ESP	> 99	< 10	ESP: 0.24-1 US\$/Mg pig iron
	Wet scrubbers	> 99	< 10	∞
	Wet ESP	> 99	< 10	∞
Blast furnace	Capture of fugitive emissions and FF or ESP (casting bay dedusting, cast house dedusting)		1 – 15 (5 – 15 g/t pig iron)	
BOF	Primary dedusting: wet separator/ESP/FF	> 99		Dry ESP: 2.25 US\$/Mg steel
	Secondary dedusting: dry ESP/FF	>97	FF: 5 – 15 ESP: 20 – 30	FF: 0.26 US\$/Mg steel
Fugitive emissions	Closed conveyor belts, enclosure, wetting stored feedstock, cleaning of reads	80 – 99		
Hot metal	efficient capture and exhaust		FF: 5 – 15	

Emission source	Control measure(s)	Dust reduction efficiency (%)	Dust emission levels (mg/Nm ³)	Abatement costs
treatment, casting	plus FF or ESP		ESP: 20 – 30	

30. Direct reduction and smelting reduction are two proven alternative iron making processes to the coke oven/blast furnace route that may reduce the need for sinter plants and blast furnaces in the future. The application of these technologies depends on the ore characteristics and requires the resulting product to be processed in an electric arc furnace, which should be equipped with appropriate controls.

II. Secondary iron and steel industry (annex II, category 3)

31. The secondary production of iron and steel is mainly based on the use of Electric Arc Furnaces (EAF). It is very important to capture all the emissions from the melting process efficiently. That is possible by a combination of direct off gas extraction or doghouses and hood systems, or by total building evacuation. 98% and more collection efficiency of primary and secondary emissions from EAF are achievable and considered as BAT. The captured emissions must be cleaned. For all dust-emitting processes in the secondary iron and steel industry, dedusting in fabric filters, which reduces the dust content to less than 5 mg/Nm³ for new plants, and less than 15 mg/Nm³ for existing plants, shall be considered as BAT. When BAT is used also for minimizing fugitive emissions, the specific dust emission (including fugitive emission directly related to the process) will not exceed the range of 0.1 to 0.35 kg/Mg steel. There are many examples of clean gas dust content below 10 mg/Nm³ when fabric filters are used. The specific dust emission in such cases is normally below 0.1 kg/Mg.

32. For the melting of scrap, two different types of furnace are in use: open-hearth furnaces and electric arc furnaces (EAF) where open-hearth furnaces are about to be phased out.

33. The content of the heavy metals of concern in the emitted dust depends on the composition of the iron and steel scrap and the types of alloying metals added in steelmaking. Measurements at EAF have shown that 95% of emitted mercury and 25% of cadmium emissions occur as vapour. It is recommended as a best environmental practice to implement operating practices to prevent and minimize the presence of mercury and other heavy metals in the scrap, e.g. to remove mercury-bearing components prior to recycling in secondary iron and steel facilities. The most relevant dust emission reduction measures are outlined in table 5.

34. In recent years a number of new furnace types have been introduced, that might be realised at industrial scale, and that show advantages with regard to heavy metals and dust emissions, like the Comelt EAF, the Contiarc furnace, or direct reduction; the use of

liquid iron might be a further option. Mercury originated from contaminated steel scrap and is identified as a significant source of mercury emissions. Using activated carbon adsorption of mercury in waste gas from furnace have, in pilot scale tests, given reductions of up to 85 % reduced emissions of mercury.

Filters using dust particles < 5 mg/Nm³ give significant reduction of emissions of other heavy metals as well. Lead and cadmium will pass the dust filter and be caught in the carbon adsorber.

Table 5*: Emission sources, control measures, dust reduction efficiencies and costs for the secondary iron and steel industry

Emission source	Control measure(s)	Dust Reduction efficiency (%)	Emission levels (mg/Nm ³)	Abatement costs (total costs US\$)
EAF	ESP	> 99		
	FF	> 99.5	< 5 (new plants) < 15 (existing plants))	24/Mg steel

III. Iron foundries (annex II, category 4)

35. In the foundry process, emissions to air will typically not be limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from melting and pouring processes). It is very important to capture all the emissions efficiently. That is possible by installing doghouses or movable hoods or by total building evacuation. The captured emissions must be cleaned. In iron foundries, cupola furnaces, electric arc furnaces, induction furnaces, and rotary furnaces are operated. Direct particulate and gaseous heavy metal emissions are especially associated with melting and sometimes, to a small extent, with pouring. Fugitive emissions arise from raw material handling, melting, pouring and fettling. The most relevant emission reduction measures are outlined in table 6 with their achievable reduction efficiencies and costs, where available. The BAT associated emission level for dust, after collecting and dedusting exhaust gases, for all types of furnaces (cupola, induction, and rotary furnace) and mouldings (lost mould and permanent mould) as well as finishing operations is 5-20 mg/m³.

