REPORT

Mercury management in non-ferrous metal industry in China – a baseline study

For the Swedish Environmental Protection Agency

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Report Summary

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The Non-Ferrous metal (NFM) industry (producing e.g. Copper, Zink and Lead) is a major source of mercury emissions to the atmosphere. In 2011 there were over 8 000 smelters for NFM in China with varying production capacity and technological status. Emissions of mercury are controlled by mercury contents in ores or concentrates, the process technology used in the specific plant, the presence of air pollution control technologies, or mercury capture technologies. The development of emission inventories is thus complex and requires large amounts of information. In this report available information on China´s NFM sector is presented along with a summary of existing emission estimates for mercury. Finally, recommendations for improvement of these emission inventories are provided.

Keyword

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Foreword

This study was initiated within the framework of the bilateral environmental cooperation agreement between Sweden and China, the Swedish Environmental Protection Agency (EPA) and the Ministry of Environmental Protection in China (MEP). The two authorities started cooperating on mercury, in conjunction with the first international negotiating meeting on a global binding instrument on mercury, held in Stockholm in June 2010.

In 2012, IVL Swedish Environmental Research Institute was appointed to lead a base-line study with the aim to compile available information on mercury emissions from the non-ferrous metal industry in China, along with information on abatement measures other sector information.

Summary

The Non-Ferrous metal (NFM) industry (producing e.g. Copper, Zink and Lead) is a major source of mercury emissions to the atmosphere. In 2011 there were over 8 000 smelters for NFM in China with varying production capacity and technological status. Emissions of mercury are controlled by mercury contents in ores or concentrates, the process technology used in the specific plant, the presence of air pollution control technologies, or mercury capture technologies. The development of emission inventories is thus complex and requires large amounts of information. In this report available information on China´s NFM sector is presented along with a summary of existing emission estimates for mercury. Finally, recommendations for improvement of these emission inventories are provided.

Contents

Introduction

To provide input to the continued cooperation on mercury with the Chinese MEP, the Swedish EPA has commissioned this consultant study on mercury emission management of non-ferrous metal industries in China. The focus of the study is on production of zinc, lead and copper, but information on production of gold has been included where data has been available. The study has encompassed the following components.

1. A sector overview of non-ferrous metal industries in China, including among others capacity and geographic location of the production facilities.
2. An overview of production processes and technology level of the sector.
3. An overview of the emission situation and emission control measures with focus on emissions to air of mercury as well as of PM and SO_2 (and NOx where data has been available).
4. An inventory/estimation of mercury emissions with focus on emissions to air, built upon, among others, the recent mercury policy study report from the China Council for International Cooperation on Environment and Development, and relevant information from the global mercury emission inventories within the framework of AMAP and UNEP.
5. An overall assessment of the availability and quality of emission data, and recommendations on how to further improve the emission inventory in the future.
6. A brief analysis of the potentials and possible measures for mercury emission prevention and control of non-ferrous industries in China, giving co-control of mercury and some other major emissions to air (like PM, SO_2 and NOx) a high priority.

The report is based on public reports and scientific publications, as well as official Chinese documents related to the non-ferrous metal sector.

Sector overview of non-ferrous metal industries in China

Production capacity

According to the Second National Economic Census of China, 2011 (including companies in the gold industry), it is reported that at the end of 2008 there were some 31 000 non-ferrous metal (NFM) industrial facilities with legal registrations in China, which is 8 000 more than in 2004. This corresponds to an increase in number of installations of 35 % during the period 2004-2008. These facilities include mines, smelters and various metal processing plants. Out of the 31 000 non-ferrous facilities, the number of smelters was 8 200 in 2011 according to CCICED (2011).

The copper, lead and zinc mining capacities in 2008 are described in Table 1. The production of all three metals has increased by 11-18% per year in the period 2004 to 2008.

Table 1. Mining capacity of copper (Cu), lead (Pb) and zinc (Zn) in 2008 and 2004 (Unit: 10 000 metric tonnes/yr.) (CCICED, 2011).

Metal	2008	2004	Annual increase (%)
Cu	98.4	64	11
Pb	154	80	18
Zn	374	200	17

According to China Nonferrous Metals Industry Yearbook Editorial Board (2012), NFM production is distributed over 30 provinces, provincial level cities and autonomous regions. The production of refined copper, lead and zinc by provinces is presented in Tables 2, 3, 4 and 5, respectively. Only provinces with an annual production of more than 100 000 metric tonnes are listed. Note that the production of these metals exceeds the mining capacity presented in Table 1, indicating a large dependency on import of ores and concentrates.

The copper production in China has more than doubled over the period 2004 - 2011, see Table 3.

Table 2. Production of refined copper (Cu) by province, (only provinces with production over 100 000 metric tonnes in 2008 are listed).*

Province	**Production in 2008 (10 000 metric tonnes)**	**Production in 2004 (10 000 metric tonnes)**	**Increase (%)**
Jiangxi	78	44	79
Anhui	53	30	75
Shandong	47	10	355
Gansu	37	19	89
Yunnan	31	24	33
Zhejiang	30	17	79
Hubei	27	18	51
Jiangsu	17	17	1
Inner Mongolia	15	4	253
Shanghai	11	14	-24
Sum	**345**	**197**	**75**
China total	**370**		

*China Nonferrous Metals Industry Yearbook Editorial Board (2012)

Table 3. Total copper production by year in China (10 000 metric tonnes).

Year	**Cu production (10 000 metric tonnes)**
2004	203
2005	250
2006	290
2007	340
2008	370
2009	426
2010	475
2011	548

Table 4. Production of lead (Pb) by province (only Provinces with production over 100 000 metric tonnes in 2008 are listed). NA – Not available in this study.

Province	Production in 2011 (10 000 metric tonnes)	Production in 2008 (10 000 metric tonnes)	Production in 2004 (10 000 metric tonnes)	Rate of increase 2004-2011 (%)
Henan	131	111	61	114
Hunan	96	54	37	158
Anhui	80	40	13	540
Yunnan	43	36	19	122
Jiangsu	19	13	8	123
Guangxi	17	15	13	29
Hubei	16	NA	NA	
Jiangxi	11	NA	NA	
Guangdong	2	13	8	-73
Sum	**415**	**281**	**160**	**159**
China total	**465**			

Table 5. Production of zinc (Zn) by province (only Provinces with production amount over 100 000 metric tonnes in 2008 are listed).

