The China Council for International Cooperation on Environment and Development

Final Report

SPECIAL POLICY STUDY ON

MERCURY MANAGEMENT IN CHINA

CCICED 2011 Annual General Meeting
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ABSTRACT

The Study Team reviewed mercury management experiences in advanced countries and China's situation regarding the management of mercury. The aim was to identify ways to reduce mercury pollution in China and its impacts on human health and the environment while remaining mindful of the societal and economic costs of proposed measures. The methods considered included the modernization of the associated industries and changes to policies and the regulatory regime.

The Team studied a number of urgent mercury management matters including: environmental and human health impacts, social impacts, economic costs, atmospheric emissions, the machinery of government, and international trends in mercury management. The report provides a ten-point action plan, including actions in seven sectors, and offers four recommendations for priority actions. It identifies possible reductions in the use and emissions of mercury that could result from implementation of these recommendations. [1]

Key Words: mercury, heavy metals, pollution control, public health, policy recommendations, contaminated sites, air pollution, mines, smelters, coal combustion.

[1] Note on Limitations of the Study:
The Special Policy Study Team encountered many information gaps on the mercury situation and the management of mercury in China. Information that was available often conflicted with information from other sources. The Study Team's term was too short to undertake research to fully validate or to gather new information on the management of mercury in China. Therefore, even though the Study Team endeavoured to ensure they were working with the best available and referenced data, the reader should be mindful of the limitations. The recommendations in this report include measures to address these challenges.

ABBREVIATIONS

APCD	Air Pollution Control Devices
BAT	Best Available Technique
BEP	Best Environmental Practice
CAS	Chinese Academy of Sciences
CWS	Coal Water Slurry
CRC	Chemical Registry of China (Located within MEP)
EC	Environment Canada
EPBs	Environmental Protection Bureaus (at Provincial and Local Levels)
ESP	Electrostatic Precipitator
FF	Fabric Filter
FGD	Flue Gas Desulfurization
GHGs	Green House Gases
Hg	Mercury
HCl	Hydrochloric Acid
LNB	Low Nitrogen Burner
MACT	Maximum Achievable Control Technology
MeHg	Methyl Mercury
MEP	Ministry of Environmental Protection of the PRC
MIIT	Ministry of Industry, Information and Technology of the PRC
NDRC	National Development and Reform Commission
NOx	Nitrogen Oxides
NPC	National Peoples' Congress
OECD	Organization for Economic Cooperation and Development
PM	Particulate Matter
PRC	The Peoples' Republic of China
PTWI	Provisional Tolerable Weekly Intake
PVC	Poly Vinyl Chloride
RIAS	Regulatory Impact Analysis Statement
SCR	Selective Catalytic Reduction
SO_2	Sulphur Dioxide
SPS	CCICED - Special Policy Study
UNEP	United Nations Environment Programme
US-EPA	United States Environmental Protection Agency
VCM	Vinyl Chloride Monomer
WFGD	Wet Flue Gas Desulfurization
WTO	World Trade Organization
WWT	Waste Water Treatment

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PREFACE

In order to propose policies regarding China's approach to the protection of the environment and public health from mercury, the China Council for International Cooperation on Environment and Development (CCICED) carried out the following *Special Policy Study of Mercury Management in China*. It focuses on mercury pollution and management measures, and offers recommendations for priority actions to reduce mercury release and use in China.

THE ISSUES

i. Preventing the Exposure of Chinese Citizens to Mercury.
ii. Reducing Mercury Releases to the Environment

1. BACKGROUND

Mercury[3] is a naturally occurring element that is persistent, bio-accumulative and toxic at very low levels to human health and aquatic and terrestrial ecosystems.

Mercury is also an important environmental contaminant that is long lived in the atmosphere and can be transported globally. It is unlike any of the other metals, and several characteristics that are unique to mercury — liquid at room temperature, readily transported in the atmosphere and in water — give rise to risks from its release to the environment that must be addressed.

The Arctic

The Arctic Monitoring and Assessment Program[10] reports that a substantial amount of the mercury arrives via long-range transport from human activities at lower latitudes.

Mercury is released from many industrial processes (coal-fired power generation, mining, non-ferrous metal smelting, etc.) and is used in the production of numerous manufactured products (PVC, medical devices, compact fluorescent lights, batteries, dental fillings, etc.). Its control thus requires complex and widespread measures. International action is required to reduce environmental and health risks at local, regional and global scales[4].

There are several different chemical forms of mercury, including elemental, inorganic and organic forms. Methyl mercury, an organic form, is particularly toxic and is formed in the environment through microbial activity. Methyl mercury in a local environment accumulates in living organisms and is concentrated as it moves up the food chain (bioaccumulation). Human exposure can cause damage to the brain, nerves, kidneys, and lungs, and in extreme cases can result in coma and death. Exposure to even low levels of methyl mercury can cause

[3] When the word 'mercury' is used in these recommendations, it should be interpreted to include all species, particularly oxidized and elemental mercury – the sum of these is named total mercury - and methyl-mercury .
[4] UNEP Report on "A general qualitative assessment of the potential costs and benefits associated with each of the strategic objectives set out in Annex 1 of the report of the first meeting of the Open Ended Working Group." June 30, 2008.

neurodevelopmental effects in humans and mammals, particularly during the vulnerable development stages of fetuses and children. Young women of childbearing age are therefore a particularly vulnerable segment of the population.

Mercury released from either natural and anthropogenic[5] sources can travel long distances through air and water (Figure 1), and inorganic forms of mercury will change into methyl mercury under certain environmental conditions, for example in sediments and wetland environments.

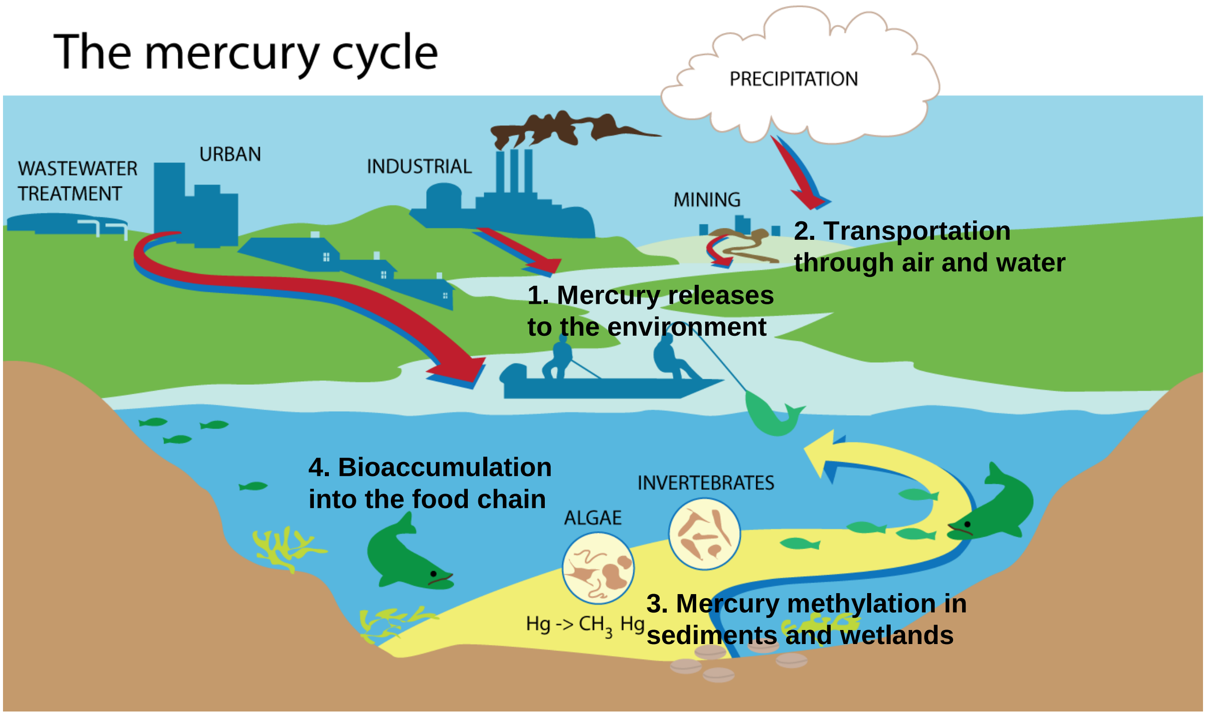


Figure 1. A Simplified Illustration of the Cycle of Mercury[6]

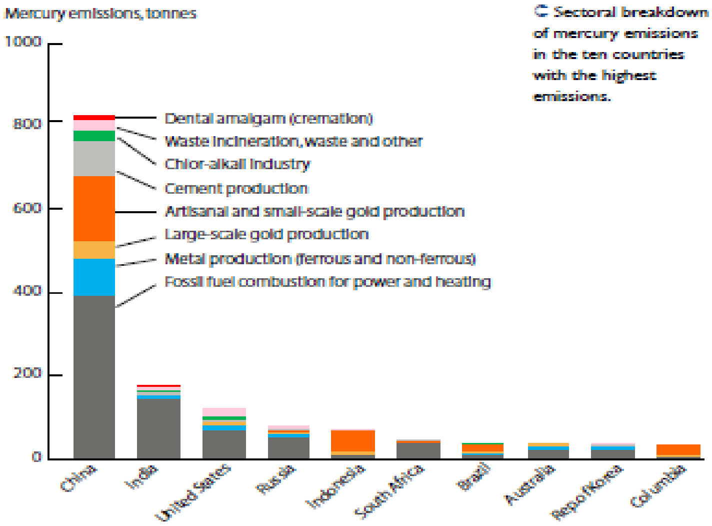
The toxic properties of mercury have been known for centuries, but the first evidence of the severe impacts through environmental exposure, emerged in Japan in the 1950s. In the fishing village of Minamata, more than 20,000 people were poisoned after a factory released methyl mercury into the local bay and area residents consumed fish from that same water. Among other things, the disaster demonstrated the elevated sensitivity of the human fetus to methyl mercury: mothers whom themselves had minimal symptoms of poisoning gave birth to severely damaged infants[7]. Additional evidence of the severe impacts of methyl mercury became evident in Iraq in the 1970s where about 6,500 people were affected after consuming methyl mercury-impregnated grain.

Evidence of the transformation of methyl mercury from releases of inorganic mercury and

[5] Human activities.
[6] ML Erwin, MD Munn. United States Geological Survey (USGS) Fact Sheet FS-102-97. August 1997. http://wa.water.usgs.gov/pubs/fs/fs.102-97
[7] KR Mahaffey. *Fish and Shellfish as Dietary Sources of Methyl Mercury and the Omega-3 Fatty Acids, Eicosahexaenoic Acid and Docosahexaenoic Acid: Risks and Benefits*, *Environmental Research*, 2004, 95: 414-428.

subsequent accumulation in fish emerged from research in Swedish lakes in the late 1960s and early 1970s. Shortly after, bioaccumulation of methyl mercury was also found elsewhere in Europe and North America. Today, mercury exposure is a widespread concern. For example, the US-EPA estimates that more than 300,000 newborns each year in the United States have an increased risk of learning disabilities associated with *in utero* exposure to methyl mercury[8].

Historically, Europe and North America have been the major regions for anthropogenic mercury releases. However, after substantial reductions of the releases in these regions over the past three decades, Asia is today by far the largest source of mercury releases (Figure 2a & 2b.), and China is the largest contributor.



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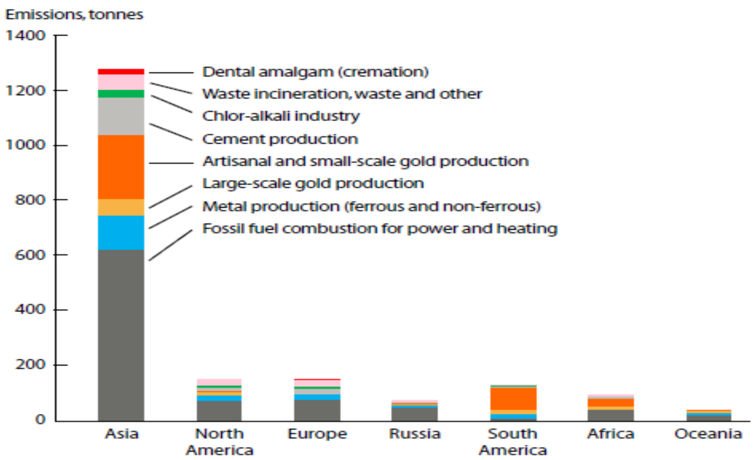

2b

Figure 2a & 2b. Anthropogenic Atmospheric Emissions of Mercury (2005)[9]

[8] http://www.epa.gov/hg/exposure.htm (Accessed: Sept. 6/2011).
[9] United Nations Environment Programme. Chemicals Branch, DTIE. December 2008. *The Global Atmospheric Mercury Assessment: Sources, Emissions and Transport*. Geneva Switzerland, P.18. http://www.unep.org/hazardoussubstances/LinkClick.aspx?fileticket=Y0PHPmrXSuc%3d&tabid=3593&laguage=en-US

An Arctic Monitoring and Assessment Program reported recently that mercury continues to present risks to Arctic wildlife and human populations as levels are continuing to rise in some species despite reductions in mercury emissions from human activities over the past 30 years in some parts of the world[10].

Mercury pollution has gained global attention. At present 140 member countries of the United Nations are negotiating a binding treaty to reduce risks to human health and the environment because mercury pollution is an important global concern. Action is needed in China to ensure that it can continue its remarkable economic growth while reducing its contribution to global mercury emissions and domestic mercury pollution. Due to the special chemical properties of mercury, it can remain in the atmosphere for a long time (months to years) and be transported to the most remote places. China, as the world's largest emitter of mercury, is therefore particularly important when targets are being set for reducing total global releases and reducing impacts of mercury. Hence China is a crucial country in the negotiations of a global mercury treaty.

Meaningful treaty obligations will allow China to have a track record on mercury that is consistent with its green development plans. Reduced use and releases of mercury in China will benefit China not only by protecting its environment and human health, but also by safeguarding its international trade which could otherwise be compromised by restrictive measures as trading nations seek to limit their exposure to mercury (illustrated by recent EU measures to restrict trade in mercury).