36. The following techniques are considered as BAT:

- For cupola furnace melting, use divided blast operation for cold blast cupolas, use oxygen enrichment of the blast air with oxygen levels between 22 and 25 %, minimise the blast-off periods for hot blast cupolas, use coke with known properties and of a controlled quality, and clean furnace off-gas using a bag filter or wet scrubber.

- For induction furnace melting, increase furnace efficiency, maximize off-gas collection during the full working cycle, and use dry flue-gas cleaning keeping dust emissions below 0.2 kg/tonne molten iron.
- For rotary furnace melting, optimise furnace operation and increase the melting efficiency, and to collect the off-gas close to the furnace exit, apply post combustion, cool it using a heat ex-changer and to apply dry dedusting.
- For moulding, enclose all the unit operations and to dedust the exhaust gas, if necessary post combustion.
- For finishing operations, BAT is to collect and treat the finishing off-gas using a wet or dry system.

Table 6: Emission sources, control measures, dust reduction efficiencies and costs for iron foundries

Emission source	Control measure(s)	Dust reduction efficiency (%)	Emission levels (mg/Nm ³)	Abatement costs (total costs US\$)
Induction furnace	FF/dry absorption + FF	> 99	5 – 20	..
Cold blast cupola	Below-the-door take-off: FF	> 98		..
	Above-the-door take-off: FF + pre-dedusting	> 97		8-12/Mg iron
	FF + chemisorption	> 99		45/Mg iron
Hot blast cupola	FF + pre-dedusting	> 99		23/Mg iron
	Disintegrator/venturi scrubber	> 97		..

IV. Primary and secondary non-ferrous metal industry (annex II, categories 5 and 6)

37. This section deals with emissions and emission control of Cd, Pb and Hg in the primary and secondary production of non-ferrous metals like lead, copper, zinc, tin, and nickel and aluminium. Due to the large number of different raw materials used and the various processes applied, nearly all kinds of heavy metals and heavy metal compounds might be emitted from this sector. Given the heavy metals of concern in this annex, the production of copper, lead and zinc, manganese and the secondary aluminium production are particularly relevant.

38. The main environmental issues for the production of most non-ferrous metals from primary raw materials include the potential emission to air of dust and metals/metal compounds. The pyrometallurgical processes are potential sources of dust and metals

from furnaces, reactors and the transfer of molten metal. The production from secondary raw materials is also related to the off-gases from the various furnaces and transfers that contain dust and metals. In the majority of cases process gases are cleaned in fabric filters. Gas cleaning using wet scrubbers and wet electrostatic precipitators is particularly effective for process gases that undergo sulphur recovery in a sulphuric acid plant. In some cases where dust is abrasive or difficult to filter, wet scrubbers are also effective. The use of furnace sealing and enclosed transfers and storage is important in preventing fugitive emissions. The significance of fugitive emissions in many processes is very high and fugitive emissions can be much greater than those that are captured and abated. In these cases it is possible to reduce environmental impact by following the hierarchy of gas collection:

- Process optimisation and minimisation of emissions;
- Sealed reactors and furnaces;
- Targeted fume collection;
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39. Use of mercury is declining, yet some significant uses remain. The main global uses are gold mining, batteries and the chlor-alkali industry, together accounting for over 75% of consumption. Large amounts of mercury are currently brought out of use as a result of ongoing and anticipated substitution of mercury-based chlor-alkali production in Europe and North America. A globally harmonised effort is proposed to phase out primary production of mercury and to stop surpluses re-entering the market. Thus, BAT to produce mercury is the production of mercury from secondary raw materials. Only in situations where waste mercury cannot be obtained, for primary mercury production from cinnabar using the Herreschoff furnace is BAT.