Province	Production in 2011 (10 000 metric tonnes)	Production in 2008 (10 000 metric tonnes)	Production in 2004 (10 000 metric tonnes)	Rate of increase 2004-2011 (%)
Hunan	120	86	62	93
Yunnan	87	76	38	126
Shaanxi	66	35	21	219
Guangxi	47	31	25	85
Inner Mongolia	40	20	5	706
Liaoning	34	36	28	19
Henan	30	19	3	949
Sichuan	28	17	24	16
Gansu	24	21	22	14
Guangdong	13	25	18	-26
Qinghai	9	10	3	184
Sum	**497**	**378**	**249**	**100**
China total	**522**			

From the above tables it can be seen that the annual increase rate for copper production 2004-2008 is 19% and for lead and zinc 2004-2011 23% and 14%, respectively. According to the 12th 5-year plan for non-ferrous metal industry development (Ministry of Industry and Information, 2011), the predicted annual consumption demand increases 2010-2015 for copper, lead, zinc and mercury (Cu/Pb/Zn/Hg) are expected to be 5.2%/7.9%/5.2%/2.4%, respectively.

Policies and Standards

A number of environmental related standards and policies have been issued in China related to the non-ferrous metal industry. There are national standards for emissions of pollutants as well as specific standards for lead and zinc industries (GB25466-2010) and for copper industries (GB25467-2010). These specific standards came into force on October 1, 2010. In Zhu Yuhua et al. (2011) industrial standards are presented for cleaner production in copper smelting industry (YS/T 441.1-2001), for cleaner production in lead smelting industry (YS/T 441.2-2001), and for cleaner production in zinc smelting industry (YS/T 441.3-2001). In addition to these emission standards and specific industry cleaner production standards, there are also other standards of relevance for the non-ferrous industry, such as business entry standards, heavy metal pollution comprehensive prevention and control planning standards, etc.

For copper smelters, regulated air emission limit values are given in standard GB25467-2010 and summarized in Table 6. Since January 1, 2012, these limit values apply for all plants. Besides emission limit values (Table 6), the standard also prescribes limit values for concentrations in ambient air in the vicinity of the plants (Table 7). The limit values in ambient air apply to all plants. The concentration limit for mercury in ambient air adjacent to a copper plant is 0.0012 mg mercury/m^3.

Table 6. Air emission concentration limit values for copper production plants in China according to standard GB25467-2010 (unit: mg/m^3).

Pollutants	**Process**	**Limit values (mg/m^3)**
Particles	Smelting	80
SO_2	Smelting	400
Arsenic and its compounds	Smelting	0.4
Lead and its compounds	Smelting	0.7
Mercury and its compounds	Smelting	0.012
Particles	Acid production	50
SO_2	Acid production	400
Arsenic and its compounds	Acid production	0.4
Lead and its compounds	Acid production	0.7
Mercury and its compounds	Acid production	0.012

Moreover, the Business Entry Standards for copper smelters prescribe that newly-built or retrofitted plants have to comply with laws and regulations in aspects of environmental protection, energy saving and energy management, industry policy and plan requirements in China, as well as regulations in land use planning, land supply policy and land use standards. For those new or retrofitted plants which cannot meet industry policy and entry permits, necessary permits for starting up activities, e.g. construction and energy use, will not be issued.

The Business Entry Standards for copper smelters also regulate the allowed smelting processes, energy efficiency and environmental protection requirements, and plant supervision. For example, in the smelting process, an oxygen-enriched bath smelting process or an oxygen enriched flotation smelting process are required, and in acid making facilities, energy saving measures shall be implemented.

Table 7. Concentration limit values in ambient air in the vicinity of copper plants in China according to standard GB25467-2010 (unit: mg/m^3).

Pollutants	**Concentration (mg/m^3)**
SO_2	0.5
Total Suspended Particles	1.0
Sulphuric smog	0.3
Chloride	0.02
Hydrogen chloride	0.15
Arsenic and its compounds	0.01
Nickel and its compounds	0.04
Lead and its compounds	0.006
Fluoride and its compounds	0.02
Mercury and its compounds	0.0012

For the lead and zinc industries emission standards entered into force in 2010 and are since Jan. 1, 2012, in force for all plants. The air emission limit values are presented in Table 8. Concentration limit values in ambient air in the vicinity of lead and zinc plants are illustrated in Table 9 and for mercury the concentration limit is 0.0003 mg/m^3.

Table 8. Air emission concentration limit values for lead and zinc plants (unit: mg/m^3).

Pollutants	**Process**	**Limit values (mg/m^3)**
Particles	All	80
SO_2	All	400
Sulphuric smog	Acid production	20
Lead and its compounds	Smelting	8
Mercury and its compounds	Sintering and smelting	0.05

The Industry Entry Permission for lead and zinc industries came into force in 2007. Similar to the entry permission for copper industries, it regulates and prescribes requirements for the technical process and equipment, energy consumption, energy utilization, environmental protection, safety and occupational hazard, management supervision as well as land use planning and policies, etc.

Table 9. Concentration limit values in ambient air in the vicinity of lead and zinc production plants (unit: mg/m^3).

Pollutants	**Concentration (mg/m^3)**
SO_2	0.5
Total Suspended Particles	1.0
Sulphuric smog	0.3
Lead and its compounds	0.006
Mercury and its compounds	0.0003

Currently China is increasing its investments in heavy metals pollution control, and it is reported that the Ministry of Environmental Protection (MEP) in 2010 set up a Special Fund for heavy metals pollution control, in coordination with other related departments. Supported areas are pollution control and treatment, demonstration projects and technology innovation in relation to production of lead, mercury, cadmium, chromium and arsenic. The detailed plans are not publically available at this time.