In facing these great challenges China has the benefit of its proven capacity to bring innovation and modern techniques to bear in the search for solutions. China has set itself on an exemplary course with its commitments to clean energy strategies, energy conservation and green production systems. These efforts, including China's ambitious climate change undertakings, will offer direct and indirect benefits through reduced mercury pollution. The co-benefits[11] of action to address climate change and other atmospheric pollutants can be optimized through improved coordination in planning and implementation. In turn, actions to reduce mercury pollution will also assist in reducing pollution from other heavy metals.

[10] AMAP, 2011. Arctic Pollution 2011. *Arctic Monitoring and Assessment Program (AMAP)*, Oslo. Vi+ 38pp ISBN-13 978-82-7971-066-0.

[11] When equipment is installed to capture or reduce air pollutants such as particulates, SO_2 and NOx, then mercury emissions may also be captured or reduced as an additional benefit of the processes. Energy efficiency measures or a switch to clean fuels can also reduce mercury emissions from the burning of coal.

The Special Policy Study

To propose policies to strengthen the prevention and control of mercury pollution the China Council for International Cooperation on Environment and Development (CCICED) carried out this Special Policy Study of Mercury Management in China.

The project organization is shown in Figure 3.

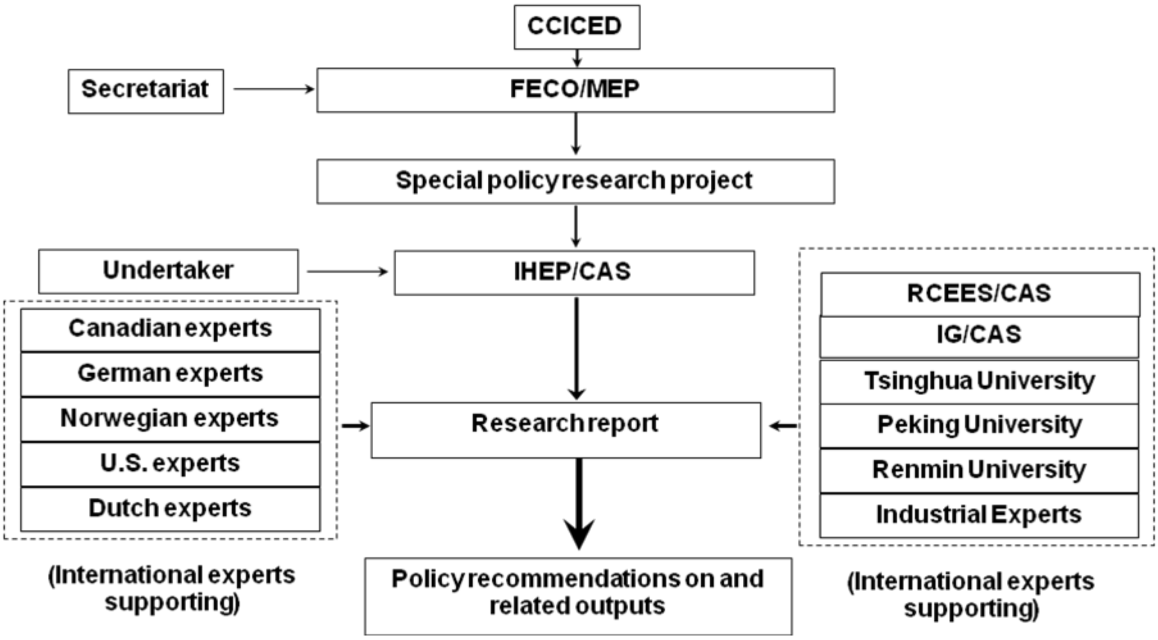

Figure 3. The Project Organization Framework

(CAS: Chinese Academy of Sciences; IHEP: Institute of High Energy Physics; RCEES: Research Center for Eco-Environmental Sciences; IG: Institute of Geochemistry)

2. MERCURY POLLUTION IN CHINA

2.1 Mercury Pollution in China: Status, Trends and Problems

The historic use of mercury in China dates back to 1100 BC, as early as the Shang Dynasty, when people began to use cinnabar (HgS) as a coloring pigment. Currently China is by far the world's largest producer, consumer, and releaser of mercury. The intentional mercury use in China exceeds 1000 tonnes annually[12], which accounts for about 50% of the world's total. Almost all the 11 categories and 59 sub-categories of emission sources defined by the *UNEP Toolkit for Identification and Quantification of Mercury Release*[13] are present in China.

China is one of the few countries still undertaking mercury mining. Some of its core industries will continue to use mercury in the near future. The PVC production process, for example, is the largest intentional user of mercury in China. A large part of PVC is produced from coal and this process currently requires the use of a mercury-containing catalyst (most other countries produce PVC using oil or natural gas, ingredients for which the process does not require a mercury catalyst). The other major use of mercury is in the production of goods to which mercury is deliberately added: these include: medical equipment (thermometers and blood pressure monitors), batteries, and fluorescent lamps (Figure 4). Unless measures to reduce mercury use are taken, the consumption of mercury is projected to increase rapidly.

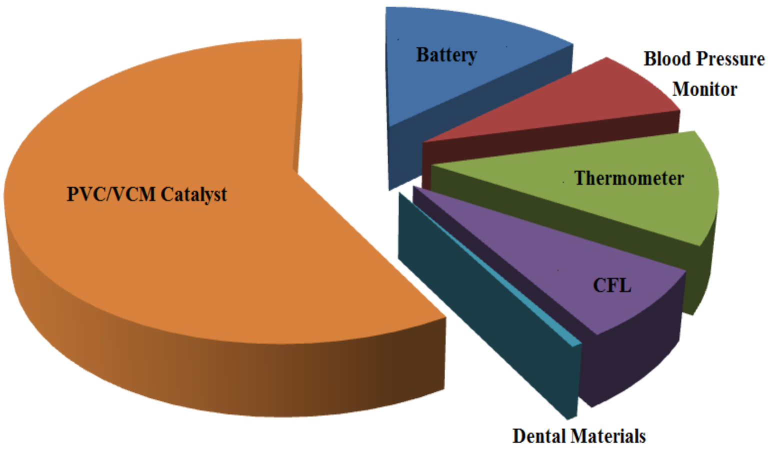

Figure 4. Major Sectors and Their Scale of Mercury Use in China in 2007

Mercury is released to the environment by a wide range of sectors, including key industries such as mining, power generation, non-ferrous metal production, and the cement and chemical industries. While all sectors keep growing, the techniques and means to control relevant environmental pollution lag far behind the needs of international and social environmental development.

The industrial use of mercury in China has caused severe pollution incidents in the past, for example in the Second Songhua River in the northeast and in the Jiyun River in Hebei Province in the 1970s. Today, as a result of past practices, very high mercury levels are found in water, soil and rice near abandoned mercury mining and smelting areas, for example in some areas of Guizhou Province.

The release of mercury to the environment is also high from industrial activities of which mercury

[12] There are uncertainties in the figures regarding mercury use and different sources of data report different numbers.
[13] www.chem.unep.ch/mercury/toolkit or www.unep.org/hazardoussubstances/mercury/publications - *Toolkit for Identification and Quantification of Mercury Releases; revised level 2; March 2010.*

is an unintentional by-product. Mercury is incidentally released to air, water and soil, but quantitative estimates are available only for the emissions to the atmosphere.

Rapid industrialization and urbanization has caused a dramatic increase in China's mercury emissions to the atmosphere over recent decades. Atmospheric emissions in 2007 were estimated to be at least 643 tonnes[14]. The uncertainties in the figures are considerable, and earlier estimates suggest that the overall uncertainty may be as great as ±50%[15]. While there is some debate about the fate of these emissions, mercury's ability to stay in the atmosphere over long periods of time assures that significant amounts travel downwind from China and are thus a concern for other nations[16].

Despite the numerous ways that mercury finds its way into the air, coal combustion in industrial boilers and power plants remains the largest source of atmospheric mercury emissions in China, accounting for more than 50% of the total (Figure 5)[17], with substantial additional contributions from non-ferrous metals smelting and cement production.

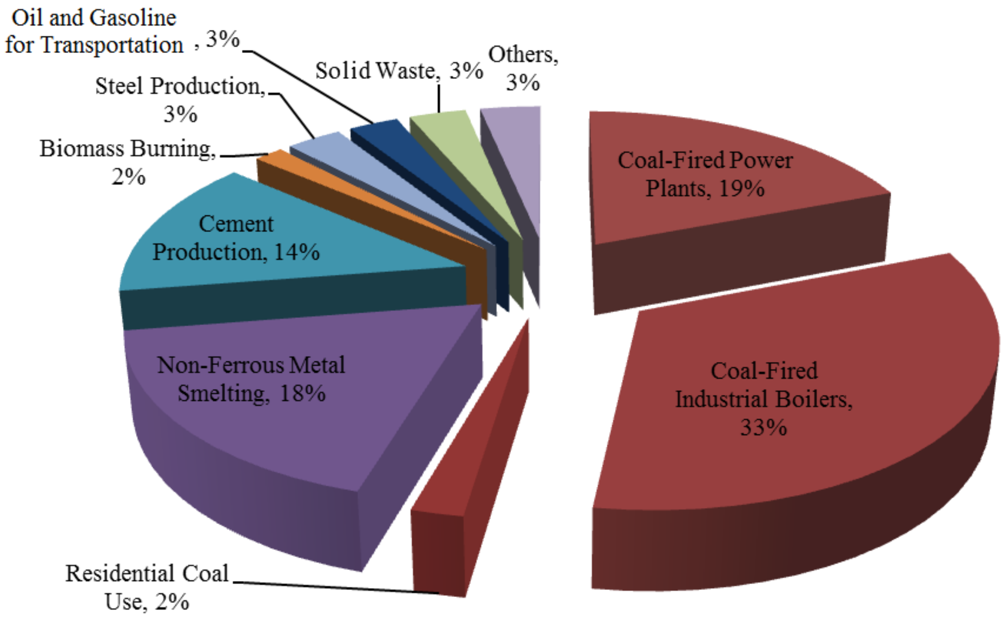

Figure 5. Atmospheric Mercury Emissions from Major Sectors in China in 2007

Atmospheric Emissions

Approximately half of the mercury released to the air falls out locally. The other half of the mercury travels, and while doing so, changes its chemical and physical form. Most local deposition occurs as dry particles, while global deposition occurs mainly with rain and snow[16].

China has serious problems with local mercury pollution, particularly in areas near abandoned mercury mines and old, highly polluting smelting and non-ferrous metal plants. In addition, the industries where mercury is released to the atmosphere as an unintentional by-product (e.g. coal

[14] Source: SPS Mercury Team 2011.
[15] Y Wu, SX Wang, DG Streets et al. *Trends in Anthropogenic Mercury Emissions in China from 1995 to 2003.* Environmental Science &Technology, 2006, 40, 5312-5318.
[16] RP Mason. GR Sheu. *Role of the Ocean in the Global Mercury Cycle*. Global Bio- Chem Cycles. 2002, *16(4): 1093.*
[17] Source: SPS Mercury Team 2011.

burning, non-ferrous metal production) contribute to the mercury loading of the environment locally as well as regionally and globally.

2.2 Health Impacts from Mercury Pollution

2.2.1 Toxicity of Mercury Compounds

The toxicity of mercury depends on its chemical form. The toxicity of methyl mercury is much higher than that of inorganic mercury. Its impact on neurological development is of particular concern.

2.2.2 Mercury Exposure

(1) Intake from foods

Fish and marine mammals are often considered to be the main sources for human exposure to mercury, mostly in the form of methyl mercury (70-90% or more of the total). Mercury concentrations vary greatly, due to factors such as species, age and size of the fish. Large predatory fish usually contain high concentrations of mercury. The intake of mercury is affected not only by the levels of mercury in the fish, but also by the amount of fish consumed.

(2) Indoor non-occupational air exposure

Many objects in the home contain mercury, such as thermometers, and some mercury-containing medicines. A common source of exposure is mercury droplets from broken mercury thermometers. In addition, the use of metallic mercury in religious, ethnic, or ritualistic practices may also cause significant exposures during the practice, and afterwards from contaminated indoor air.

(3) Occupational exposure

Mercury in the working environment can result in elevated exposures. As a result considerable knowledge on the toxic effects of mercury and its different compounds has been attained during the investigation of occupational exposures. In general, the severity of effects depends on the types of occupational activity and extent of implemented protective measures.

(4) Other exposures

Apart from routes mentioned above, mercury exposure may occur through the use of mercury-containing creams for personal skin protection, some traditional medicines, ritualistic uses, and certain pharmaceuticals. In addition, some traditional Chinese medicines or traditional Asian medicines can also lead to significant exposure for mercury.

Mercury exposure from dental amalgam remains controversial and has been widely discussed in many countries and internationally. However, no conclusions have been reached about whether dental amalgams can cause adverse effects. Nevertheless as it is relatively inexpensive to capture dental amalgam in the waste streams at dental offices, this is now done in many countries to prevent this mercury from entering municipal sewage systems and then waterways or sludge that may be used as a fertilizer.

2.2.3 Mercury Levels in Environmental Media of China

(1) Air

Some studies have documented elevated atmospheric Hg concentrations in Chinese cities [18]. Atmospheric Hg concentrations are significantly affected by the combustion of coal, the main source of energy. They are usually higher in heating periods than in non-heating periods. The atmospheric Hg concentrations in remote areas are significantly lower than the concentrations in cities, but still higher than those observed from different remote areas in Europe and North America (usually lower than 2.0 ng m^{-3}), and also higher than the background values for the Northern Hemisphere (1.5-1.7 ng m^{-3})[19].