40. For gold various alternative processes to amalgamation have been developed. The use of the copper route for smelting precious metals has a lower potential for the emission of lead to all environmental media and should be used if the combination of raw materials, equipment and products allows it. In the case of high content of mercury in the ore it is necessary to use an activated carbon adsorber bed. By applying pollution prevention measures, including carbon adsorption units, mercurous chloride scrubbers, venturi scrubbers, and chemical additives to improve mercury capture, mercury emissions from gold production have been reduced by 75 %.

41. Non-ferrous metals are mainly produced from sulphidic ores. For technical and product quality reasons, the off-gas must go through a thorough dedusting ($< 3 \text{ mg/m}^3$) and could also require additional mercury removal before being fed to an SO_3 contact plant, thereby also minimizing heavy metal emissions. To remove mercury vapour from the gas stream, the following techniques are considered to be BAT: the Boliden/Norzink process, the Bolchem process, the Outokumpu process, the Sodium thiocyanate process, or the use of an activated carbon filter. For processes where mercury removal from the gases is not practicable the Superlig Ion Exchange process and the potassium iodide process to reduce the mercury content in sulphuric acid produced during the production of non-ferrous metals are considered to be BAT.

42. Fabric filters should be used when appropriate. FFs may not be BAT for the recovery of non-ferrous metals from sulphur-bearing concentrates due to the potential for condensation of sulphuric acid on the baghouse filter media. For sticky or abrasive dusts, wet electrostatic precipitators or scrubbers can be effective. A dust content of less than 5 mg/m³ can be obtained. The dust of all pyrometallurgical production should be recycled in-plant or off-site, while protecting occupational health. BAT for gas collection and abatement for the various process stages regarding to PM and heavy metals are summarized in the following table:

Materials handling and storage.	Correct storage, handling and transfer. Dust collection and fabric filter if necessary.
Grinding, drying.	Process operation. Gas collection and fabric filter.
Sintering/roasting, Smelting, Converting, Fire refining	Gas collection, gas cleaning in fabric filter, heat recovery.
Slag treatment.	Gas collection, cooling and fabric filter.
Thermal refining.	Gas collection and fabric filter.
Electrode baking, graphitisation	Gas collection, condenser and ESP, afterburner or alumina scrubber and fabric filter.
Metal powder production	Gas collection and fabric filter.
Melting and casting.	Gas collection and fabric filter.

43. Depending on the raw materials available, BAT for primary lead production, are the Kaldo process TBRC, ISF and New Jersey Distillation, QSL, Kivcet furnace, Kaldo Furnace, ISA Smelt Furnace and Blast Furnace.

44. Secondary lead is mainly produced from used car and truck batteries, which are dismantled before being charged to the smelting furnace. Depending on the raw materials available, processes that are BAT are: The blast furnace (with good process control), ISA Smelt/Ausmelt, the electric furnace and the rotary furnace. When only clean lead and clean scrap is used, also melting crucibles and kettles is BAT. Oxy-fuel burners can reduce waste gas volume and flue dust production by 60%. Cleaning the flue-gas with fabric filters makes it possible to achieve dust concentration levels of 5 mg/m³.

45. Primary zinc production is carried out by means of roast-leach electrowin technology. Pressure leaching may be an alternative to roasting and may be considered as a BAT for new plants depending on the concentrate characteristics. Emissions from pyrometallurgical zinc production in Imperial Smelting (IS) furnaces can be minimized by using a double bell furnace top and cleaning with high-efficiency scrubbers, efficient evacuation and cleaning of gases from slag and lead casting, and thorough cleaning of the CO-rich furnace off-gases (< 10 mg/m³). For any of these processes, good process control, gas collection and abatement systems are necessary.

46. To recover zinc from oxidized residues these are processed in an IS furnace. Very low-grade residues and flue dust (e.g. from the steel industry) are first treated in rotary

furnaces (Waelz-furnaces) in which a high-content zinc oxide is manufactured. Metallic materials are recycled through melting in either induction furnaces or furnaces with direct or indirect heating by natural gas or liquid fuels or in vertical New Jersey retorts, in which a large variety of oxidic and metallic secondary material can be recycled. Zinc can also be recovered from lead furnace slags by a slag fuming process. For any of these processes, good process control, gas collection and abatement systems are necessary.