Technology Level

Mercury is naturally present in the copper-, zinc- and lead-containing ores used as raw material by the non-ferrous metal sector. The sequence of processes used in extracting and refining metals from ores varies according to a number of factors: the metal being extracted, the ore type, the mineral content, and the mineral concentrations. Metal concentrations are usually quite low in non-ferrous ores and a first step of beneficiation is normally used to produce concentrates. The concentrate is then subjected to thermal pre-treatment, or pyrometallurgical processes, which may include *sintering* (heating to below the metal melting point to produce a more concentrated ore, often used in lead production), *roasting* (where the ore concentrate is heated to dry it and remove the sulphur). Roasting is typically used in the production of copper, nickel, cobalt, and zinc, although in some smelters this step is bypassed and the charge is added directly to the smelting furnace. The next step is the *smelting,* where reduction of the oxides of the metal is achieved. After this several steps remain to refine the crude metal produced in the smelting.

In the description of the on-going GEF project in China, "Reduction of mercury emissions and promotion of sound chemical management in zinc smelting operations" (2011) the zinc smelting processes are described as follows. There are two major categories of zinc smelting processes, zinc hydrometallurgy and zinc pyrometallurgy (Figures 1 and 2). The traditional zinc metallurgy is in fact a mix of hydrometallurgy and pyrometallurgy, including five main steps of roasting, leaching, purification, electrowinning and casting. Generally, most of the new zinc smelters use zinc hydrometallurgy. The main advantages are: improved working conditions, reduced environmental pollution, continuous production, automated, large-scale and comprehensive utilization of raw materials, improved product quality, reduced overall energy consumption, and increased economic benefits.

At the roasting stage, which is a first step in both pyrometallurgy and hydrometallurgy of zinc (Figures 1 and 2), the zinc sulphide (ZnS) concentrate is roasted to zinc oxide (ZnO, or zinc calcine) with the presence of oxygen. At the same time, the sulphur and the mercury in the concentrate are converted into sulphur dioxide (SO_2) and Hg^0 in gaseous form, respectively.

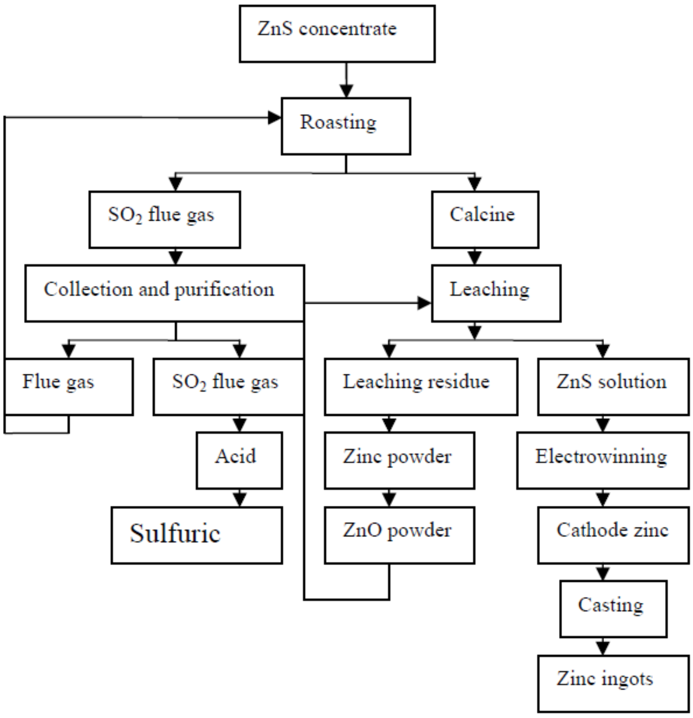

Figure 1. The process of zinc pyrometallurgy (Gao Bao-Jun, 2008, as referred in the GEF project description).

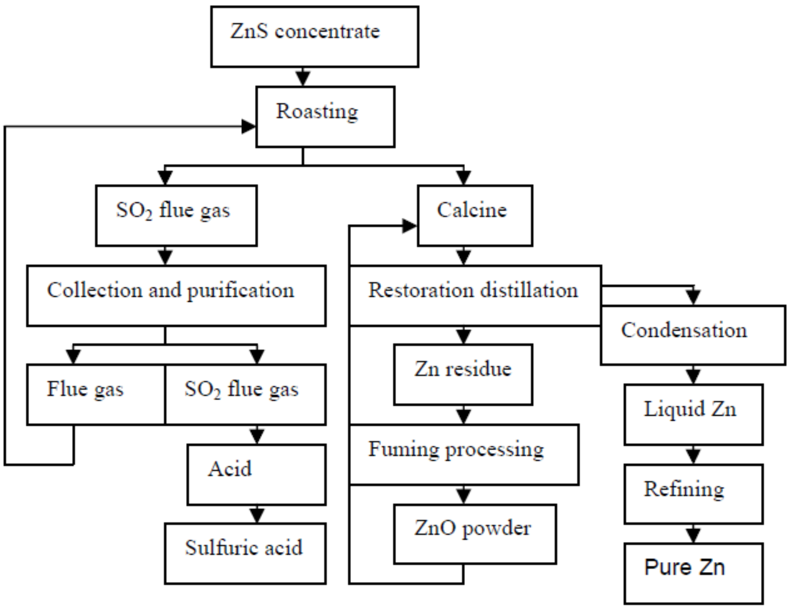

Figure 2. The process of zinc hydrometallurgy (Gao Bao-Jun, 2008, as referred in the GEF project description).

The non-ferrous metals copper, lead and zinc are generally present as sulphides in the ores and the mercury impurity is mainly released during the initial thermal processes (roasting/sintering) when the sulphide minerals are converted to oxides and the sulphur is removed as sulphur dioxide (SO_2) gas (or if the roasting is by-passed in the smelting step). The SO_2 is often converted to sulphuric acid (Figure 1 and 2). Mercury released in the roasting/sintering follows the flue gas stream and can be collected and used as a resource, released as a pollutant in other by-products (e.g. in sulphuric acid), or released into wastewater, solid waste or to the atmosphere.