(2) Soil

The background levels of Hg in soil in China are reported to range from 20-200 μg kg^{-1} [20] with an average of 65 μg kg^{-1} [21]. A Chinese National Standard for Soil Environmental Quality[22] establishes three classes of soil quality. The Hg concentration of class I should be under 150 μg kg^{-1}, which represents the natural background value. The Hg concentration of class II should be under 1000 μg kg^{-1} which is limit for agriculture. The Hg concentration of class III should be under 1500 μg kg^{-1} which is the limit for normal growth of plants. Mercury concentrations of many urban topsoils and agricultural soils were generally above the background value but lower than the limit for class II soil. Topsoil Hg levels in industrial areas are usually higher than Hg levels of other land uses. Topsoil Hg levels are generally higher than those for subsoil, likely due to human activities.

(3) Water

- There are some reports on the Hg concentrations in different water samples, including seawater, river water, well water and lake water[23]. Because there is no systematic study and the spatial and temporal distribution of Hg in water changes constantly it is difficult to give an overall evaluation of the Hg concentrations in water. The reported concentrations of Hg in the large rivers are generally high[24]. All large rivers in China flow through several major

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[18] S Wang, X Feng, G Qiu, et al. *Mercury Exchange Fluxes Between Air and Soil Interface over Different Type of Land in Wanshan Hg Mine Area*, Environmental Science, 2006, 27(8), 1487-1494.
J Liu, L Cheng, W Wang, et al. *The Estimation of Mercury Deposition in Beijing*. Acta Scientiae Circumstantiae, 2001, 21(5), 643-645.
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[19] C. Temme, et al. *Measurements of Atmospheric Mercury Species at a Coastal Site in the Antarctic and over the South Atlantic Ocean during Polar Summer*, Environmental Science & Technology, 2003: 37, 22-31.
[20] SEPA (State Environmental Protection Administration of China), *The Atlas of Soil Environmental Background Value in the People's Republic of China*, China Environmental Science Press, 1994.
[21] L Zhang, QC Wang, ZB Li, ZG Shao. *Mercury Contamination in Cities of China and Countermeasures*. Ecology and Environment, 2004, 13, 410-413. (in Chinese)
[22] SEPA (State Environmental Protection Administration of China). *Environmental Quality Standards for Soils*. GB 15618-1995; 1995.
[23] X Qian, X Feng, X Bi, et al. *Concentrations and Distributions of Mercury Species in Surface Water and Porewater of Lake Caohai, Guizhou Province*. Journal of Lake Sciences, 2008, 20(5), 563-570.
X. B.Feng, , G. H. Li, G. L. Qiu. *A Preliminary Study on Mercury Contamination to the Environment from Artisanal Zinc Smelting using Indigenous Methods in Hezhang County, Guizhou, China - Part 1: Mercury Emission from Zinc Smelting and its Influences on the Surface Waters*. Atmospheric Environment, 2004, 38(36), 6223-6230.
C Y Chen, et al. *Mercury and Arsenic Bioaccumulation and Eutrophication in Baiyangdian Lake, China*. Water Air and Soil Pollution, 2008a, 190(1-4), 115-127.
[24] W Zheng, SC Kang, XB Feng, et al. *Mercury Speciation and Spatial Distribution in Surface Waters of the Yarlung Zangbo River, Tibet*. Chinese Sci Bull, 2010, 55(20), 2026-2032, doi: 10.1007/s11434-010-3294-1
Z Ding; C Liu; Q Tang, et al. *Environmental Pollution in Estuary of the Yangtze River and Coastal Water Mercury as an Example*. Resources and Environment in the Yangtze Basin, 2005, 14(2), 204-207.

cities with significant industrial activities and hence receive large amounts of wastewater that may be contaminated with Hg along with many other pollutants. The water from rivers contributes to the Hg concentrations in estuaries and coastal seas.

- On the other hand, there are reports that reservoirs are relatively less impacted [25]. Given the experience of other countries it would seem important to fully explore whether the methylation of mercury following the flooding of lands for the creation of hydro-reservoirs might in fact represent a problem in China.

2.2.4 Mercury Intake and Impacts in China

(1) Mercury intake

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a provisional tolerable weekly intake (PTWI) of 1.6 μg kg^{-1} bw $week^{-1}$ (micro-grams per kilogram of body weight per week) for MeHg [26]. The US Environmental Protection Agency (USEPA) uses a reference dose value (RfD) for MeHg of 0.1μg kg^{-1} bw day^{-1}[27]. Both limits are based on the same epidemiological cohort studies on fetal mercury exposure; the main differences between them is the assessment and uncertainty factors applied.

Recently, Shang et al.[28] investigated the MeHg intake for adult males of twelve provinces by means of the 2007 Chinese Total Diet Study. MeHg was only reported in the aquatic food group among the twelve food groups analysed. MeHg intakes from aquatic foods for adult males of the twelve provinces ranged from 0.003 to 0.138 μg kg^{-1} bw $week^{-1}$ with an average of 0.041 μg kg^{-1} bw $week^{-1}$, which were far below the PTWI set by the FAO/WHO JECFA.

Many surveys have shown that the mercury levels in Chinese freshwater and seawater fishes are generally low [29]. This is probably because many fish of economic importance in China are not only at low trophic levels, but also fast growing. As for the effect on human health, it is also related to the consumption habits of Chinese people. For the general population, it is still safe to consume the fishes on the market.

Z J Ci, et al. *Distribution and Air-sea Exchange of Mercury (Hg) in the Yellow Sea*. Atmospheric Chemistry and Physics, 2011, 11(6), 2881-2892.

[25] L Jin, X Xu. *Methylmercury Distribution in Surface Water and Fish in the Three Gorge Reservoir Area*. Resources and Environment in the Yangtz Valley, 1997, 6(4), 324-328.

X-b Ran Z-g Yu, H-t Chen, et al. *Distributions of Dissolved Inorganic Mercury in the Lower Part of the Three Gorges Reservoir*. Environmental Science, 2008, 29(7), 1775-1779.

[26] JECFA (Joint FAO/WHO Expert Committee on Food Additives). 2003. Joint FAO/WHO Expert Committee on Food Additives, Sixty-first Meeting, Rome, 10–19 June 2003, Summary and Conclusions. Available: https://apps.who.int/pcs/jecfa/Summary61.pdf [accessed 19 July 2010].

[27] US EPA. *MethylmercuryMethyl mercury (MeHg)* (CASRN 22967-92-6). Washington (DC): USEPA. Available from: http://www.epa.gov/IRIS/subst/0073.htm/, 2001.

[28] X H Shang, X W Li, L Zhang, et al. *Estimation of Methyl Mercury Intake from the 2007 Chinese Total Diet Study*. Food Additives and Contaminants: Part B, 2010, 3, 236-245.

[29] ZS Zhang, XJ Sun, QC Wang, et al. *Recovery from Mercury Contamination in the Second Songhua River, China*. Water Air Soil Pollut, 2010, 211, 219-229.

SX Li, LF Zhou, HJ Wang, et al. *Feeding Habits and Habitats Preferences Affecting Mercury Bioaccumulation in 37 Subtropical Fish Species from Wujiang River, China*. Ecotoxicol ,2009a, 18, 204–210.

HY Yan, A Rustadbakken, H Yao, et al. *Total Mercury in Wild Fish in Guizhou Reservoirs, China*. J Environ Sci, 2010, 22, 1129–1136.

J Fang, KX Wang, JL Tang, et al. *Copper, Lead, Zinc, Cadmium, Mercury, and Arsenic in Marine Products of Commerce from Zhejiang Coastal Area, China, May 1998*. Bull Environ Contam Toxicol, 2004b, 73, 583–90.

GL Qiu, XB Feng, SF Wang, et al. *Mercury Distribution and Speciation in Water and Fish from Abandoned Hg Mines in Wanshan, Guizhou province, China.* Sci Total Environ, 2009, 407, 5162–5168.

In recent years, mercury in rice was found to be a concern in places where rice is grown at contaminated sites. The concentrations of THg in rice growing in contaminated sites of Guizhou, such as Wanshan and Wuchuan, are much higher than China's limit for Hg in crops (20 μg kg^{-1} d.w)[30]. High concentrations of MeHg were also found in these samples since rice paddy fields offer a pathway for methylation. However, the THg and MeHg concentrations in rice growing in areas where no significant Hg pollution occurs are generally low. The Hg levels in rice should be systematically monitored.

(2) Health impacts

Mercury exposure of the general population most often involves dietary intake of methyl mercury. Globally the greatest concern is the uptake of methyl mercury through fish and marine mammals. In China, however, different dietary habits in different parts of the population will mean differences in mercury exposure. In the coastal populations, fish and seafood are important sources; for people living inland, rice consumption may be more important[31].

Mercury exposure of the general Chinese population appears comparable to levels found among human populations elsewhere that have low fish consumption. There are, however, small groups of people who may be exposed to dangerously high levels of mercury. These include people living close to mercury-contaminated sites and dependent on locally grown food, fishermen and their families having particularly high fish and seafood consumption, and workers with occupational exposure in the mining, smelting and PVC industries. It is also important to note that there exist large uncertainties regarding the risks of mercury exposure through rice consumption; the uncertainty is due to the lack of data for dose-response analysis of rice consumption.

There is a paucity of data on human mercury exposure in China, but several studies have been carried out in Guizhou Province. Here, the mercury intake levels estimated for the general population were low, but with important exceptions in heavily contaminated mining areas. Since mercury pollution exists at many contaminated sites where rice is also grown, further investigation is critical to assess exposure and to correlate it with human bio-monitoring (especially for pregnant women) and with potential health effects. It is uncertain whether the advisory limits for human intake, which are based on fish consumption, provide adequate protection for a population with rice-based exposure; rice lacks the micronutrients found in fish that might partly offset neurotoxicity. Data on health impacts are not available.

Blood, hair, urine and milk have been used to assess human exposure to mercury. Hair is a particularly attractive human sample as it is easy and relatively non-intrusive to obtain, and as it gives information of exposure over time (typically one cm of hair records one month of dietary exposure). Some data exist on the mercury content of human hair from assessments of mercury exposure in China: a survey[32] of the general population (659 individuals) in coastal areas found a geometric mean concentration of 0.83 μg/g and values ranging from 0.03 to 8.7 μg/g. Fifty-seven percent of the samples had concentrations below the reference dose value set by the US-EPA[33] and 13% above the tolerable daily intake value set by WHO[34].

[30] MOH (Ministry of Health of China). *Maximum Levels of Contaminants in Foods.* GB 2762-2005. 2005. (in Chinese)
[31] H Zhang, XB Feng, T Larssen, et al. *Bioaccumulation of Methyl Mercury Versus Inorganic Mercury in Rice (Oryzasativa L.) Grain*. Environmental Science & Technology 2010; 44: 4499-4504.
[32] XJ Liu, JP Cheng, YL Song, et al. *Mercury Concentration in Hair Samples from Chinese People in Coastal Cities.* Journal of Environmental Sciences-China 2008, 20: 1258-1262.
[33] Mercury study report to congress. *A Hair Concentration of 1 μg/g Corresponds to US-EPA's Reference Dose for MeHg Exposure.* EPA-452/R-97. US Environmental Protection Agency, 1997.
[34] The FAO/WHO Expert Committee on Food Additives value for provisional tolerable weekly intake is 1.6 μg/kg body weight/week, corresponding to 2.2 μg/g in the hair.

There are large differences in the distribution of mercury concentration in hair in different parts of the Chinese population due to very different food consumption patterns. An identified high exposure population is found on the Island of Zhoushan, off the coast of Zhejiang province, where many of the inhabitants are fishermen and their families, with a large portion of wild-caught fish in their diet. The mean mercury concentrations in their hair samples were higher than the corresponding concentration of the WHO provisional tolerable weekly intake[35]. These levels of mercury in hair were similar to what is reported in other populations with a fish-rich diet (including fishermen in Malaysia, Kuwait and Colombia, sport fishermen in Canada, and many Japanese communities[36]).

High mercury concentrations in hair were also reported for workers living in the mercury mining areas in Guizhou province[37,38]. These workers have both occupational exposure to gaseous mercury and exposure from contaminated rice in their diet.

Also, workers in other industries have occupational exposure to mercury, together with other toxic substances in the forms of gases and dust. Higher-risk industries include mining and smelting in general, and industries intentionally using mercury in the process or as a part of the final product. Workers in the VCM/PVC industry are one example of a situation of particular concern where there is exposure to numerous toxic compounds.

2.3 Mercury Pollution Prevention and Control in China by Sector

2.3.1 Coal Fired Power Plants and Industrial Boilers

China is the largest consumer of coal in the world, with coal accounting for almost 75% of its energy production. The coal-fired industry includes coal-fired power plants and industrial boilers. Of these two, the power plants sector is the largest consumer of coal, but the industrial boiler sector is a larger source of atmospheric mercury emissions due to less air pollution control in this sector. Typical mercury content in the coal being burnt is 0.15-0.20 μg/g, but there are large variations between regions and coal qualities.

(1) Power Plants

Coal-fired power plants in China consumed 1.33 billion tons of coal in 2007, accounting for 42% of national coal consumption. The coal demand by power plants is predicted to double by 2020, and, without further pollution control measures, such an increase would also double the mercury emissions. However, there are considerable co-benefits in terms of reduced mercury emissions from control measures for other pollutants ((SO_2, NOx, PM) (Table 1.)).

Because of the stricter control of SO_2 during the 11th 5-Year Plan period (2005-2010), the installation of flue gas desulfurization (FGD) has become mandatory for coal-fired power plants. In 2005 only 10% of the power plants had FGD installed; by 2009, 71% had the technology. As a

[35] Hair concentrations were 5.7 and 3.8 μg/g, respectively, for men, 2.3 and 1.8 μg/g for women, and 2.2 and 1.7 μg/g for children;
JP Cheng, LL Gao, WC Zhao, et al. *Mercury Levels in Fisherman. and Their Household Members in Zhoushan, China: Impact of Public Health*. Science of the Total Environment 2009; 407: 2625-2630.

[36] Comparison between available data from Chinese populations and other countries provided in a background document from Prof. Thorjørn Larssen and Yan Lin.Thorjorn.larssen@niva.no (June 2011)

[37] YF Li, CY Chen, L Xing, et. al. *Concentrations and XAFS Speciation in Situ of Mercury in Hair from Populations in Wanshan Mercury Mine Area, Guizhou Province*. Nuclear Techniques, 2004, 27: 899-903.