Table 7(a): Emission sources, control measures, dust reduction efficiencies and costs for the primary non-ferrous metal industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs US\$)
Fugitive emissions	Furnace sealing, suction hoods, enclosure etc. off-gas cleaning by FF or ESP	Cleaning efficiency >99.75 (precipitator)	..
Roasting/sintering	Updraught sintering: ESP + scrubbers (prior to double contact sulphuric acid plant) + FF for tail gases	..	7 - 10/Mg H ₂ SO ₄
Conventional smelting (blast furnace reduction)	Shaft furnace: closed top/efficient evacuation of tap holes + FF, covered launders, double bell furnace top
Imperial smelting	High-efficiency scrubbing	>95	..
	Venturi scrubbers
	Double bell furnace top	..	4/Mg metal produced
Pressure leaching	Application depends on leaching characteristics of concentrates	> 99	site-specific
Direct smelting reduction processes	Flash smelting, e.g. kivcet, Outokumpu and Mitsubishi process
	Bath smelting, e.g. top blown rotary converter, Ausmelt, Isasmelt, QSL and Noranda processes	Ausmelt: Pb 77, Cd 97; QSL: Pb 92, Cd 93	QSL: operating costs 60/Mg Pb

Table 7(b): Emission sources, control measures, dust reduction efficiencies and costs for the secondary non-ferrous metal industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs US\$)
Lead production	Short rotary furnace: suction hoods for tap holes + FF; tube condenser, oxy-fuel burner	99.9	45/Mg Pb
Zinc production	Imperial smelting	> 95	14/Mg Zn

47. In general, processes should be combined with an effective dust collecting device for both primary gases and fugitive emissions. The most relevant emission reduction measures are outlined in tables 7(a) and (b). The BAT associated emission levels for dust are 1 – 5 mg/m³ using high performance fabric filters or alumina scrubber, and below 5 mg/m³ using wet ESP or ceramic filters.

48. For primary copper smelting, the continuous processes from Mitsubishi and Outokumpu/Kennecott are considered to be BAT for the smelting and converting stage. Similar environmental performance can be achieved using the Outokumpu Flash Smelting Furnace and the ISA Smelt furnace, which are used in combination with the Peirce-Smith (or similar) converter. Depending on the raw materials available, other processes might be appropriate. Gases from the primary smelting and converting processes should be treated to remove dust and volatile metals.

49. For secondary copper smelting, Blast Furnaces, mini-smelter, TBRC, Sealed Submerged Arc Electric furnace, ISA Smelt, and the Peirce-Smith converter are considered BAT. The submerged arc electric furnace is a sealed unit and is therefore inherently cleaner than the others. For high grades of copper scrap without organic contamination, the reverberatory hearth furnace, the hearth shaft furnace and Contimelt process are considered to be BAT in conjunction with suitable gas collection and abatement systems. If batch operated converters such as the Peirce-Smith converters (or similar) are used they should be used with total enclosure or efficient primary and secondary fume collection systems. The ISA Smelt furnace can be operated batch-wise, where smelting is carried out in a first stage followed by conversion in a second stage, and is also considered as BAT.

50. For secondary aluminium production, the Reverberatory furnace, Tilting rotary furnace, Rotary furnace, Meltower Induction furnace, are considered to be BAT, when equipped with a sealed feeding system and targeted fume extraction systems and the use of fabric or ceramic filters for dust removal. The use of intelligent damper controls can improve fume capture and reduce fan sizes and hence costs. Sealed charging cars or skips

are used with a reverberatory furnace at a secondary aluminium smelter and reduces fugitive emissions to air significantly by containing emissions during charging.

51. The application of selenium filter is proposed as a dry media process, which can be applied at both steel and non-ferrous metal smelters. Mercury removal of above 90 % has been achieved through this technique reducing the mercury concentrations to below 0.01 mg/m³. Selenium filters are recommended for the removal of mercury from the flue gas stream upstream of the acid plant in non-ferrous metal smelters. The mercury reduction of a selenium scrubber is about 90–95%, resulting in mercury concentrations of about 0.2 mg/m³. However, at low incoming Hg concentrations the removal efficiency can be less than 90 %. For the Odda chloride process, mercury concentrations of the treated gases are 0.05-0.1 mg/m³.

52. For manganese production, depending on the content of mercury in manganese ore, it is a significant source to emissions of mercury. Using activated carbon adsorption of mercury in waste gas from furnace can give reductions of up to 99 %. Filters reducing dust particles < 1 mg/Nm³ give significant reduction of emissions of other heavy metals as well.

53. Various processes are under development for the primary and secondary non-ferrous metal industry that may reduce dust and heavy metals emissions from this industry.