A major factor determining the emissions of mercury is if efficient air pollution control technologies are installed at the plant, and specifically if there is mercury-specific controls or if there is a sulphuric acid plant. Air pollution control devices designed primarily for reducing other air pollutants than mercury can also as in some cases contribute to mercury removal.

For copper, the main method for processing of metal ores is pyrometallurgy, accounting for 85% of the total copper production (CRAES, 2012). Blast furnaces have largely been eliminated in copper metallurgical companies, in favour of more advanced equipment/technologies, such as flash smelting, Noranda smelting, and 'double flash furnace' (flash smelting and flash blowing). According to a recent study of copper production in China by Streicher-Porte and Althaus (2010), 15 copper productions plants representing 82% of the production capacity in 2009, all had acid plants (SO_2 conversion), particle emission control (Fabric Filters, ESP, cyclones), and additional emission control with wet or semidry scrubber of lime/carbon adsorption. No information was available on mercury emissions, but an overall removal efficiency of more than 90% can most likely be achieved as co-benefit with the above technologies. Some of this mercury may however, depending on the actual configuration, be trapped in the sulphuric acid or end up in solid or water waste streams.

Mercury trapped in the sulphuric acid can be released to the environment in later steps when the acid is used. Some plants have mercury reclaiming technologies installed before the acid plant where mercury is extracted from the roasting gas as a by-product. If mercury is not recovered as a by-product (i.e. for commercial purposes) it can be removed from the flue gases prior to the acid plant using commercially available techniques such as the Boliden Norzinc process. The removal of mercury prior to the acid plant has the additional benefit of production of sulphuric acid with low mercury content, thus allowing a wider range of use of the acid and a potential commercial advantage.

According to CRAES (2012) the NFM sector in China has undergone large technological improvements and modernization in recent years and many out-dated technologies have been replaced by modern, which is also reflected in the report by Streicher-Porte and Althaus (2010). However, according to the China Council report (CCICED, 2011), many small- and medium-sized plants use out-dated technology and have large mercury releases to the environment. Most likely this refers to plants without SO_2 trapping and conversion, which would imply that also large emissions of mercury may occur.

For zinc and lead, specific information on environmental emission control is not available. However, also these sectors are undergoing modernization to achieve the standards in force from January 1, 2012, most likely leading to increased emission control of air pollutants. According to CRAES (2012), 50% of the Chinese lead production industry has been modernized to globally advanced standards. In the last 20 years, hydrometallurgy of zinc has been developed, and at present 70-80% of the zinc in China is produced by hydrometallurgy. Since hydrometallurgy requires that sulphur is removed from the ores, the metal extraction in the hydrometallurgical step is preceded by roasting (see Figure 2). The GEF project description (2011) states that China´s zinc smelting industry is rather decentralized and made up of many scattered medium to small-sized businesses, and that there are approximately 70 zinc smelters spread throughout 27 provinces.

For assessing current mercury emissions from the NFM sector in China, additional information about remaining plants with no or inefficient SO_2 recovery is needed. Even with a modernization degree of over 80% (as in the example for copper above), the remaining production plants can contribute with much higher emissions of mercury and other pollutants, despite representing only a small share of the total production capacity.

Example of mercury emission monitoring and measurements from the non-ferrous metal sector in China

The non-ferrous metal sector is one of the key mercury emission sources in China. According to Chinese estimations, mercury emissions from zinc, lead, and copper production are 100 to 200 tonnes per year, with zinc accounting for the largest share of the emissions. Data on mercury emissions from lead and copper industries in China are scarce and available data indicate large variations and uncertainties. For instance, one study of lead smelters showed that the mercury concentrations in the stack gas of four different plants were 5.7, 59, 1020 and 4480 ppm respectively (CRAES, 2012).

Tsinghua University has collected over 280 samples of zinc refinery ores from all over of China, and monitored their mercury concentration (Song et al., 2010). It was shown that the mercury concentrations were in the range of 0.07~2534 g/t. Average mercury concentrations in refinery zinc ores are the highest in Shaanxi and Gansu provinces, 233 g/t, and 499 g/t, respectively. Weighted average of mercury concentration of zinc refinery ores from 16 provinces is 73.2 g/t. Figure 3 shows the mercury content in zinc refinery ores from different locations. By using arithmetic mean, geometric mean, and weighted average of 82 zinc ores mercury concentrations, Tsinghua University estimated the mercury emission factor in zinc refineries to be 76.9 g/t, 4.6 g/t and 35.4 g/t, respectively. These variations in zinc ore mercury concentration show that it is very important to have information on the mercury content and amounts of the various ores used at the plant as input information in order to be able to estimate emissions of mercury with reasonable certainty. Additionally, information on removal efficiencies by any installed emission control technology is of course also essential.

China Academy of Science, Guiyang Geology branch office, estimated the mercury emissions at a big vertical retort zinc metallurgy plant located in the northern part of China. The mercury concentration in raw material, in roasting products, and other zinc melting products (dust, gas cleaning water, gas and sulphuric acid) of two production lines was analysed. The results showed that mercury is mainly emitted from the roasting process. By use of a mass balance approach, the mercury emission factors in 2 production lines were estimated to 38 g and 30 g per produced tonne of zinc, respectively.