[38] P Li, X Feng, G Qiu, et. al. *Mercury Exposure in the Population from Wuchuan Mercury Mining Area, Guizhou, China*. Science of the Total Environment, 2008, 395: 72-79.

result, despite a large increase in energy consumption and coal use over that period, there was a slight *reduction* in the SO_2 emissions and a slight *reduction* in mercury emissions from the power plants. An example of the co-benefit of SO_2 emission abatement and mercury emissions abatement in the power plant sector is illustrated in Figure 6.

During the 12th 5-Year Plan period (2010-2015), NOx emission control is given priority and equipment to reduce NOx (Selective Catalytic Reduction – SCR) is to be installed at coal-fired power plants. SCR installations can further reduce mercury emissions from power plants (Table 1).

Table 1. Co-Benefit of Mercury Removal by Various Air Pollution Control Devices (%)

Control methods	Intentional pollutant to be controlled	Hg removal efficiency (%)
Coal washing	Particulate matter and SO_2	30
ESP	Particulate matter	29
ESP+WFGD	Particulate matter and SO_2	62
ESP+WFGD+SCR	Particulate matter, SO_2 and NOx	66
FF	Particulate matter	67
WSCRB	Particulate matter	6.5
CYC	Particulate matter	0.1

ESP: electrostatic precipitator; WFGD: wet flue gas desulfurization; SCR: selective catalytic reduction; FF: fabric filter; WSCRB: water scrubber; CYC: cyclone dust collector.

As mercury is removed from the flue gas by the air pollution control devices (APCDs), the mercury enters the solid by-product and waste streams from the power plant as fly ash, gypsum, and as sludge from the waste water treatment (WWT). The mercury trapped by the particle control devices ends up in the fly ash and that trapped by the FGD system ends up only partially in the gypsum. Most of the trapped mercury ends up with the fines in the FGD blow down to be treated in the in the WWT plant. Both the fly ash and gypsum are resources that can be used in other industrial processes, for instance the ESP fly ash and the FGD gypsum in the cement industry, or the FGD gypsum in the wall board manufacturing industry. Proper handling of the by-products as well as of the mercury-rich WWT-sludge becomes increasingly important as these control methods take effect.

As mercury is removed from the flue gas by the air pollution control devices (APCDs), the mercury enters the solid waste streams from the power plant. The mercury trapped by the particle control devices ends up in the fly ash and that trapped by the FGD system ends up in the gypsum. Both the fly ash and gypsum are resources that can be used in other industrial processes, for instance in the cement industry. Proper handling of the mercury-containing solid wastes thus becomes increasingly important as these control methods take effect.

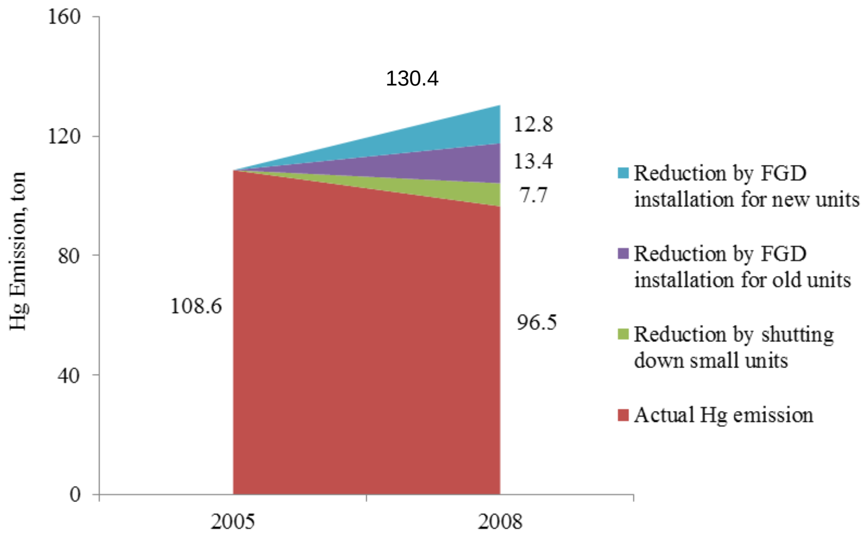

Figure 6. Illustration of the Co-benefit of Mercury Removal by SO_2 Control Measures during 2005 - 2008

Figure 6 illustration of the co-benefit of mercury removal by SO_2 control measures during 2005 - 2008. If no measures for SO_2 control were taken, the mercury emissions in 2008 would have been 130.4 tonnes. The four different types of control measures that have been undertaken have brought that total down to an actual emission of 96.5 tonnes[39].

The total mercury emission from power plants was estimated to be 123.3 tonnes in 2007, with Jiangsu, Inner Mongolia, Shandong, Henan and Guangdong the provinces having the highest emissions (12.4, 11.8, 10.8, 9.9, and 7.5 tonnes, respectively).

(2) Industrial Boilers

There are nearly 550,000 industrial boilers in China. The total coal consumption associated with these was 960 million tonnes in 2007, accounting for 30% of the total coal consumption in China (38% if coke consumption is included).

The application of APCDs on industrial boilers is not widespread and usually involves only simple equipment for particle removal that only removes a small fraction of the mercury. Due to limited capture of mercury by APCD, mercury emissions from industrial boilers are higher than from power plants. Total emissions were about 213.5 tonnes, with Shandong, Henan, Shanxi, Hebei and Guizhou as the top five emitters (22.6, 20.1, 19.4, 16.1, and 15.7 tonnes)

In summary, total mercury emission from coal combustion in China in 2007 was 368.5 tonnes. Of the total, power plants contributed 33%, industrial boilers 58%, residential use 5%, and other 4%. It bears repeating that even though power plants burn far more coal, mercury emission from power plants was lower than that from industrial boilers because modern APCDs were applied.

[39] Source: SPS Mercury Team 2011.

2.3.2 Non-Ferrous Metals Smelting

The non-ferrous metal smelting industry includes zinc smelting, lead smelting, copper smelting and gold smelting (and other metals not discussed here). Current production of zinc, lead and copper is shown in Table 2.

Mercury is found in ores used by the sector. It is released during the smelting process, after which it can variously be: collected and used as a resource; released as a pollutant in other by-products (e.g. sulphuric acid); released into wastewater, solid waste or the atmosphere.

Non-ferrous metal smelting in China still involves a large number of small- and medium-sized plants. Many use out-dated technology and hence have large mercury releases to the environment. These mercury emissions are a great challenge; the sector is developing rapidly while pollution-prevention techniques remain out-dated. The total mercury emission from non-ferrous metal smelting in China in 2007 was 116 tonnes. Emission from zinc smelting was the highest, estimated at 50 tonnes.

Table 2. Zinc, Lead and Copper Production in China in 2010[40]

Metals	Production (10^6 Tonnes)
Zinc	5.16
Lead	4.20
Copper	4.57

(1) Zinc Smelting

China has been the biggest zinc producer in the world since 2002.

The out-dated small- and medium-sized smelters usually allow a very high fraction of the mercury in the ore to be emitted to the atmosphere. More modern and larger smelters typically use the sulphur in the ore to produce sulphuric acid as a by-product. At these plants about 99% of the mercury will be absorbed in the sulphuric acid rather than being emitted to the atmosphere. The most modern plants also have mercury removal and reclamation equipment, which may reduce the atmospheric mercury emissions further and reclaim mercury from the sulphuric acid. Removal of mercury from the sulphuric acid is important if the acid is to be sold for other uses, and in particular for fertilizer used to grow food crops. The mercury removal efficiency of each process of the zinc industry is shown in Table 3.

Table 3. Mercury Removal Efficiency (%) for Different Technologies

	Mercury Removal + Acid Plant	Acid Plant	Without Acid Plant	Artisanal Process
Efficiency	99.3	98.9	15.2	0

The mercury content of zinc concentrate (refined ore) is a very important parameter for emission estimation and varies greatly with the source of the ore. Especially for out-dated smelters, where mercury is not captured, the concentration of mercury in the zinc concentrate is determinative for

[40] CNIA (China Nonferrous Metals Industry Association), http://www.chinania.org.cn/web/website/index_1010030397983910000.htm

the emissions. In modern plants that are able to capture and reclaim, this is obviously of less importance.

As an illustration (Table 4), Province 'A' had mercury content in their concentrate of 500 ppm, while Province 'B' had less than 5 ppm. 'A' produces 230,000 tonnes of zinc while 'B' produces 780,000 tonnes. Despite having more than three times higher production of zinc in 'B', the mercury emissions were much lower (1.4 tons in 'B' vs. 22 tons in 'A') due to the difference in the mercury content of the raw material and the more out-dated equipment in 'A'.

Table 4. Example of Zinc Production, Mercury Content in Zinc Concentrate and the Mercury Emission from the Zinc Smelting in Two Provinces.

Province	Zinc Production (Tonnes)	Mercury Content in Concentrate (ppm)	Mercury Emissions
A	230 000	500	22
B	780 000	5	1.4

The total mercury emission from zinc smelting was estimated to be 50 tonnes, with 14% from large smelters, and 86% from small smelters. In contrast, the zinc production is 87% by large smelters and 13% from small ones. Enlarging the scale is necessary for applying modern technology and reducing mercury emission.

(2) Copper Smelting

Mercury emissions from copper smelting were estimated to be 10.2 tonnes in 2007. Among the provinces, mercury emissions were highest in Inner Mongolia, Yunan and Hubei. High mercury content in copper concentrate and out-dated processes may be the reason for high mercury emissions in Inner Mongolia despite a relatively low copper production. In contrast, although high copper production and high mercury content in copper concentrate occur in Jiangxi province, mercury emissions are not high because of the low-emission process applied.

(3) Lead Smelting

It is estimated that the mercury emission from lead smelting in China was 21.0 tonnes in 2007. The most important provinces were Henan, Hubei and Anhui.

(4) Gold Smelting

In 2007, gold production was 236.5 tonnes. The mercury emission from gold smelting was estimated to be 37.2 tonnes, with 5.0 tonnes coming from large smelters and 32.2 tonnes from small smelters.

2.3.3 Cement Production

There are about 4,000 cement producers in China currently, but this is expected to drop to between 500 and 1,000 through industry restructuring in the next five years[41]. Close to half of the world's

[41] Quote of Lei Qianzhi, China Cement Association, China Daily, page 17, September 21/2011.

cement is produced in China[42]. Mercury is a trace element in the raw feedstock materials, and in the fuels (mostly coal), making the cement industry a major mercury pollution source. In 2005, just over one billion tons of cement were produced in China[43], while 1.68 billion tons were produced in 2009. Cement demand will keep growing in the near future as development goals continue to be pursued.

2.3.4 VCM/PVC Industry

PVC is a type of plastic that is used for everything from water and sewer pipes to plastic toys and clothing. Most manufacturing of PVC around the world uses natural gas or petroleum as the raw material from which the plastic is manufactured. However, most PVC manufacturing in China uses a different process (the calcium carbide process) that starts with coal as the feedstock to produce VCM (from which PVC is made). In that coal-based process, mercury is a catalyst to spark the chemical reaction among the ingredients.

In PVC production through the calcium carbide process, low-mercury catalyst has been used to some extent in several VCM plants. However the industry has indicated that the use of this catalyst requires careful attention to process conditions (temperature less than 150 centigrade and controlled acetylene flow rates)[44]. This may be difficult for smaller and less advanced plants as significant capital investments are required.

Currently there are no mercury-free catalysts available for commercial use but there are ongoing efforts by Chinese institutions[45] to develop a mercury free catalyst for VCM production using coal. Recently a UK-Dutch consortium reported promising results from a pilot scale test of a catalyst that may be affordable[46]. If this catalyst proves to be effective and affordable under commercial operating conditions, optimistic estimates are that the technology could be available for initial commercial use as early as 2013. The mercury free catalyst is based on a noble metal, which will require care in catalyst transport and recycling.

As a result, large amounts of waste mercury catalysts, mercury-containing active coal, mercury-containing HCl, and mercury-containing alkaline agents are generated during production and, with the exception of the used catalyst, these are rarely recycled for technical and economic reasons. Each type of material poses serious environmental risks.

Handling of the used catalyst causes an additional problem, as workers are exposed to high levels of extremely reactive chemicals, including the mercury.

In 2009, the coal-based process was used at 94 of China's 104 VCM/PVC plants. The VCM/PVC industry has used between 570 and 940 tonnes of mercury annually in recent years (Figure 7). It is predicted that by 2012, China's VCM/PVC industry will reach 10 million tonnes of production and exceed 1,000 tonnes of mercury consumption. The PVC production is planned to double from 2010 to 2020 and with continued use of the standard mercury catalyst, the mercury use in the sector will

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[42] http://www.cembureau.be/sites/default/files/Activity_Report_2010.pdf

[43] Lawrence Berkeley National Laboratory Report (LBNL-60638). *Opportunities for Improving Energy and Environmental Performance of China's Cement Kilns*.

[44] UNEP Workshop on Feasibility of China's Mercury-Free Catalyst Research and Development in the VCM Industry. *R&D and Application of the Technology for the Replacement with Low-mercury in PVC Industry*. Xinjiang Tianye Co. Ltd. Beijing September 19, 2011.

[45] UNEP Workshop on Feasibility of China's Mercury-Free Catalyst Research and Development in the VCM Industry. *The Study Development of Chinese Mercury-free Catalyst.* China Petroleum and Chemical Industry Federation and China Chlor Alkali Industry Association. Beijing, September 19, 2011.

[46] UNEP Workshop on Feasibility of China's Mercury-Free Catalyst Research and Development in the VCM Industry. *Mercury Free VCM Catalyst*. Presentation by Johnson-Matthey and Jacobs (copyright).Beijing, September 19, 2011.

also double. China's VCM/PVC manufacturing industry is among the most significant users of mercury in the world today.