Table 7(c): Emission sources, control measures, mercury reduction efficiencies and costs for the non-ferrous metal industry

Emission source	Control measure(s)	Reduction efficiency (%)	Mercury content after cleaning (mg/m ³)	Abatement costs (annualised costs per t of product in US\$)
Gold production	carbon adsorption, mercurous chloride scrubbers, venturi scrubbers, chemical additives	75		
Sulphuric acid production	Superlig Ion Exchange process, Potassium Iodide process		~ 0.02	
Non ferrous metal production	wet scrubber	30 – 50		
	spray dry systems (+ FF)	35 – 85		
	Selenium filter	~ 90	< 0.01	10 – > 50 (for copper production, about 50% lower for lead)
	Lead sulfide process	99	0.01 – 0.05	
	Selenium scrubber	< 90 – 95	0.2	
	Odda chloride process		0.05 – 0.1	
manganese production	combination of wet scrubber, wet ESP and Hg absorber	99		(full scale gas cleaning 5 Mio € /smelter in 2001/2002)

V. Cement industry (annex II, category 7)

54. Cement kilns may use secondary fuels such as waste oil or waste tyres. The co-incineration of waste in cement kilns is treated within the waste incineration category. Mercury emissions can be reduced by controlling the amount of mercury in the input of the kiln. Fuels and raw materials with low mercury content should be used

55. Particulates are emitted at all stages of the cement production process, consisting of material handling, raw material preparation (crushers, dryers), clinker production and cement preparation. Mercury is primarily introduced into the kiln with raw-materials (usually 90% of the mercury is in the material input) with generally a minor amount (about 10%) coming from the fuels. It is generally the raw material input and not the process type which has the greater effect on heavy metal emissions.

56. For clinker production the following kiln types are available: long wet rotary kiln, long dry rotary kiln, rotary kiln with cyclone pre-heater, rotary kiln with grate pre-heater, shaft furnace. The selected process has a major impact on the energy use and air emissions from the manufacture of cement clinker. For new plants and major upgrades the best available technique for the production of cement clinker is considered to be a dry process kiln with multi-stage preheating and precalcination.

57. For heat recovery purposes, rotary kiln off-gases are conducted through the preheating system and the mill dryers (where installed) before being dedusted. The collected dust is returned to the feed material.

58. Less than 0.5% of lead and cadmium entering the kiln is released in exhaust gases. The high alkali content and the scrubbing action in the kiln favour metal retention in the clinker or kiln dust.

59. The emissions of heavy metals into the air can be reduced by, for instance, taking off a bleed stream and stockpiling the collected dust instead of returning it to the raw feed. However, in each case these considerations should be weighed against the consequences of releasing the heavy metals into the waste stockpile. Another possibility is the hot-meal bypass, where calcined hot-meal is in part discharged right in front of the kiln entrance and fed to the cement preparation plant. Alternatively, the dust can be added to the clinker. Another important measure is a very well controlled steady operation of the kiln in order to avoid emergency shut-offs of the electrostatic precipitators. These may be caused by excessive CO concentrations. It is important to avoid high peaks of heavy metal emissions in the event of such an emergency shut-off.

BAT for the manufacturing of cement with regard to particulate matter and heavy metals emissions the combination of the following general primary measures:

- A smooth and stable kiln process.
- Minimising fuel energy use.
- Careful selection and control of substances entering the kiln; when practicable selection of raw materials and fuels with low contents of sulphur, nitrogen, chlorine, metals and volatile organic compounds should be preferred.

and

- The minimisation/prevention of dust emissions from fugitive sources
- The efficient removal of particulate matter from point sources by application of electrostatic precipitators with fast measuring and control equipment to minimise the number of carbon monoxide trips or fabric filters with multiple compartments and ‘burst bag detectors’.

60. The most relevant emission reduction measures are outlined in table 8. To reduce direct dust emissions from crushers, mills, and dryers, fabric filters are mainly used, whereas kiln and clinker cooler waste gases are controlled by electrostatic precipitators or fabric filters. Dust can be reduced to concentrations less than 30 mg/m³. In best performing installations, clean gas dust content can be reduced to below 10 mg/m³.

61. A way to minimize mercury emissions is to lower the exhaust temperature. When high concentrations of volatile metals (especially mercury) occur, adsorption on activated carbon is an option.