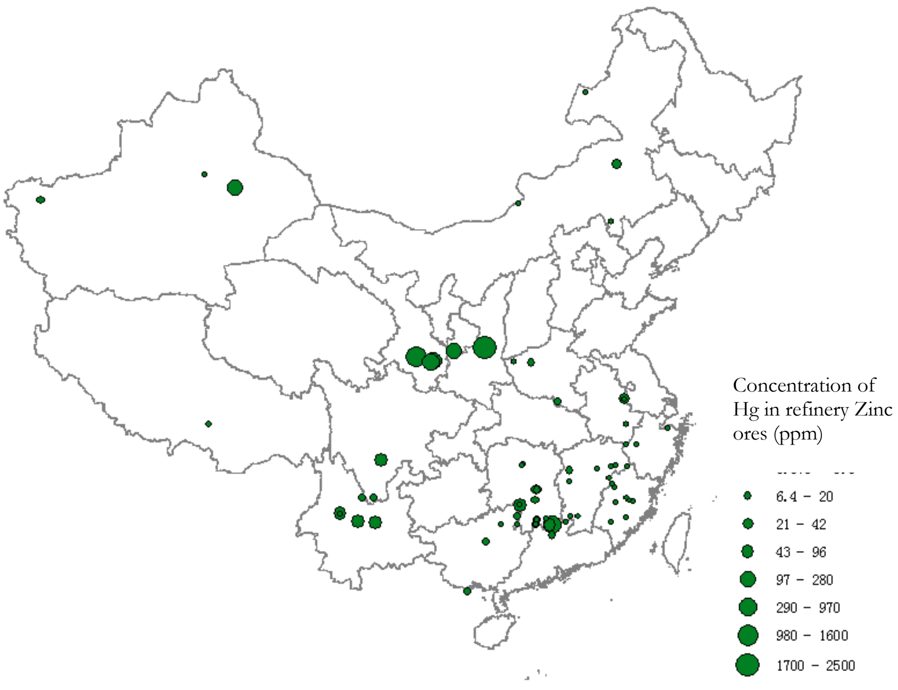

Figure 3. Mercury content in zinc ores in different regions (ppm = g/tonne)

Emissions of air pollutants from the non-ferrous metal sector in China

Information on emissions of SO_2 (sulphur dioxide) and particles from the non-ferrous metal sector in China was submitted as information to UNEP Chemicals in 2010 for the so called Paragraph 29 study (UNEP, 2010). A summary of this information is provided in Table 10. During the time period covered in the table, 2005-2008, the estimated emissions of SO_2, soot and dust have decreased while the estimated removal efficiency has increased substantially. This means that the air pollution control has improved, which could have implications also for emissions of mercury, as air pollution abatement equipment also reduces mercury emissions to some extent. However, some uncertainties remain in the available information, e.g. regarding remaining production facilities with out-dated technologies or lack of emission control. This information is of crucial importance to provide more accurate estimates of the mercury emissions from NFM production in China.

Table 10. Summary of information provided by China to inform the UNEP Paragraph 29 study in 2010.

Year	SO_2 (10kt)		Particles (10kt)			
			Soot		Dust	
	Emission	Removed	Emission	Removed	Emission	Removed
2005	70.7	434.5	19.2	284.5	18.7	379.3
2006	69.5	560.0	15.0	268.5	14.1	332.4
2007	68.36	611.52	15.39	301.50	10.69	497.15
2008	66.88	693.70	13.49	407.90	8.51	435.95

Summary of available emission inventories for mercury from the non-ferrous metal sector in China

There are several international studies published providing estimates of emissions of mercury to air from non-ferrous metal production in China for years between 1999 and 2009 (Table 11). In addition, Table 11 and Table 12 show preliminary results for 2009 from the on-going AMAP/UNEP work (2012) on updating the global mercury emission inventory reported in 2008 (AMAP/UNEP, 2008). It is obvious (Table 11) that the estimated emission levels vary significantly, especially regarding emissions from zinc and artisanal gold production. Hence, estimating mercury emissions from the non-ferrous sector in China is associated with large uncertainties.

Table 11. Published estimates of mercury emissions to air from production of non-ferrous metals (Cu, Pb, Zn, Au) in China for years 1999-2010 (metric tonnes).

Year	Cu	Pb	Zn	Total NFM, excl. gold	Gold, large scale	Gold, artisanal	Reference
1999	10	40	148	198	16	29	Streets et al (2005)
2003	18	71	188	276	16	29	Tsinghua University (2006), Wu et al (2006)
2003				203	45		Feng et al (2009) cited in Pirrone et al (2010)
2005	16	30	38	83			Hylander and Herbert (2008)
2005				66	45	156	UNEP/AMAP (2008)
2006			104				Li et al (2010)
2007	10	21	50	81	37		CCICED (2011)
2009	24	3.3	43	70.7	12.7	167	UNEP/AMAP (2013)
2010	2.5	30.6	39.4	72.5			Wu et al (2012)

In Streets et al. (2005) it was estimated that 198 metric tonnes of Hg was emitted in 1999 from non-ferrous metal production. Hg emissions from gold production were estimated at 16 and 29 metric tonnes, large scale and artisanal, respectively. The study was based on production statistics from the China Nonferrous Metals Industry Yearbook, provincial emission factors for zinc, and national emission factors for copper, lead and gold production. The emission factors were mostly taken from Jiang (2004). Uncertainties in mercury emissions were estimated to ±100% (95% confidence interval) for zinc and copper smelters, ±200% for lead and large scale gold smelting, and ±450% for artisanal gold production.

In Tsinghua University (2006) and Wu et al. (2006) the same methodology for estimating Hg emissions from non-ferrous metal production and gold production as in Streets et al. (2005) was applied for the time-series 1995-2003, resulting in 276 metric tonnes Hg emissions in 2003 from non-ferrous metal production.

In Feng et al. (2009) cited in Pirrone et al. (2010) mercury emissions in China 2003 were estimated to be 203 metric tonnes from non-ferrous metal smelters and 45 ton from large scale gold production

Hylander and Herbert (2008) have estimated Hg emissions from copper, lead and zinc smelters 2005 to be 83 ton. Data on mercury content in concentrates from the major mines as well as amounts of concentrates fed to individual smelters, sulphur abatement technology used and, when present, mercury specific removal techniques were collected from market studies published by Brook Hunt and Associates Ltd.

In AMAP/UNEP (2008) mercury emissions in China 2005 from non-ferrous metal production (including copper, zinc and lead) was estimated at 66 ton; large scale gold production at 45 ton, and artisanal gold production at 156 ton. Estimates were based on global statistics for basic activity data and default emission factors. In the study uncertainties of ±30% (95% confidence interval) of global mercury emission estimates are mentioned for the non-ferrous metal industry.