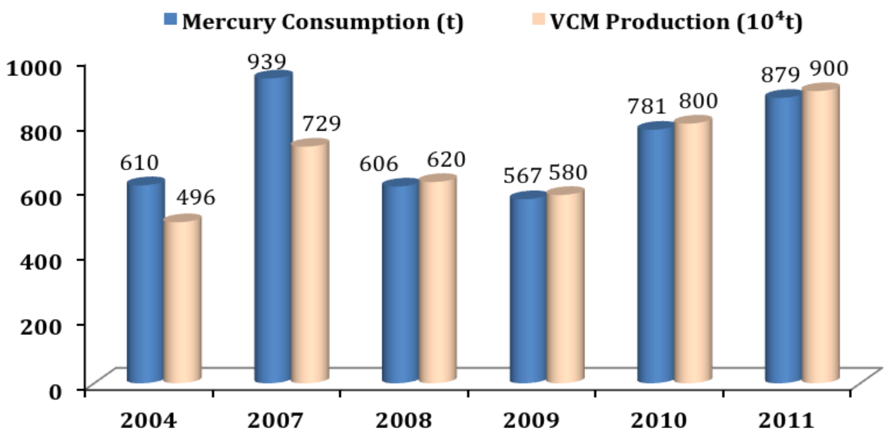

Figure 7. VCM Production and Mercury Consumption in VCM industry[47,48]

In China, three different ministries (NDRC, MIIT and MEP) carried out a series of programs to initiate reduction of the mercury consumption by this sector. They have established the following goals:

- By 2012: achieve 50% of the VCM industry using low-mercury catalyst, which is expected to reduce mercury use by 208 tonnes annually;
- By 2015: only use low-mercury catalyst (mercury use per tonne of PVC produced to drop 50%) and full recycling of the used low-mercury catalyst[49,50]; and
- By 2020: promote mercury-free catalyst and gradually become mercury-free across the VCM/PVC industry[51].

With the VCM/PVC sector forecast to grow significantly in the near-term, experts suggest that the industry should actively seek opportunities to shift from the coal-based acetylene process to the ethylene process and to encourage facilities using the acetylene process to further invest in the transformation to lower-mercury and eventually to mercury-free methods.

2.3.5 Mercury-Added Products

In the production of mercury-added products such as medical devices, dental amalgam, fluorescent lamps, and batteries, the major problems are the management and disposal of wastes. Currently in China, most mercury-added products are sent to landfills along with municipal solid waste. The absence of an effective recycling system and proper hazardous waste handling process therefore poses a risk of mercury pollution to the environment.

[47] D Liu, H Fan. *Strengthen Mercury Contamination Prevention and Treatments Promote Calcium Carbide Process PVC Industry Health Sustainable Development*. China Chlor-Alkali. 2011, 4: 1-3.
[48] X Jian, Y Shen, W Yao, et al. *Status Analysis and Reduction Countermeasures of China s Mercury Supply and Demand*. Research of Environmental Sciences. 2009, 22 (7): 788-792.
[49] *Cleaner Production Technologies Program in the PVC Industry*, MIIT (Ministry of Industry and Information Technology of the People's Republic of China), 2010. http://www.dhp.gov.cn/upload/2011/3/2412262376.pdf
[50] *Mercury Prevention and Control in respect to Industries related to PVC Produced by Calcium Carbide Method Program*, MIIT (Ministry of Industry and Information Technology of the People's Republic of China), 2010. http://baike.baidu.com/view/3717369.html
[51] *Mercury Prevention and Control Planning in the VCM Industry*. CPCIF (China Petroleum and Chemical Industry Federation), CCAIA (China Chlor-Alkali Industry Association). http://wenku.baidu.com/view/4188021ba8114431b90dd883.html

(1) Medical Products

China's current suite of mercury-added medical products include thermometers and blood pressure monitors. Annual thermometer production was 107 million units with about 50% being exported; blood pressure monitors production was 2.6 million units with about 20% being exported.

Table 5. Mercury Consumption in Medical Devices (Tonnes)

Industry	Product	1995[52]	2000[53]	2004[54]	2007[55]	2008[56]
Medical Devices	Thermometer	40.4	100	179	210-233	109
	Blood Pressure Monitor	15.7	50-60	95	86-98	118
Dental Material	Amalgam	6	5-6	6	5-6	Not Known
Total		62.1	155-166	280	301-337	227

(2) Compact Fluorescent Lamps

Mercury-containing bulbs remain the standard for energy-efficient compact fluorescent lamps (CFL). Ongoing industry efforts to reduce the amount of mercury in each lamp are countered, to some extent, by the ever-increasing number of energy-efficient lamps purchased and installed around the world. There is no doubt that mercury-free alternatives such as light-emitting diodes (LEDs) will increasingly become available, and technological developments have led to marketing of comparable mercury-free alternatives to the CFLs. Nevertheless, at present, for most lighting applications, the alternatives are very limited and/or quite expensive.

China is the world's largest producer of compact fluorescent lamps, with approximately 500-600 fluorescent lamp-producing enterprises. From 2000 to 2010, the industry's output increased from about 1 billion to about 6.7 billion lamps (Figure 8), accounting for 80% of global production[57]. Of those 6.7 billion units, 55% were exported. The latest available information indicates that the sector used 78.2 tonnes of mercury in the production of 4.8 billion lamps in 2008[58].

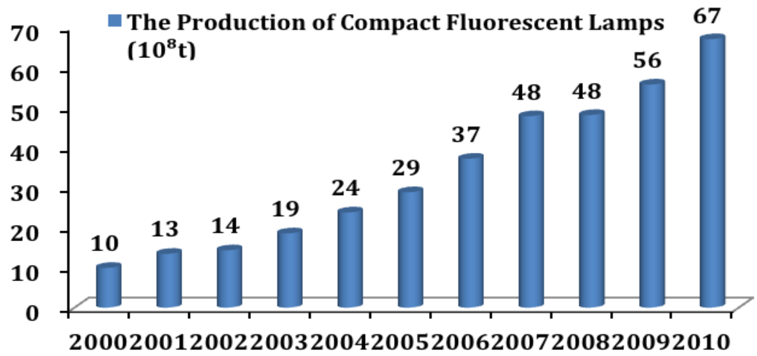

Figure 8. Fluorescent Lamp Production in China

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[52] SEPA (Now MEP). *The Study of Environmental Protection Register and Important Environmental Management in the 21st Century*. Beijing: China Environmental Science Press, 2001, 229.

[53] The investigated results of five key mercury related industries.

[54] X Jian, Y Shen, W Yao, et al. *Status Analysis and Reduction Countermeasures of China s Mercury Supply and Demand*. Research of Environmental Sciences. 2009, 22 (7): 788-792.

[55] Ibid.

[56] China Association for Medical Devices Industry (CAMDI). http://www.camdi.org/

[57] Source: SPS Mercury Team 2011.

[58] *Mercury Related Industries Inventory Report*, 2008, MEP/CRC.

CFLs in China are produced using three processes:

- Small-scale processing uses manual pipetting to deposit the mercury. The pipetting drops can range from 20 – 60 mg per lamp.
- State of the art factories with automatic dosing of the mercury. The range of mercury dosing is 10 – 20 mg per lamp.
- Best available technology where the dosing technology is via mercury-amalgam glass capsules plus special glass preparation. The range of mercury dosing is 3.5 - 5 mg per lamp.

In recent times the government has been working with the industry association to have producers work towards limiting the mercury content of CFLs to 5 mg, but MEP officials advised that that this goal may not be reached until about 2013. With such a reduction the mercury consumption of the industry would decrease by about 35 tonnes. Additionally, China produces a large number of regular fluorescent lamps for use in residential, commercial, and industrial settings. For these, MEP officials advised that the government, in collaboration with industry, has established an anticipated limit of 10 mg per bulb. Unfortunately the production levels and mercury consumption of this sub-sector are not well understood at the moment.

(3) Batteries

The use of mercury in batteries, while still considerable, continues to decline as many nations have implemented policies to deal with the problems related to mercury pollution from batteries.

While mercury use in Chinese batteries was confirmed to have been high before 2000, most Chinese manufacturers have reportedly now shifted to lower-mercury technologies, following both domestic and international legislative trends and customer demands. However, there are still vast quantities (tens of billions) of batteries with relatively low mercury content produced in China, and lesser quantities in other countries as well. From statistics, the current mercury consumption is reported by CRC/MEP to be 200 tonnes per year (2008)[59] however it is reported by MIIT to be 140 tonnes (2009)[60](Figure 9). Over this same period, annual battery production was 39 billion units with 56% being exported[61].

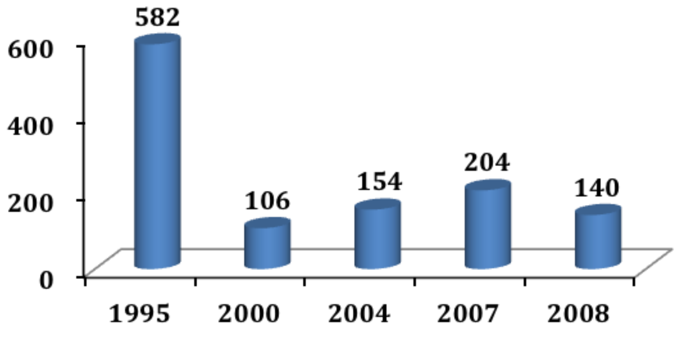

Figure 9. The Mercury Consumption of the Battery Industry in China in Tonnes[62]

The MIIT Heavy Metal Pollution Comprehensive Prevention Plan[63] released for consultation in

[59] CRC/MEP, 2010. X Jian, Y Shen, G Cao. *Investigation of Mercury Usage in the Battery Production and Recommended Reduced Countermeasures*. Environmental Science and Management, 2008, 33(10): 10-16.
[60] http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/13505234.html (Chinese only accessed Sept 21, 2011).
[61] *Mercury Related Industries Inventory Report*, 2008, MEP/CRC.
[62] Source: SPS Mercury Team 2-11.
[63] http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/13505234.html (Chinese only accessed Sept

November 2010 sought agreement with the battery industry to phase out production by 2013 of alkali manganese button batteries having more than 5ppm mercury[64]. The plan also calls for the Chinese battery industry to reduce its use of mercury by 80% by 2015.

2.3.6 Mercury Mining Industry

China is one of only two countries in the world that still produces primary mercury (i.e., from mining). Most of China's mercury production is probably used domestically, though data on the domestic trade, imports, and exports of mercury are not available. The mercury used in industry in China is supplied by several sources: mining, imports, and recycling. In fact, China continues to import several hundred tons of mercury each year to meet domestic demand. Although mercury mining decreased temporarily about a decade ago, domestic mercury production has since increased steadily each year to meet the domestic demand.

In China there is currently only one active, large scale — and legal — mercury-mining operation, located at Xunyang, Shaanxi Province. This mine is reportedly close to being fully depleted, and is expected to produce for only a few more years. The possible depletion of domestic resources is of potential concern for China's mercury-using industry, though less mining may increase recycling efforts and may promote efforts to find alternatives. On the other hand, it may also put pressure on the authorities to relax import restrictions, and also encourage illegal imports.

Mercury mines and smelting generate mercury-containing gases, water and wastes which contain a large amount of soluble mercury, imposing a serious impact on the local ecology and environment. Surveys indicate that long-term, large scale mercury mining has led to significant accumulations of methyl mercury in animals and plants.

Surface soils impacted by mercury mining activities exhibited total mercury concentrations, ranging from background levels to several hundreds of mg/kg. For example, total mercury concentrations in surface soils impacted by mining activities at Wanshan mines reached up to 790 mg/kg[65], and at Wuchuan Hg mines riparian soil about 20 km distance away from mercury retorts still contained up to 24 mg/kg of total mercury[66]. High concentrations of MeHg can also be observed in soils from mercury mining areas, ranging from 1.27 to 22.5 μg/kg at Wanshan[67,68], and from 0.69 to 20 μg/kg at Wuchuan[69]. Different types of soils exhibited different MeHg levels: rice paddy generally showed higher levels than soils in which vegetables are grown[70]. Soil from corn fields showed the lowest values of MeHg.

Results for Hg concentrations in crops from the Hg mining areas in China were heavily

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21, 2011).

[64] 5 ppm is considered the natural background of mercury therefore when 5 ppm is mentioned as a target it means 'no added mercury'.

[65] G L Qiu, X B Feng, S F Wang, et al. *Mercury and Methylmercury in Riparian Soil, Sediments, Mine-waste Calcines, and Moss from Abandoned Hg Mines in East Guizhou Province, Southwestern China*. Appl. Geochem. 2005, 20 (3), 627-638.

[66] G L Qiu, X B Feng, S F Wang, et al. *Environmental Contamination of Mercury from Hg-mining Areas in Wuchuan, Northeastern Guizhou, China*. Environ. Pollut. 2006, 142 (3), 549-558.

[67] M Horvat, N Nolde, V Fajon,et al. *Total Mercury, Methylmercury and Selenium in Mercury Polluted Areas in the Province Guizhou, China*. Sci. Total Environ. 2003, 304 (1-3), 231-256.

[68] G L Qiu, X B Feng, S F Wang, et al. *Mercury and Methylmercury in Riparian Soil, Sediments, Mine-waste Calcines, and Moss from Abandoned Hg Mines in East Guizhou Province, Southwestern China*. Appl. Geochem. 2005, 20 (3), 627-638.

[69] G L Qiu, X B Feng, S F Wang, et al. *Environmental Contamination of Mercury from Hg-mining Areas in Wuchuan, Northeastern Guizhou, China*. Environ. Pollut. 2006, 142 (3), 549-558.

[70] "Vegetation soils" means "soils where vegetables are grown".

contaminated by mercury. Levels of total Hg in green cabbages, corn, rape, tobacco, and rice grown at Hg mining sites exhibited higher values than the permissible limit of mercury in food (0.01-0.02 mg/kg). Though inorganic Hg species predominate in most of Hg-containing plants, high MeHg concentrations (up to 174 µg/kg) were reported in rice (*Oryza sativa L.*) grown at Hg mining areas[71].