Table 8: Emission sources, control measures, reduction efficiencies and costs for the cement industry

Emission source	Control measure(s)	Reduction efficiency (%)	Reported dust emissions (mg/m ³)	Abatement costs	
Direct emissions from crushers, mills, dryers, rotary kilns, clinker coolers	Primary measures plus FF or ESP	Cd. Pb: > 95	< 20 – 30 (best performing: < 10)		
Direct emissions from rotary kilns	Carbon adsorption	Hg: > 95			

VI. Glass industry (annex II, category 8)

62. In the glass industry, lead emissions are particularly relevant given the various types of glass in which lead is introduced as raw material Lead is used in fluxes and colouring agents in the frit industry, in some special glasses (e.g. coloured glasses, CRT funnels) and domestic glass products (lead crystal glasses). In the case of soda-lime container glass, lead emissions depend on the quality of the recycled glass used in the process. External cullet is an important source of metal contamination particularly for lead. The lead content in dusts from crystal glass melting is usually about 20 - 60%.

63. Dust emissions stem mainly from batch mixing, furnaces, diffuse leakages from furnace openings, and finishing and blasting of glass products. They depend notably on the type of fuel used, the furnace type and the type of glass produced. Oxy-fuel burners can reduce waste gas volume and flue dust production by 60%. The lead emissions from electrical heating are considerably lower than from oil/gas-firing. In general and where it is economically viable, predominantly electrical melting is considered BAT for lead crystal, crystal glass and opal glass production, since this technique allows efficient control of potential emissions of volatile elements. Where crystal glass is produced with a less volatile formulation, other techniques may be considered when determining BAT for a particular installation.

64. The batch is melted in continuous tanks, day tanks or crucibles. During the melting cycle using discontinuous furnaces, the dust emission varies greatly. The dust emissions from crystal glass tanks (< 5 kg/Mg melted glass) are higher than from other tanks (< 1 kg/Mg melted soda and potash glass).

65. Some measures to reduce direct metal-containing dust emissions are: pelleting the glass batch, changing the heating system from oil/gas-firing to electrical heating, charging a larger share of glass returns in the batch, and applying a better selection of raw materials (size distribution) and recycled glass (avoiding lead-containing fractions). In general, BAT for controlling dust emissions from furnaces in the glass industry is the use of either an electrostatic precipitator (ESP) or fabric filter system, operating where appropriate, in conjunction with a dry or semi-dry acid gas scrubbing system. The BAT emission level for dust associated with these techniques is 5 - 30 mg/Nm³ which generally equates to less than 0.1 kg/tonne of glass melted. In some cases, the application of BAT for metals emissions may result in lower emission levels for dust. The emission level associated with BAT for metals including lead (As, Co, Ni, Se, Cr, Sb, Pb, Cu, Mn, V, Sn) is < 5 mg/ Nm³. Secondary dust abatement represents BAT for most glass furnaces, unless equivalent emissions can be achieved with primary measures. The corresponding emission reduction efficiencies are given in table 9.

66. The development of crystal glass without lead compounds is in progress. The Plasma Melter makes use of the electrical conductivity of molten glass and operates with negligible dust emissions. It is however not expected to be a viable technique for melting within the foreseeable future.

67. For potentially dusty downstream activities BAT is considered to be dust minimisation, e.g. by cutting, grinding or polishing under liquid or by extraction of off gases to a bag filter system.

Table 9: Emission sources, control measures, dust reduction efficiencies and costs for the glass industry

Emission source	Control measure(s)	Dust reduction efficiency (%)	Abatement costs (total costs)
Direct emissions	FF	> 99	
	ESP	> ~ 95	