In Li et al. (2010) Hg emissions from zinc smelters in China 2006 were estimated to 104 metric tonnes. Four industrial-scale zinc plants and one artisanal zinc smelting area in China were investigated and the results were used to estimate Hg emissions from zinc production in all of China. Production statistics was taken from the China Nonferrous Metals Yearbook and the mercury emission factors were estimated based on a mass-balance method and various statistical sample measurements of mercury content in zinc concentrates, dust captured in pollution control appliances, mercury in flue gases, in sulphuric acid, etc.

In China Council for International Cooperation on Environment and Development (CCICED) (2011) mercury emissions from non-ferrous metal production were estimated at 81 ton in 2007, zinc being the largest contributor (50 ton). Hg emissions from gold smelters were estimated at 37 metric tonnes.

Wu et al. (2012) estimated that atmospheric mercury emission from non-ferrous metal smelters in 2000, 2003, 2005, 2007 and 2010 was 67.6, 100.1, 86.7, 80.6 and 72.5 t, respectively. In 2010, the amounts of mercury emitted into atmosphere were 39.4±31.5, 30.6±29.1, 2.5±1.1 t from primary zinc, lead and copper smelters, respectively.

Results from the AMAP/UNEP global mercury emission inventory project

Preliminary unpublished information for China from the on-going AMAP/UNEP (2013) project estimates mercury emissions to be 136 metric tonnes from non-ferrous metal production in China 2009 (Table 12). Mercury emissions from large scale gold production are preliminarily estimated at 13 metric tonnes and at 200 metric tonnes from artisanal gold production (AMAP/UNEP, 2013). The estimated emissions from artisanal gold mining is derived from mercury consumption data (www.mercurywatch.org). The non-ferrous metal production (copper, lead, zinc) estimates are based on production statistics from USGS Minerals Yearbook 2009 and 2010. Uncontrolled non-ferrous metal (incl. large scale gold production) emission factors (g/ton produced metal) are taken from the UNEP Toolkit (UNEP, 2011), whereas abatement efficiencies and application rates of the abatement technologies for copper, lead and large scale gold production are based on factors derived from international published studies judged to be relevant.

For zinc production, information from Li et al. (2010) was used as a basis for developing the factors. It is assumed that 3% of the zinc produced in China is produced using artisanal methods (with no controls). Dry processes (waste heat boiler, cyclone collector, electrostatic precipitator) are applied in ca. 74% of the production (with a removal efficiency of mercury of ca. 10%), sulphuric acid plants (in combination with air pollution controls, assumed to remove 60% of the mercury) is applied in 20% of the production, and the air pollution control technologies at the remaining 3% of the production of zinc includes mercury reclaiming towers resulting in high (95%) removal efficiency.

In AMAP/UNEP (2013) emissions of mercury from lead, copper and zinc production was estimated using information on activity (production of metals), technology profile (status of emission control) and emission factor based on country-specific information. The basic information and calculated emissions are presented in Table 12.

Table 12. Mercury emissions in China 2009 from non-ferrous metal production (metric tonnes) reported in AMAP/UNEP (2013)

Metal	Technology profile	Hg removal efficiency (%)	Degree of application (%)	Activity (t/yr)	Emissions (kg/yr)
Copper	None	0	3.36	89 040	9 527
	APC but no acid production	50	0.7	18 550	992
	APC with acid production	95	95.94	2 542 410	13 602
	Total			**2 650 000**	**24 122**
Lead	None (artisanal production)	0	3.36	83 328	1 302
	APC but no acid production	50	0.7	17 360	137
	APC with acid production	95	95.94	2 379 312	1 857
	Total			**2 480 000**	**3 296**
Zinc	None (artisanal production)	0	2.3	98 440	8 781
	APC but no acid production	50	9.9	423 720	18 917
	APC with acid production	95	77.4	3 312 720	14 795
	APC with acid production and mercury removal tower	98	10.4	445 120	813
	Total			**4 280 000**	**43 306**

APC = Air Pollution Control.

Non-ferrous metal industry development planning

With the aim of promoting a transformation and upgrading of the non-ferrous metal sector in China, on Dec 4, 2011, the Ministry of Industry and Information issued the 'Nonferrous Metal sector 12^{th} 5-year plan' as a continuation of its 11^{th} 5-year plan. During the 11^{th} 5-year plan, the Chinese non-ferrous metal sector experienced a fast development period regarding equipment technology level and in quality of the produced metals. Moreover, in the sector, the energy consumption and process emissions were reduced significantly, while production capacity was increased.

The progress of the non-ferrous metal sector during the 11^{th}- 5 year period was in line with the plan and with the requirements of the national economy and of social development, and forms a concrete basis for future development of the sector. Meanwhile, existing problems in industry structure, weak capacity of self-innovation, severe environmental problems, and increased requirements on emission reduction and energy savings create major challenges.

According to a presentation by the Foreign Economic Cooperation Office, Ministry of the Environment (FECO – MEP) at the Inception meeting for the Special Policy Study on Mercury in China, November 16, 2011(FECO/MEP, 2011), the targets defined for 2015 in the "12th 5-year plan for Heavy Metals Pollution Control" are:

- To establish a comparatively complete heavy metals pollution control system, emergency response system and Environment, Health and Safety assessment system, try to solve a number of prominent problems concerning the public health;
- Further optimize heavy metals-based industry structure, basically keep down the trend of frequently emerging of heavy metals pollution accidents;
- Effectively control heavy metals pollution through reducing the release of key heavy metals in key regions by 15% over 2007 and keeping the release of key heavy metals in non-key regions not exceeding the level of 2007.

In the 12^{th} 5-year plan, the main target for the non-ferrous metal sector is thus to adjust and upgrade the industrial structure, but also to achieve an annual increase of industrial added value by 10%. Some specific targets are:

1. Increased production capacity. Ten kinds of non-ferrous metals (refined Cu, Al, Pb, Zn, Ni, Sn, Sb, Hg, Mg, Ti) production capacity shall be around 46 million tonnes with an annual increase rate of 8%. Production capacity for refined copper: 6.5 million tonnes, lead 5.5 million tonnes, and zinc 7.2 million tonnes, which means annual production increase averaged by 7.3%, 5.2% and 6.9%.