Human health risk assessments of Hg exposure in the Hg mining areas were conducted in several studies. In Wuchuan, an average hair total Hg and MeHg for smelting workers was 69.3 and 2.32 mg/kg, respectively[72]. Workers in artisanal smelters were heavily exposed by elemental mercury, with total Hg in urine and the urinary β2 protein reaching up to 779 mg/kg creatinine and 208.5 mg/kg creatinine, respectively[73]. The results indicated that rice is an important MeHg exposure route for residents in the Wanshan Hg mining area and the main human exposure to MeHg is via consumption of rice rather than fish.

Clearly the legacy of closed mines is a major problem for China. There are dangers for local populations not just from the mercury pollution described above, but also from possible mine tailing pond collapses, several of which have occurred in China recently[74,75].

2.4 Mercury Pollution Prevention and Control in China

2.4.1 Regulatory System for Mercury Pollution Prevention and Control

In recent years China has paid increasing attention to the prevention and control of mercury pollution. Since the 1990s China has conducted research on mercury emissions to the atmosphere. It has created numerous primary and secondary laws that contribute to the prevention and control of mercury pollution. Notable amongst these are the *Law on the Prevention and Control of Atmospheric Pollution* and the *Cleaner Production Promotion Law of the People's Republic of China* that contribute amongst other things to the control of mercury pollution. In 2009, the General Office of the State Council issued the *Guiding Opinion on Strengthening Prevention and control of Heavy Metal Pollution*, to set objectives and provide funding for heavy metal pollution prevention and control.

The following are some key steps that have been taken by China since 1990 to prevent and control mercury pollution:

- In May 1992 and April 2004, respectively, the Chinese government ratified the Basel Convention and the Rotterdam Conventions that include mercury in their scope of actions. Since 2002, China has implemented a policy that requires imported mercury to be processed at fixed locations, to prevent pollution from imported mercury.
- In 2005, China began to regulate mercury-containing catalysts as hazardous waste. In 2007, the State Council released the *Guiding Directory on Industrial Structure Adjustment (2007)* that restricted the use of mercuric chloride catalysts.
- In November 2009, the Ministry of Environmental Protection issued the *Notice on*

[71] G L Qiu, X B Feng, P Li, et al. *Methylmercury Accumulation in Rice (Oryza sativa L.) Grown at Abandoned Mercury Mines in Guizhou, China*. J. Agric. Food Chem. 2008, 56 (7), 2465-2468.
[72] P Li, X Feng, G Qiu, et al, *Mercury Exposure in the Population from Wuchuan Mercury Mining Area, Guizhou, China*. Sci. Total Environ. 2008, 395 (2-3), 72-79.
[73] P Li, X Feng, G Qiu, et al, *Mercury Exposure in the Population from Wuchuan Mercury Mining Area, Guizhou, China*. Sci. Total Environ. 2008, 395 (2-3), 72-79.
[74] http://www.wise-uranium.org/mdaf.html
[75] http://www.chinadaily.com.cn/bizchina/2011-02/18/content_12040016.html

Furthering the Special Inspection of Enterprises for Heavy Metal Pollution, requiring monitoring of heavy metal pollution sources. China has gradually established a system to strengthen the monitoring of mercury pollution.

- In December 2009, the *Notice on Strengthening Guidance on Prevention and control of Heavy Metal Pollution of the Ministry of Environmental Protection Forwarded by the General Office of the State Council* (G.B.F. (2009) No.61) was issued.

In addition,

- For mercury-involving products, there are requirements in terms of environmental protection and labor protection during the production processes that generate solid wastes that are listed in the National Hazardous Waste Inventory.
- Some products are banned, including pesticides, cosmetics and high-mercury batteries.
- Backward techniques such as indigenous mercury production methods, illegal gold smelting using highly toxic substances and gold extracting through mercury are being phased out.
- Enterprises with an annual mercury yield below 10t are also listed in the elimination directory.
- Acetylene methods with a PVC capacity below 80,000t/year are restricted.

In February 2011, the *Heavy Metal Pollution Prevention and control Plan (2011-2015)* was approved for implementation by the State Council. It provides an integrated approach to the prevention and control of heavy metals such as mercury, lead, cadmium, arsenic and chromium. The Plan stipulated that:

> "by the end of 2015, a few prominent problems that endanger public health and the ecological environment should be settled; a complete heavy metal pollution prevention and control system, emergency handling system and environmental and health risks assessment system should be established to solve prominent problems that impair public health; the heavy metal-related industrial structure should be further optimized and the frequent occurrence of contingent heavy metal pollution should be suppressed".

Implementation of the Plan will require that the prevention and control of heavy metal pollution be a major priority in environmental protection both currently and in the future. Work is needed to improve the scope, stringency and implementation of the pertinent regulations and to strengthen the capacity of the institutions and systems for mercury pollution prevention and control in China to meet the requirements of an environmentally-friendly society.

2.4.2 Responsible Authorities for Mercury Pollution Prevention and Control

(1) National Level

The Environmental and Resources Protection Committee (ERPC) of the NPC is responsible for developing, reviewing and enacting environmental laws.

Under the State Council, the MEP, the highest administrative body for environmental protection, is responsible for developing environmental policies and programmes. The MEP deals with policy and regulatory matters from standards setting to enforcement, environmental impact assessments, and international conventions.

As a cabinet-level ministry, the MEP can be directly involved in high profile decision making and has the authority to co-ordinate other cabinet-level ministries in order to address environmental

problems. Several ministries and agencies under the State Council are involved in environmental management. In particular, the State Development and Reform Commission, the Ministry of Health, the Ministry of industry and Information Technology, and the State Food and Drug Administration play different roles in environmental protection associated with infrastructure construction and management (including environmental impact assessment), industrial policy, human health, food and drugs and implementing international agreements related to mercury management.

An environmental protection management system spanning the relevant departments is gradually being established, but needs further development. Approaches to engage the broader society in mercury management still need to be developed.

(2) Local Levels

The MEP supervises Environmental Protection Bureaus (EPBs) at the provincial, prefectural and county levels. As part of the provincial Governors' Offices, EPBs implement national and provincial environmental protection laws, regulations and standards and monitor pollution. Since the MEP became a cabinet-level Ministry in 2008, Directors of the EPBs will all eventually report directly to the MEP rather than the Governors' Offices. This change is being phased in with some Directors still operating under a co-management arrangement.

Various other sub-national administrative units also play important roles in environmental protection: Mayors' Offices; Planning Commissions; Industrial Bureaus; Finance Bureaus, and Urban Construction Bureaus. As at the national level, local levels are establishing coordination mechanisms under which EPBs take the leading role and are supported by other departments.

(3) Industrial Associations

There are many different industrial associations related to mercury management in China, for example the China National Coal Association, China Petroleum and Chemistry Federation, China Non-ferrous Metals Industrial Association, China Association of Light industry, China Battery Industrial Association and China Medical Devices Association.

The China National Coal Association is a non-profit national organization formed voluntarily by enterprises, public institutions, social groups and individuals in the national coal industry. Its functions include planning and tracking of major investments and construction projects within the industry; conducting industry research entrusted by government departments; participating in the formulation and revision of the standards and norms of the industry, and organization and promotion of their implementation by member units.

The China Petroleum and Chemistry Federation is a national organization of Petroleum and Chemistry Federation in China. It represents the China Petroleum and Chemical Industry externally, and strengthens cooperation and communication with foreign and overseas counterparts. It provides intra-industry organization, coordination and implementation for the inventory work of China's petrochemical industry.

The China Non-ferrous Metals Industrial Association is a voluntarily association of enterprises, institutions, social organizations and individual members of the China nonferrous metals industry. It carries out industry surveys and the collection, collation, processing and analysis of industry information for publication. It puts forward comments and suggestions for governments to guide industry development, industrial policy, relevant laws and regulations, and assists relevant governmental departments in the development, revision and monitoring of national standards for the industry.

The China Association of Light Industry is a national and comprehensive intermediary industrial organization that provides services and management functions for the China Light Industry. It collects industry statistics, analyses and publishes industry information and conducts industry research. It puts forward comments or suggestions on economic policies and legislation, participates in the formulation and revision of national and industry standards, and monitors their implementation.

The China Battery Industrial Association falls under the authority of the State-owned Assets Supervision and Administration Commission of the State Council and at the same time is under the management of Ministry of Civil Affairs and China National Light Industry Council. The functions of the China Battery Industry Association are to put forward proposals on battery industry policies; draft development plans for the battery industry and battery product standards; organize the evaluation of relevant research projects and technical transformation projects, conduct technical consultations, provide information and statistics, information exchange and personnel training; develop the market for the industry, organize China (international) exhibition fairs, and coordinate issues regarding production, sale and export work. It strengthens self-management in the industry, assists the government and enterprises through consultation and coordination services, and establishes and improves rules and agreements within the industry. It plays a role of bridge and link between the government and enterprises.

The China Medical Devices Association is a national, industry-based, non-profit, voluntary group of organizations and individuals engaged in medical equipment production, management, research and development, product testing and educational training. It falls under the authority of the State-owned Assets Supervision and Administration Commission with the State Council, while it is hosted by China Federation of Industrial Economics and accepts the operational guidance of the Ministry of Civil Affairs, the State Food and Drug Administration and other relevant departments. It investigates and studies problems of the medical device industry to develop and provide opinions and suggestions on policy, legislation and other initiatives. It also works on industry statistics and collects, analyses and publishes industry information. It conducts industry consultations and publishes and promotes national standards and specifications.

A more efficient and effective process is needed to engage all of the relevant industries.

3. ANALYSIS AND EVALUATION OF MERCURY POLLUTION PREVENTION AND CONTROL TECHNOLOGY

3.1 Techniques to Reduce Mercury Emissions from Coal or Fuel Combustion

As coal burns, most mercury enters into the atmosphere along with the flue gases, while a small portion enters the cinder/slag. Gases with strong oxidizing properties such as SO_2, Cl_2 and Br_2 can increase the transformation of elemental mercury into oxidised mercury such as $HgCl_2$ and $HgSO_4$ and HgO. These forms of mercury are more easily captured by flue gas cleaning devices. For instance water soluble, $HgCl_2$ can be easily washed off; poorly volatile, HgO mostly appears in particles, and can be captured by particle capture devices[76].

3.1.1 Techniques for Preventing Mercury Emissions from Coal Combustion[77,78,79,80]

Means to control mercury emissions to the atmosphere from coal combustion include non-technical and technical control measures.

(1) Non-technical control measures include the use of low-mercury coal; the use of mercury-free or low-mercury natural gas, oil and other non-petroleum fuels as substitutes for coal; the increase of energy efficiency and reduction of energy use.

(2) Technical control measures include pre-processing of fuel, improvement of fuel techniques and flue gas purification. These measures are also known as pre-combustion mercury removal, in-combustion mercury removal and post-combustion flue gas mercury removal. Despite various methods for control of mercury emissions from coal combustion, none of them can solve the mercury pollution problem completely.

3.1.1.1 Pre-combustion and in-combustion mercury removal techniques

Several techniques are available for treatment of the coal before combustion. Some remove part of the mercury before the coal is combusted while others add chemicals that increase the removal of mercury from the flue gas. The main methods for mercury removal include:

(1) Coal washing: Through coal washing, we can remove 37%-68% of the mercury in the coal, thereby reducing the emission of mercury from downstream flue gases. The efficiency

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[76] *Review on Removal of Mercury in Coal-Fired Power Plant.* http://wenku.baidu.com/view/115e220003d8ce2f006623dc.html?from=rec&pos=3&weight=11&lastweight=7&count=5

[77] Q Liu, W Gao , C Lu, L Dong. *Research and Development of Mercury Removal Technology in Coal-fired Power Plant.* Gas & Heat. 2009, 29 (3): A06-A09.

[78] L Xu, C Li, X Ablikin, Z Gao. *Development of Mercury Pollution Control of Flue Gas with Existing Treatment Equipments and Techniques in Coal-Fired Power Plant* , Environmental Engineering, 2010, 28(3): 77-80.

[79] M Kuang, G Yang, W Hu, W Chen. *Analysis and Prospect of Technology for Removing Mercury from Flue Gas* Environmental Science & Technology, 2008, 31(5):66-70.

[80] Y Zhao; X Ma. *Research on Removing Mercury Technology Using Existing Pollution Control Device of Flue Gas*, Electric Power, 2009, 42(10): 77-79.

of mercury removal depends on the cleaning procedure, coal type and the pollutants in the coal.

(2) Coal mixing: In the presence of a selective catalytic reduction (SCR) device, bituminous coal and sub-bituminous coal are mixed to increase the contents of halogen elements in the fuel, so as to increase the oxidation of mercury in the flue gas, and improve the efficiency of mercury removal by the downstream gas purification equipment.

(3) Halogen addition: Adding halogen compounds (inorganic bromide or /chloride salts [81]) to oxidize the elementary mercury in the flue gas improves the efficiency of mercury removal by the downstream flue gas purification equipment.

(4) Mild pyrolysis of bituminous coal. Mild pyrolysis effectively reduces the content of mercury in the bituminous coal, thereby reducing the emission of mercury in the flue gases.

Among these four methods, coal washing is the pre-combustion mercury removal techniques are the most widely applied around the world. The other three techniques are being demonstrated and applied full scale by some power plants.

3.1.1.2 Alternative fuels

Increasing the use of alternative fuels is the most effective means for reducing mercury release from energy production. Alternative fuels include low-mercury coal, oil, natural gas, biomass and also to utilize wastes. Coal-bed gas (a type of natural gas that increasingly are extracted from the coal beds) may be used as a substitute for coal in energy generation, which will promote reduction of the emission of multiple atmospheric pollutants including mercury.

3.1.1.3 Flue gas mercury removal technique

These techniques remove mercury from the flue gas by the flue gas purification equipment. This includes technologies used to remove conventional air pollutants that also reduce mercury to some extent. In addition there exist a few technologies that specifically remove mercury.

Methods targeting the conventional air pollutants include:

(1) Electrostatic precipitator (ESP). The ESP technique removes particles form the flue gas and hence also the fraction of mercury attached to these particles. Typically about 25-30% of the mercury in the flue gas is removed with ESP[82]. ESP can handle a large amount of flue gas, can be used in situations with high-temperature, high-pressure, high-humidity and high-sulfur content, and is capable of continuous and automatic operation at a low cost. ESP is now used in most power plants.