VII. Chlor-alkali industry (annex II, category 9)

68. In the chlor-alkali industry, Cl₂, alkali hydroxides and hydrogen are produced through electrolysis of a salt solution. Commonly used in existing plants are the mercury process, the diaphragm process and the membrane process. All these processes need the introduction of good practices to reduce environmental problems. The selected process technology has a major impact on the energy use and emissions from the manufacture of chlor-alkali. BAT for the production of chlor-alkali is considered to be membrane technology. Non-asbestos diaphragm technology can also be considered as BAT. The use of mercury-cell technology has been declining in Europe and North America over the past few decades, as many such plants have shut down or been converted to non-mercury processes. Moreover, European and North American producers are committed to not building any new mercury-cell facilities. In addition, North American and European regulations do not allow the construction of these facilities. Mercury releases from chlor-alkali operations can be entirely eliminated only by converting to a non-mercury process such as the membrane cell process. Conversion to membrane cell technology is considered as BAT. Decision 90/3 of 14 June 1990 of the Commission for the Prevention of Marine Pollution from Land-based Sources (PARCOM) recommends that existing mercury cell chlor-alkali plants should be phased out as soon as practicable with the objective of phasing them out completely by 2010. The Decision 90/3 was reviewed in 1999-2001 without any changes. Among OSPARCOM countries and in the EU there has been considerable discussion about the possible impacts the re-marketing of the mercury from decommissioned chlor-alkali facilities will have on the global mercury market. In 1999 all West European chlor-alkali producers presented the authorities with a voluntary commitment, one clause of which commits them not to sell or transfer mercury cells after plant shutdown to any third party for re-use. There is a proposed globally organised effort to phase out primary production of mercury and to stop surpluses re-entering the market.

69. The specific investment for replacing mercury cells by the membrane process is reported to be in the region of US\$ 700-1000 /Mg Cl₂ capacity. Although additional costs may result from, inter alia, higher utility costs and brine purification cost, the operating cost will in most cases decrease. This is due to savings mainly from lower energy consumption, and lower waste-water treatment and waste-disposal costs.

70. The sources of mercury emissions into the environment in the mercury process are: cell room ventilation; end box ventilation air; by-product hydrogen. With regard to emissions into air, Hg diffusely emitted from the cells to the cell room is particularly relevant. Preventive measures and control are of great importance and should be prioritized according to the relative importance of each source at a particular installation. In any case specific control measures are required when mercury is recovered from sludges resulting from the process.

71. During the remaining life of mercury cell plants, all possible measures should be taken to protect the environment as a whole including:

Minimising mercury losses to air by:

- Use of equipment and materials and, when possible, a lay-out of the plant that minimise losses of mercury due to evaporation and/or spillage;
- Good housekeeping practices and good maintenance routines;
- Collection and treatment of mercury-containing gas streams from all possible sources, including hydrogen gas. Typical devices for removal of mercury air emissions are shown in table A;
- Reduction of mercury levels in caustic soda;
- Minimising current and future mercury emissions from handling, storage, treatment and disposal of mercury-contaminated wastes;
- Decommissioning carried out in a way that prevents environmental impact during and after the shutdown process as well as safeguarding human health.

Table A: Control measures, reduction efficiencies and costs for Chlor Alkali plants emissions

Emission source	Control measure	Reduction efficiency [%]	Abatement costs
Chlor-alkali production	gas stream cooling to remove mercury from hydrogen stream; mist eliminators; scrubbers; adsorption on activated carbon and molecular sieves.	> 90	---

72. These measures can cut mercury emissions to values well below 2.0 g/Mg of Cl₂ production capacity, expressed as an annual average. All plants comply with the limit value of 2 g Hg/t Cl₂ for air emissions in PARCOM Decision 90/3, and it is clear that in many plants, air emissions continue to fall. However, for reported emissions a wide range

in actual values from 0.14 to 1.57 g Hg/t Cl₂ is shown. The best performing mercury cell plants are achieving total mercury losses to air, water and with products in the range of 0.2 – 0.5 g Hg/t Cl₂ as a yearly average, and with regard to air emissions 0.21 – 0.32 g Hg/Mg Cl₂, as shown in table B. Since emissions depend to a large extent on good operating practices, the average should depend on and include maintenance periods of one year or less.

Table B: Mercury losses to air from best performing mercury cell plants

	g Hg/t Cl ₂
Air: cell room	0.2 – 0.3
process exhausts, including Hg distillation unit	0.0003 – 0.01
untreated cooling air from Hg distillation unit	0.006 – 0.1
hydrogen gas	< 0.003