2. Energy saving and emission reduction. Eliminate technologically outdated production facilities and reduce energy consumption. The energy consumption at non-ferrous metal production is to be reduced to 300 kg standard coal/ ton Cu, for Pb to 320 kg standard coal/ton, and for Zn to 900 kg standard coal/ ton.

3. Technology innovation. At key large and middle scale enterprises an integrated technology innovation system shall be established, and R&D investment shall account for 1.5% of main business income of companies.

4. Structure adjustment. Optimize industry structure and enhance industrial concentration and clusters. By 2015, the top 10 companies should produce 90% of the total copper production, 60% of the lead, and 60% of the total zinc production.

5. Environmental treatment and efficient control of heavy metals pollution. In key areas (defined and regulated by central and local governments) heavy metal pollution in 2015 shall be reduced by 15% compared to 2007.

6. Energy security. Improve energy efficiency, enhance international cooperation, and strengthen main non-ferrous metal facilities energy security.

With regard to the technology level, it is highly encouraged to apply more advanced technologies in the non-ferrous metal sector by e.g. upgrading of outdated technologies in existing plants and by introducing more automated processes in the production steps of non-ferrous metals. In Table 13, a selection of indicators of the 12th 5-year plan for the non-ferrous metal industry is presented.

Table 13. Selected indicators of 12th 5-year plan development of the non-ferrous metal industry.

Indicator	2010	2015
Annual industrial added value (IAV) increase (%)	15.8	10
Proportion of R&D cost in medium and large scale plants (%)	0.65	>1.5
Total production amount of 10 non-ferrous metals (10,000 tonnes) [1]	3121	4600
Elimination of outdated copper smelting (10,000 ton)	50	30
Elimination of outdated Al smelting (10,000 ton)	84	80
Elimination of outdated Pb smelting (10,000 ton)	40	120
Elimination of outdated Zn smelting (10,000 ton)	20	40
Energy reduction rate/unit IAV (%)		18
CO_2 emission reduction rate/unit IAV (%)		18
SO_2 emission reduction rate in 12th 5-year plan compared to 11th 5- year plan (%)		10

[1] The 10 non-ferrous metals are: refinery Cu, electrolysis Al, Pb, Zn, Ni, Sn, Sb, Hg, Mg, Ti.

In the efforts of controlling heavy metals emission, there will be more strict industry entry permit procedures and stricter requirements for optimized industry structure and location. New establishment and/or expansion of existing industries with heavy metal discharges is prohibited in nature reserve areas, in drinking water source protection areas, and in other special protection areas, and in urban and suburban areas.

Assessment of availability and quality of emission data and recommendations for how to further improve the emission inventory

To assess implemented policy measures and support cost-effective strategies for improving air quality related to mercury, there is generally a need for a solid and comprehensive national emission inventory. An inventory is also a valuable tool for prioritizing efforts for new air quality policies by identifying large emission sources or sources with significant emission trends. The inventory should therefore reflect national total emissions as well as emissions from subcategories, and enable follow-up of trends by intermittent updates of underlying information.

In order to develop a comprehensive and transparent emission inventory of high quality, large amount of underlying data together with sufficient and clear documentation representative for the regional and national circumstances is needed. Once an emission inventory is set up, annual or intermittent updates are possible using less detailed information.

There are different ways of developing a national emission inventory. The most rigorous method includes continuous emission monitoring at all significant plants. The following section gives a brief guidance on good practice for establishing an emission inventory for mercury emissions to air from non-ferrous metal industries in China.

As China is a large country with about 8 200 non-ferrous metal smelters (CCICED, 2011), information on emission measurements for all individual plants is likely not available. Instead, collecting information from a sample of representative smelters (of various sizes, type of non-ferrous metal production process, air pollution control (APC) technologies and geographical location) and using national production statistics to estimate national emissions is a preferable method. In addition to any actual mercury air emission measurements, the plant specific information should include production volumes, mercury contents in ores and concentrates, and air pollution technologies installed (co-control and/or mercury specific) and associated removal efficiencies.

A majority of the non-ferrous metal smelters in China are small scale production plants. In 2005, 13 main copper smelters produced 2 097 ktonnes copper, amounting to 81% of the total capacity and out of the 775 zinc smelters in China, 50 smelters produce more than 85% of the total zinc production (Response to Questionnaire for the UNEP paragraph 29 study, 2010). In CCICED (2011) it is indicated that smaller and more out-dated zinc smelters in China account for the majority of the mercury emissions. This is mainly due to higher mercury content in zinc concentrates used and less modern and efficient emission reduction technologies in smaller plants.

Several studies on mercury emission factors in Chinese non-ferrous metal smelters (e.g. Streets et al., 2005, Wang et al., 2010, Jiang, 2004) indicate that there are large variations and uncertainties in mercury emissions to air depending on mercury contents in the concentrates, the level of air pollution control (APC) and the presence of integrated sulphuric acid plants and mercury-specific control technologies. It is thus very important, when conducting an inventory survey, to select smelters which represent typical processes and conditions. Detailed information for these representative plants can then be used to derive process/technology-specific emission factors and other necessary information. The information derived from this selection of plants will then form the basis for scaling up estimated emissions from groups of similar plants to a national total estimate for China, using process- and/or technology specific activity data. As many smaller and inefficient smelters in China are likely to be shut-down in the near future (12th 5-year plan), it is also of importance to keep track of the small scale smelters to be able to take this foreseen structural change of the sector into account in the inventory.

In order to establish a solid and regularly updated mercury emission inventory for non-ferrous metal production, several aspects need to be considered;

- Is annual production statistics available? If so, can it be split into subcategories of non-ferrous metals (Cu, Pb, Zn, Au, etc.) and/or production processes/technologies (hydrometallurgical or pyrometallurgical processes, integrated sulphuric acid plants, etc.)?
  - ✓ In China, there is official information available on annual production of Cu, Pb and Zn by Province which seems to be regularly updated and to be of sufficient quality (China Nonferrous Metals Industry Yearbook Editorial Board, 2012).
  - ✓ Through Sulphuric Acid on the Web, information on smelters with acid plants is available. Some of the larger non-ferrous metal smelters in China are also intermittently covered in dedicated studies.
  - ✗ There is however no official data covering all non-ferrous metal smelters, including smaller scale smelters, and on what type of production processes that are applied.