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[81] Bromide is much more efficient than chloride.
[82] S X Wang, L Zhang, G H Li, et al. *Mercury Emission and Speciation of Coal-fired Power Plants in China*, Atmos. Chem. Phys., 2010: 10, 1183–1192.

(2) Fabric filter (FF). The fabric filter is also a particle removal control technology. Especially for smaller particles it is more efficient than ESP. As a considerable part of mercury may be bound to the smaller particles, the fabric filter has a larger mercury removal rate than ESP. However, FF is more demanding in terms of operation routine and cost compared to ESP and is not yet widely used in China.

(3) Flue gas desulfurization (FGD). The flue gas desulfurization facility is intended for reduction of SO_2 emissions. It absorbs water-soluble Hg^{2+} from the flue gas with limestone or lime adsorbents. Chinese data show that the combination of ESP and FGD typically removes 70% of the mercury in the flue gas[83].

(4) Denitrification facility. Denitrification techniques can be divided into selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) methods. Denitrification techniques can enhance mercury oxidation to improve the efficiency of mercury removal by the WFGD facility, and has good prospects for application.

Regarding methods targeting mercury specifically, there are mainly two technologies reasonable well established and in some full scale application worldwide:

(1) Bromides can be used for mercury control in various ways, including in sprays on coal before combustion, in flue gas additives such as HBr, and in sorbents injected at several points in the generation process[84]

Use of injected bromine powder active carbon adsorbents behind the boiler increases the efficiency of mercury removal from the flue gas. By injecting bromide powder active carbon before the ESP or FF device, the bromine in the active carbon reacts with and is absorbed by the mercury in the flue gas, and later removed by ESP or FF, and this technique can achieve a high mercury removal rate (>90%) in power plants equipped with ESP as the sole dust control device.

Use of bromine additives before the boiler increases the mercury removal efficiency of the WFGD device. Bromide solution is injected onto the coal transmission belt or into the stoker in the power plant, or directly injected into the boiler. The added bromide ions form bivalent mercury with the oxidized elementary mercury in the flue gas, and is removed by the desulfurization device. This technique is quite effective for coal power plants equipped with SCR and WFGD devices. It has good prospects as a low cost and efficient mercury removal technique for power plants.

(2) Adsorbent injection is a technique where mercury in the flue gas is absorbed using Adsorbents and removed downstream by the gas purification equipment. Adsorbents in use include active carbon, modified active carbon and calcium adsorbents, which can be sprayed before the dust remover, or behind the FGD and dust remover.

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[83] S X Wang, L Zhang, G H Li, et al. *Mercury Emission and Speciation of Coal-fired Power Plants in China*, Atmos. Chem. Phys., 2010: 10, 1183–1192.

[84] Power Engineering International. 01/04/2010. *Bromine Provides New Weapons to Combat Mercury Emissions*. http://www.powerengineeringint.com/articles/print/volume-19/issue-4/features/bromine-provides-new-weapons-to-combat-mercury-emissions.html (Accessed October 6, 2011)

In practical engineering applications, joint control techniques will be applied in addition to the existing flue gas purification facilities to control mercury emissions. The most widely used joint control techniques in modern power plants include ESP + FGD/WFGD + SCR/SNCR.

3.1.2 Costs of mercury emissions control in the coal-fired sectors

At present, it is uncommon for any country to invest solely in mercury specific technologies to reduce mercury emissions from coal fired power plants. Approaches and technologies for controlling conventional air pollutants, including particulate matter, SO_2, and NO_x, typically result in some reduction of mercury emissions as a co-benefit, as mentioned earlier in this chapter. In most countries, mercury controls are contingent upon controls for conventional pollutants, although the degree of the mercury capture by various technologies varies widely. In this context, the incremental cost of adding a mercury reduction effort to a national strategy is kept low by seeking co-benefits from the other pollution control efforts.

Table 6. Abatement Cost for Installations Used to Reduce Hg Emissions from Coal Combustion Processes[85]

Sector	Emission control technology	Hg reduction (%)	Annual costs (US$ 2008/MWhe)		
			Annual investment costs	Annual operating costs	Annual total costs
Hard and brown coal combustion	dry electrostatic precipitator (ESP) – medium emission control efficiency	24	0,45	0,90	1,35
	fabric filters (FF) – medium emission control efficiency	20	0,46	1,47	1,93
	dry ESP – retrofitted from medium to high control efficiency	32	0,92	0,52	1,44
	FF + wet or dry scrubbers + sorbent injection – state-of-the-art (BAT)	98	0,72	1,80	2,52
	dry ESP + wet or dry scrubber + dry injection –– state-of-the-art	98	2,73	2,40	5,13
	electro-catalytic oxidation – emerging method	80	8,55	11,76	20,31
	Integrated gasification combined cycle (IGCC) – emerging method	90			20,00

A major review of information on the costs of abatement for combustion of coal and other economic sectors was carried out within the EU ESPREME and DROPS projects[86]. The annualized investment and operational costs for installations that are used to remove mercury, including ESPs, FFs, FGD, and "add on" measures just for mercury removal are presented in Table 6. These costs are given in relation to the production of 1 MW electricity in utility and large industrial boilers. The information on efficiency of Hg removal using these installations is also included in Table 6.

[85] Selected technologies from the EU ESPREME project database (http://espreme.ier.uni-stuttgart.de)
[86] Selected technologies from the EU ESPREME project database (http://espreme.ier.uni-stuttgart.de).

3.1.3 Analysis and Conclusions

3.1.3.1 Pollution control techniques for mercury emission from coal combustion

In the US efforts to reduce coal mercury emissions have gone through three phases, those are

(1) Fundamental research phase (1995-2000).
(2) Technique demonstration and application phase (2000-2007).
(3) Technique promotion phase (2005-present).

This work led to an active carbon injection (ACI) technique that has now been commercialized. As of 2009 the active carbon injection system had been purchased or installed to remove mercury for 10% of boilers in the US[87].

This work led also to the boiler chemical addition **(**BCA) techniques that have now been commercialized. So far, the bromide-based BCA in particular has been purchased and commercially applied at several utility boilers (> 10 GW) in the USA. [88]

Other measures for reducing emissions of mercury from coal combustion adopted in developed countries can be summarized as follows:

(1) The replacement of coal with natural gas for power generation or the use of washed clean coal or low-mercury coal reduce mercury content in the fuels.

(2) Mercury emissions are reduced by the desulfurization, denitrification and dust removal facilities that are universally installed in coal power plants in developed countries. For example, in the US, cold side electrostatic precipitators (CS-ESP) have been installed in 80% of the power plants; both HS-ESP/CS-ESP and FF are used in 2/3 of coal power plants to control particles; in terms of denitrification, SCR units have been installed in 45% of coal power plants.

3.1.3.2 Prevention techniques for mercury emission from coal combustion in China

Due to the characteristics of China's energy structure, coal based power generation plays a dominant role in China. In order to reduce emissions of air pollution from coal based power generation, China has applied the following measures that also reduce mercury emissions:

(1) Promotion of clean coal that reduce mercury emissions at the very source. So far, the total

[87] X Liu, Y Jiang. *The Pollution Control Technology and its Development of Mercury from Coal Fired Power Plant in US*. High-Technology & Industrialization, 2009,3: 92-95
[88] T E Pearson, K. Sago. *Testing and Operating Results of the KNX^{TM} Technology at the Montana-Dakota Utilities Co. Lewis & Clark Station*. Air Quality (VIII) Conference, Arlington, VA, Oct. 2011 and M.S. Berry et al. *Bromine Injection Technology Demonstrations at Plant Miller for Removing Vapor Phase Mercury*, 12th International Conference of Electrostatic Precipitation, May 9- 13, 2011, Nuremberg (Germany) http://www.google.de/search?q=Berry%20Vosteen%20Bromine&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla:de:official&client=firefox-a&source=hp&channel=np

washing rate of raw coal has reached 43%, and that of coal used for industrial boilers and coal-fired electricity generation has reached 20%[89]. It is planned that the washing rate of raw coal reach 80% at the end of the Twelfth Five-Year Plan period.

(2) Regular air pollution control techniques also contribute to reduction of mercury emissions. By the end of 2008, in terms of particle control, 96% of coal fired power plants in China had been equipped with ESP, and about 3% had been equipped with FF; in terms of SO_2 control, the WFGD desulfurization facilities had been installed in 60% of power plants, of which 91% had used the limestone/plaster wet flue gas desulfurization technique, 3% had used seawater wet FGD, 3% had applied recycling fluidized bed FGD and another 3% had used other techniques; in terms of denitrification, over 3% of baseline coal power plants had installed denitrification devices, most of them SCR units. Involving low investment and operation costs, the low-nitrogen burning technique has been widely applied in baseline coal power plants in China.

When using the multi-pollutant approach in the coal-fired power plant sector to reduce mercury emissions, it is important to have proper management, use and disposal of the solid waste from the power generation. Mercury trapped from the flue gas will end up in different compartments of solid waste that may be used for instance in the cement industry. It is important to avoid re-emission from such industries.

3.1.3.3 Need to develop and apply specific mercury removal techniques

In the coal fired power generation sector desulfurization, denitrification and dust removal facilities are in the process of being installed in coal fired power plants in China. However techniques dedicated to mercury removal are not yet used in China to any significant extent. This gap needs to be done considering that the domination of coal in the energy structure makes the coal fired industry the greatest source of anthropogenic mercury emissions in China.

3.2 Mercury Emission Reduction Technology in Non-ferrous Metal Smelting Industry

Most of non-ferrous metal ores exist as sulfides, often associated with trace amounts of mercury. The smelting process thus generates not only a large amount of SO_2 but also high levels of mercury in the flue gas.

3.2.1 Mercury Pollution Control Technology of Non-ferrous Metal Industry

The lead and zinc smelting processes are considered as example to introduce current domestic flue gas mercury treatment technologies for the metallurgical industry.

Thermal processes generate most of the Hg emissions. Usually 10 – 30% of Hg in off-gas can be removed by particulate matter control facilities (dry and wet ESP) and the rest (90%) ends up in sulphuric acid plant (Table 7),. However, as most small smelters don't have an acid plant the emissions from these plants are high.

[89] *Coal-fired Industry 12th 5-Year Plan*. http://wenku.baidu.com/view/0af3a6d97f1922791688e8ec.html

The Hg contaminated acid cannot be used in any industry or products where there is the potential for the Hg to enter the food chain. Therefore, it is desirable to remove the Hg from the acid. Many different processes have been developed specifically to deal with the Hg problem. The Hg can be treated while it is in the off-gases (gas phase) or after it has entered the acid (liquid phase).

The removal of Hg as far upstream in the process as possible is desirable in order to minimize the chance of it entering the final acid product. If Hg is not removed from the gas stream before entering the drying tower it will end in the acid and then it is necessary to remove the Hg from the liquid phase. The basic principle of Hg removal by all methods is to use a reagent to react with Hg to form a product that can precipitate out of gas or liquid phase. Table 7 lists all the current available techniques to remove Hg from off-gas. The Boliden Norzink Process and Outokumpu Bolkem Process are the most widely used Hg removal methods. The other Hg removal methods have very few full-scale applications.

Table 7. List of Hg Removal Methods[90]

	Hg removal Method	Reactions
Gas Phase Removal	Boliden-Norzink Process	$HgCl_2 + Hg \rightarrow Hg_2Cl_2 \downarrow$
	Outokumpu process/ Bolkem process	$Hg + H_2SO_4 \rightarrow ½O_2 + HgSO_4 \downarrow + H_2O$ $HgSO_4 + Hg \rightarrow Hg_2SO_4$ $Hg_2SO_4 + ½O2 + H_2SO_4 \rightarrow 2HgSO_4 \downarrow + H_2O$
	Selenium filter/ Selenium scrubber	$H_2SeO_3 + H_2O + 2SO_2 \rightarrow Se + 2H_2SO_4$ $Se + Hg \rightarrow HgSe$
	Carbon Filter	For the adsorption of Hg, activated carbon can normally adsorb 10-12% of its own weight.
	Sulphide precipitation - gas phase	$2H_2S + SO_2 \rightarrow 3S + 2H_2O$ $S + Hg \rightarrow HgS \downarrow$ $H_2S + Hg \rightarrow HgS \downarrow + H_2$
Liquid Phase Removal	Sulphide precipitation - liquid phase	$Hg + H_2SO_4 + Na_2S_2O_3 \rightarrow HgS \downarrow + Na_2SO_4 + H_2O$
	Molecular recognition technology (MRT)	The MRT process is able to effectively and selectively separate specific individual metal species
	Toho Process	$Hg^{2+} + 2I^- \rightarrow HgI_2 \downarrow$ $2KI + 2H_2SO_4 \rightarrow I_2 + 2KHSO_4 + SO_2 + 2H_2O$ $I_2 + I \rightarrow I^{3-}$ $Hg^{2+} + 2I^{3-} \rightarrow HgI_2 \downarrow + 2I_2$

[90] DKL Engineering. 2009. Acid Plant Database [online]. http://www.sulphuric-acid.com/Sulphuric-Acid-on-the-Web/Acid%20Plants/Acid-Plant-Database-Home.htm [accessed 27. January 2011].

The Boliden Norzink process developed in 1972 is the most popular method for removing Hg from the gas phase. The process is based on the oxidation of Hg vapour by mercuric chloride to form mercurous chloride (calomel). A solution of mercuric chloride containing certain mg/l $HgCl_2$ is circulated over a packed tower. The process gas containing Hg passes through the packing where the Hg reacts with mercuric chloride to form mercurous chloride. Mercurous chloride is insoluble and precipitates out of the solution.

The Outokumpu and Bolkem processes are used by several plants to convert the elemental Hg in the gas into mercuric sulphate. The off-gas is scrubbed with H_2SO_4 at a certain temperature depending on which process is used. The acid is recirculated until the solution becomes saturated with $HgSO_4$ and precipitation begins. The crystals of $HgSO_4$ are then separated in a thickener. Hg can be recovered by mixing the solids with calcium oxide, and then heating to distill away the Hg.