VIII. Municipal, medical and hazardous waste incineration (annex II, categories 10 and 11)

73. There are wastes that are neither classified as hazardous, municipal or medical wastes, depending on national legislation (e.g., non-hazardous industrial wastes, sludge etc.), that may be incinerated as well as co-incinerated in other industries, therefore potentially constituting a relevant source of heavy metal emissions. Furthermore, there are other thermal waste treatment methods (e.g. pyrolysis) that may be a relevant source of heavy metal emissions. For BAT, no differentiation is made between municipal, hazardous and medical waste in terms of applied techniques or achievable emission limits, as all types of waste are often incinerated in the same installation. Emissions of cadmium, lead and mercury result from the incineration of municipal, medical and hazardous waste. Mercury, a substantial part of cadmium and minor parts of lead are volatilized in the process. Particular actions should be taken both before and after incineration to reduce these emissions. The only relevant primary techniques for preventing emissions of mercury into the air before incinerating are those that prevent or control, if possible, the inclusion of mercury in waste. In some countries mercury-containing components are separated out of the solid waste stream and managed or recycled properly. Removing mercury from the waste stream before it enters the incinerator is much more cost-effective than capturing mercury later from flue gases using emissions control devices. Lower emissions of mercury from municipal waste combustors and medical waste incinerators can be achieved through product substitution. Although this is potentially applicable to a wide range of components, batteries have received the greatest attention because of their significant contribution to total mercury content in municipal and medical wastes. The applicability of the product substitution to other areas should be based on technical and economic feasibility.

74. The best available technology for dedusting and reducing heavy metals emissions is considered to be fabric filters in combination with dry or wet methods for controlling volatiles. Electrostatic precipitators in combination with wet systems can also be designed to reach low dust emissions, but they offer fewer opportunities than fabric filters especially with pre-coating for adsorption of volatile pollutants. Between 30 % and 60 % of mercury is retained by high efficiency ESPs or fabric filters (FFs), and flue gas desulphurisation (FGD) systems capture further 10 to 20 %.

75. When BAT is used for cleaning the flue gases, the concentration of dust can be reduced to 1 – 5 mg/m³. In general, the use of fabric filters gives the lower levels within these emission ranges. Effective maintenance of dust control systems is very important. Controlling dust levels generally reduces metal emissions too. The concentration of mercury can be reduced to a range of 0.001 – 0.02 mg/m³ (daily average, normalized to 11% O₂). Adsorption using carbon based reagents is generally required to achieve these emission levels with many wastes. Some waste streams have very highly variable Hg concentrations and waste pre-treatment may be required in such cases to prevent peak overloading of FGT system capacity.

76. The most relevant secondary emission reduction measures are outlined in table 10. It is difficult to provide generally valid data because the relative costs in US\$/tonne depend on a particularly wide range of site-specific variables, such as waste composition.

77. If re-burn of flue gas treatment residues is applied, then suitable measures should be taken to avoid the re-circulation and accumulation of Hg in the installation.

78. Selective catalytic reduction (SCR) for control of nitrogen oxides also reduces mercury emissions as a co-benefit by changing it into a form that can be collected by fabric filters.

79. Most Parties require discontinuous monitoring of mercury emissions only, while some consider continuous monitoring as BAT; proven systems for continuous measurements of mercury emissions are available on the market.

80. For the co-incineration of waste and recovered fuel in cement kilns, in general, the BAT for cement kilns apply.

81. For the co-incineration of waste and recovered fuel in combustion installations, in general, the BAT for combustion installations apply.

82. The PECK process is a promising technique with negligible heavy metals emissions in the flue gas. It has been developed for municipal solid waste treatment but could in principle be applied to other wastes. Other options to reduce heavy metals emissions may be the heavy metal evaporation process and the hydro-metallurgical treatment plus vitrification.

Table 10: Emission sources, control measures, dust reduction efficiencies and costs for municipal, medical and hazardous waste incineration

Emission source	Control measure(s)	Reduction efficiency (%)	Abatement costs (total costs US\$)
Stack gases	High-efficiency scrubbers	Pd, Cd: >98; Hg: ca. 50	..
	ESP (3 fields) with activated carbon or equivalent adsorptive reagents	Pb, Cd: 80 – 90	10-20/Mg waste
	Wet ESP (1 field) with additives, in combination with activated carbon injection, or activated carbon or coke filters	Pb, Cd: 95 – 99 Hg: 90	1,600 – 4,000 per pound Hg removed
	Fabric filters	Pb, Cd: 95 – 99	15-30/Mg waste
	Activated Carbon injection + FF or ESP	Hg: 50 – 95	operating costs: ca. 2 – 3/Mg waste; MWCs 211 – 870; Medical Waste Incinerators, 2,000 – 4000 per pound Hg removed.
	Carbon bed filtration	Hg: > 99	operating costs: ca. 50/Mg waste; 513 – 1,083 per pound Hg removed
	Selenium filters (inlet mercury concentrations of up to 9 mg/m ³)		