- Is the number of non-ferrous metal smelters available?
  - ✓ There is information available on the number of smelters in China (Response to Questionnaire for the UNEP paragraph 29 study, 2010).

- Is mercury content in ores and concentrates available?
  - ✗ Information on Hg contents in ores and metal concentrates is not available via official statistics, but some information has been acquired via specific studies published in scientific literature.

- Is information available on air pollution control (APC) technologies, both for co-control of mercury and other air pollutants (e.g. PM, SO_X)?
  - ✗ Information is only available via special studies (e.g. CCICED 2011) and it is not possible in this study to evaluate its statistical representativeness or plans for its updating.

- Is information available on mercury specific control technologies (e.g. Boliden Norzink, Outokumpo, Sodium thiocyanate process or activated carbon, etc.) installed?
  - ✓ Through Sulphuric Acid on the Web, information on smelters with acid plants is available.
  - ✗ Information on other mercury specific control technologies is only available via special studies and it is not possible in this study to evaluate its statistical representativeness or plans for its updating.

- Is measurement data on mercury emissions to air available and up-to-date? If so, has it been used to derive representative emission factors?
  - ✗ There are a few special studies performed in China on non-ferrous metal smelters applied on national production statistics. It has not been possible in this study to evaluate their statistical representativeness or plans for their updating.

- Is there information available on trends in non-ferrous metal production, i.e. are there plans for e.g. new industries (with what type of production process and control technology), shut-down of old industries, installation of new abatement technologies (including co-control technologies), etc.?
  - ✓ In China's outline of the 12^{th} 5-year plan there are strong indications on increased closing down of technologically outdated smelters by 2015.
  - ✗ No information on new technology or new industries is available

- Is there a national database for mercury emission estimations hosted by a national entity?
  - ✗ No information on a national database or entity for mercury emission estimations has been available in this study.

Based on the limited information available in this study several key issues are in need of further clarification and development for China. First of all, to develop a national non-ferrous metal mercury emission inventory, there is a need for a national entity responsible for updating and compiling the inventory on an annual or intermittent basis. In addition, resources for training and maintenance of staff and for maintaining the emission database need to be secured. Moreover, the set-up of a step-by-step program to fill the information gaps identified in this study should be initiated, i.e. survey on measurement data (e.g. mercury in ores and concentrates as well as in air emissions), record keeping of non-ferrous metal production processes, air pollution control technologies, etc.

In 2011 a national survey on mercury use and release was conducted by the Ministry of Environmental Protection in China. No data from the survey has been available in this study, but could most likely serve as a good foundation for further efforts in prioritizing resources for improving the status of mercury emission estimations in China.

In addition, there is a newly approved UNDP-GEF (Global Environment Facility) project between the Ministry of Environmental Protection in China and UNIDO focusing on 1) characterization of mercury emissions from zinc smelting in China, where Chinese Ministry of Environment, Foreign Economic Cooperation Office (FECO) will create a coordination and monitoring system for mercury management, focusing on the zinc smelting sector, 2) demonstrate BAT/BEP in two pilot plants and evaluate cost effectiveness, and 3) develop and promote policy reform to reduce mercury emissions from the zinc smelting industry. The duration of this project is two years.

A second GEF project has also recently been approved where a detailed mercury releases inventory will be developed for two provinces (Guizhou and Hunan). It will also assist China to develop a national mercury action plan to decrease mercury releases in the years to come.

Potentials and possible measures for mercury emission prevention in non-ferrous industries in China

The development of a relevant strategy for emission control of mercury is highly dependent on the availability of information on structure and technological status of the sector, as described in the previous chapters. Also important is information on future plans for restructuring and modernizing the sector and of future industrial capacity. This can to some extent be found in the 12th 5-year plan as described above. During this project it was not possible to assess the information from the 12th 5-year plan in depth. Several of the main tasks outlined in the plan however point at the right direction for future reduced mercury emissions, such as energy savings, phasing out of less technologically advanced installations, increased control of heavy metal emissions etc. On the other hand, the plan foresees a substantial increase in production and capacity in the non-ferrous metal industry sector, which may counteract the technology improvements and stricter standards.

A few general conclusions on options for mercury emission reductions can be drawn at this stage. General energy savings as well as the closing down of small and outdated facilities will contribute to reducing the mercury emissions. Further reduction of mercury emissions can to some extent be achieved as co-benefits with emission control of air pollutants (SO_2 and particles). In order to further reduce emissions of mercury to air, installation of mercury specific removal technologies in ore processing facilities is necessary, with priorities for large plants using ores and concentrates with high mercury content. Closing down or technological upgrading of smaller plants with less advanced technology is probably an even more important and efficient approach in order to reduce mercury emissions to air.

In this context it is important to develop a high quality national emission inventory of mercury emissions to air from the non-ferrous metal industry. Such an inventory, in sufficient level of detail, would provide a valuable overview and therefore a basis for prioritizing how and where in the non-ferrous metal sector to focus the abatement actions.

A high quality emission inventory, which is updated regularly, will also allow for a stringent follow up of the results of such actions.

For development and implementation of an emission reduction strategy it is also necessary to evaluate options for emission control from the point of view of cost-effectiveness. To be able to do this, more complete information on the NFM sector is needed including technical status, Hg contents in ores from different origins as well as plans for growth, modernization and restructuring of the industry, as outlined above. An analysis of cost-effectiveness should be based on an assessment of the feasibility of different technical options for emission control, and include both co-benefits with air pollutant control and mercury specific emission reduction technologies. To develop an emission reduction strategy it is thus necessary to involve the relevant industrial groups involved in NFM production with direct access to technical and structural information about the sector as well as authorities and the scientific community with knowledge about policy development and technical options.

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