Outotec developed a revolutionary direct leaching technique. This atmospheric leaching process eliminates the conventional roasting phase in zinc processing and thus greatly reduces the Hg emissions generated in conventional roasting process. The process is already used in Boliden's Kokkola zinc plant in Finland, Odda zinc plant in Norway and Zhuzhou Smelter in China (Lahtinen et al., 2008).

3.2.2 Analysis and Conclusions

There are many medium and small-sized enterprises at different technical levels in metallurgical industry in China. The prevention and control of mercury pollutions is a challenge for the metallurgical industry of China as it rapidly develops while pollution prevention technologies remain relatively backward.

In terms of flue gas foreign non-ferrous smelting enterprises to a large extent use dedicated mercury removal techniques. Technologies are well established and commercially available

In China flue gas treatment mainly focuses on flue gas purification, industrial kiln and furnace renovation, energy conservation and smoke abatement. Advanced flue gas mercury removal technology, such as the Norzink-Boliden mercury removal technology is so far only installed in three production lines in China. Traditional smelting processes in use, such as lead smelting by sintering pot-blast furnace, haven’t adopted any control measures. Waste acid mercury removal processes and methods to recover mercury from waste are also in the stage of development..

3.3 Mercury Emission Reduction in Production of Vinyl Chloride Monomer (VCM) and Chlor-alkali

Two processes, the acetylene method and the ethylene method, are used to produce Polyvinyl chloride (PVC):

(1) Acetylene method: The main raw materials are calcium carbide, coal and raw salt. Mercuric chloride catalyst is taken as the catalyst in production;

(2) Ethylene method: The main raw material is oil.

Production outside of China is by the ethylene method while the acetylene method is widely used in China due to the abundance of coal and lack of oil and gas in some regions.

Mercury waste from PVC production using the acetylene method is found in 1) Waste catalyst (containing $HgCl_2$), 2) Catalyst wastewater (containing $HgCl_2$), 3) Spent activated carbon from mercury removal devices (containing mercury and $HgCl_2$), 4) Waste water from mercury removal devices (containing mercury and $HgCl_2$), 5) Waste acid containing mercury, 6) Alkali waste containing mercury, 7) Sublimated mercury entering the compression distillation system with VCM gas. The bulk part of the mercury ends up in the waste catalyst and the waste acid. Good mass balance estimates for the mercury flows in the VCM industry are not readily available.

3.3.1 Mercury Control Options for China's PVC Industry

Four different options are available for reducing the mercury pollution from the Chinese VCM industry:

> (1) Low-mercury catalyst: This will reduce the overall mercury use in the sector, but still requires a closed circuit in order to ensure no loss of Hg to the environment.
> (2) Develop and use a mercury free catalyst.
> (3) Switch from coal to oil or gas as feed stock (require no mercury catalyst).
> (4) Closed circuit using the standard mercury containing catalyst (i.e. ensure that no mercury is lost to the environment during the entire process and recycle all mercury entering the process).

(1) Low-mercury catalysts

In the standard low-mercury catalyst mercuric chloride ($HgCl_2$) is adsorbed on a special kind of activated carbon. This catalyst is supposed to have a higher mercury utilization rate and lower mercury sublimation rate than the traditional mercury catalyst. In 2008, the total quantity of low-mercury catalyst consumption accounted for 12% of that used in the whole industry. It has been claimed that this method has the potential to replace the traditional high-mercury catalyst without changing the production process and equipment. There are however challenges with the practical use of the catalyst.

An alternative low mercury catalyst is the molecular sieve-supported mercury catalyst. Here, molecular sieves are used instead of activated carbon as a carrier for the mercury. In the process of application of this technology, mercuric chloride does not sublime along with the increased temperature. Currently there are problems related to the use of this method in existing reactors.

Fluidized Bed Reactors (FBR) are another low-mercury alternative. This Technology generates vinyl chloride by means of a reaction of acetylene and hydrogen chloride in the

FBR. It can effectively improve the conversion rate of vinyl chloride, and avoid the volatilization loss of mercury chloride ($HgCl_2$) and hence mercury loss in the process.

(2) Mercury-free catalyst

Research currently underway on alternative mercury free catalysts was reported at an industry workshop organized in Beijing by UNEP in September 2011. There it was reported that a noble metals based catalyst is currently being tested at pilot scale in China. The developers of the catalyst offered preliminary estimates that the cost may about twice of the standard mercury based catalyst, i.e. about 2% of the total cost of PVC instead of 1% for the mercury catalyst. This was considered affordable by the industry participants who were present. Since the new catalyst is based on an expensive noble metal, careful recycling will be necessary.

(3) Feedstock change

The technology for producing VCM from oil and gas rather than coal is readily available. The challenge of shifting away from coal as feed stock in China is related to costs and availability of oil and gas (especially inland) rather than the availability of the necessary technologies. The costs and benefits of changing from coal as feedstock have not been calculated, but when taking into account the reduced energy use, environmental and occupation health benefits and other factors, feed stock shift may be beneficial for the society overall.

3.3.2 Analysis and Conclusions

The process of PVC production by the acetylene method requires large energy consumption, creates serious pollution and is characterized by distributed and small scale operations. Low-mercury catalyst alternatives and auxiliary technologies have not been widely applied in China, and mercury-free catalyst alternatives and auxiliary technologies are under development, albeit with some promising prospects. As a result, large amounts of waste mercury catalysts, mercury-containing active coal, mercury-containing HCl and mercury-containing alkaline agents are still generated during PVC production with limited recycling for technical and economic reasons. The results are serious environmental and health risks.

3.4 Mercury Pollution Control of Mercury-containing Wastes

Mercury-containing wastes mainly come from industrial manufacturing, solid wastes, medical wastes and other areas. Mercury-containing wastes from industrial manufacturing include waste mercury catalysts generated in PVC production and mercury-containing salt slurry discharged by the alkali industry; mercury in solid waste mainly comes from waste fluorescent lamps, thermometers and mercury-containing batteries. Mercury in medical waste mainly comes from the mercury sphygmomanometer, mercury thermometers, dental amalgam, some traditional Chinese medicines and laboratory reagents.

3.4.1 Mercury Pollution Control Technology of Mercury-containing Waste

3.4.1.1 Pollution control technology for mercury-containing wastes in developed countries

Many techniques are available. While an exhaustive review is beyond the scope of this document, the SPS Project Team has assembled considerable information for reference by Chinese authorities.

Solid Waste

According to the US Environmental Protection Agency, solid waste containing mercury in low concentrations (less than 260mg/kg) should be treated by extraction, or solidification technology, and that in high concentration (more than 260mg/kg) should be treated by hot fix (such as roasting/distillation), solidification/stabilization technology[91].

Mercury Stocks

To avoid the risks and potential pollution in the future as a result if sale and distribution of mercury in the global market, Sweden has adopted a strategy to treat mercury in a safe and environmental-friendly method instead of recycling it.

Used fluorescent lamps

Developed countries treat disused fluorescent lamps mainly by one of the following method: wet method, high temperature gasification, shredding directly and incisal edge purging for separation.

Mercury-containing waste batteries

For mercury-containing batteries there are mainly two types of treatment methods prevailing internationally: curing buried, and recycling. The technology of the latter is subdivided into heat treatment technology, wet treatment technology, and vacuum heat treatment technology.

Prevention technology for waste incineration mercury

There are some control technologies to prevent mercury emissions from the incineration of urban garbage and hazardous wastes. However, some advocate the separate collection and treatment of mercury-containing wastes and this may be the most effective measure for limiting the mercury emission.

[91] X Zhang, Q Wang. *Recent Advances in Stabilization/Solidification Technology for Treatment of Hg-containing Hazardous Wastes.* Environmental Science & Technology. 2009, 9: 110-115.

3.4.1.2 Domestic pollution prevention and control technology of mercury-containing wastes

(1) Waste mercury catalyst treatment technology[92]

1) Take waste mercury catalyst as raw material to recover the secondary mercury by pyrometallurgy

Take chemical pre-treatment to waste mercury catalyst to convert $HgCl_2$ into HgO, then put it into metal tank. The mercury evaporation is separated after heating, and the metal mercury is recycled after condensation.

2) Take waste mercury catalyst as raw material to chemically activate, recycle, and produce "secondary mercury catalyst"

There are several schemes in regeneration of waste mercury catalyst, in which two are typically represented. The first scheme is to separate the mercury-containing compounds and volatile components from the waste catalyst, then reactivate the remaining activated carbon to reach the purpose of regeneration of activated carbon. The second scheme is to use chemical method to reactivate the activated carbon and remove the carbon deposit and avoid catalyst poisoning on condition that the activated carbon and mercury chloride in the waste mercury catalyst, etc. will not be separated. Then add the right amount of additives and active substance mercury chloride to realize regeneration. Currently the above two schemes are under research and development stage.

3) Technology to recycle $HgCl_2$ and activated carbon existing in waste catalyst using dry distillation with controlled oxygen flow

This technology achieves the simultaneous recycling of $HgCl_2$ and activated carbon by carbonization, in line with the principle that high-temperature sublimation of $HgCl_2$ and its sublimation temperature is lower than the coking temperature of activated carbon, in the environment of negative pressure closure and inert gas atmosphere. This process can not only achieve the comprehensive utilization of resources of mercuric chloride and activated carbon, but also effectively prevent the loss of mercury in recycling process, thus enhancing the recovery rate of mercury chloride from around 75% to 99.8%.

(2) Treatment technology for mercury-containing salt slurry

1) Oxidized melt extrusion method

Oxidized melt extrusion method is to add mercury-containing slurry with saturated brine and react under the temperature of 50~55℃ and pH value of 11~12 for 40-50 min. The unsolvable mercury is then converted into soluble mercury, add the filtered clear brine into refined brine, and the metal mercury is reverted on the cathode of electrolytic tank. The treated mercury content in the salt slurry is about 100 mg/kg.

[92] *Mercury Prevention and Control Planning in the VCM Industry*. CPCIF (China Petroleum and Chemical Industry Federation), CCAIA (China Chlor-Alkali Industry Association). http://wenku.baidu.com/view/4188021ba8114431b90dd883.html

2) Chlorination – sulfuration - roasting method

Chlorination – sulfuration - roasting method is to add the salt leached chlorhydric acid into the mercury-containing slurry, and then add chlorine gas to convert the sedimentary mercury into soluble mercury compound. Sodium sulfite shall be used to remove the free chlorine from the deposited and separated clear liquid. Add sodium sulfide to convert mercury ion into mercuric sulfide, which is roasted in the roaster to evaporate mercury, and the metal mercury is acquired after cooling and recycling.

(3) Disused fluorescent lamp recycling technology

The Chinese government is actively planning the recycling of waste tubes and bulbs. At present, the recycling for disused fluorescent tubes in China mainly falls into two processes: shredding directly for separation and incisal edge purging for separation. The former features compact structure, small floor space and investment, but the phosphor cannot be used. In China, the phosphor used by straight fluorescent tube mainly consists of calcium halophosphate with low recovery value, so it is appropriate to adopt the process of shredding directly for separation. And the latter can effectively collect the rare earth phosphor by its category to facilitate the recovery and reuse, but it needs large investment. Energy saving lamps mostly adopt the rare earth phosphor raw materials with high lighting efficiency, and because of the high availability of rare earth, it is appropriate to adopt the process of incisal edge purging for separation.

(4) Disused battery recycling technology

Aiming at the recovery of mercury-containing battery, China has developed a technical system including manual sorting, dry recovery, wet recovery and dry-wet recovery. But due to the limitation of regional economic development level and the collection system for recycling the waste batteries, the demonstration projects and pilot projects for the recycling of disused batteries have now been established only in economically developed regions. But corresponding industrial standards and uniform supervision and control system are still not sufficient.

3.4.2 Economic Analysis of Mercury Emissions in Mercury-containing Wastes

The investment and maintenance costs of waste landfill are relatively low, so landfill prevention and control can be implemented to restrict the mercury emission. This is also beneficial to the management of other hazardous wastes.

3.4.3 Analysis and Conclusions

Mercury-containing waste varies by source from area to area. The amount reflects life styles, and the level of economic development, and varies from source to source. While there are large mercury emissions from industrial sources, mercury-containing products from other sources should also be properly managed through recycling programs to prevent mercury releases. In recent years, people are more and more concerned about mercury and other

pollutants from the disposal of electronic equipment as the use of electronic equipment and the resulting waste streams continue to grow.

3.5 Remediation and Management of Mercury Contaminated Sites in China

3.5.1 Remediation of Mercury Contaminated Sites in Abroad

Remediation of contaminated sites can be categorized as three groups: 1) restriction the use of contaminated sites; 2) removing contaminated soils from the sites; and 3) remediation of contaminated sites.

Traditionally, the most popular method has been to remove contaminated soils from the sites and cap the un-contaminated soils. However, the application of this method involves high capital costs and operational expenses. Moreover, it can only be used to treat contaminated soils which are concentrated, and requires some solution for disposal of the contaminated soil.

In general, the remediation of contaminated soils includes processes through which the pollutants can be removed, stabilized or transformed to less toxic species. The remediation of mercury contaminated soils can be done by a number of means: stabilization/solidification (S/S), soil washing, thermal desorption, electroremediation, nanotechnology and phytoremediation.

3.5.1.1 Stabilization/solidification (S/S)

S/S involves physically binding or enclosing contaminants within a stabilized mass (solidification) or inducing chemical reactions between the stabilizing agent and the contaminants to reduce their mobility (stabilization) [93]. Soil can be treated both in situ and ex situ. The binders such as Portland cement, sulfur polymer cement (SPC), sulfide and phosphate binders, cement kiln dust, polyester resins, polysiloxane, powder reactivated carbon[94] (PAC), thiol-functionalized zeolite (TFZ) were used to stabilize mercury[95] .

The S/S technique can be used to treat mercury at various depths[96]. The drawbacks of the method were described as follows: (1) the metals are not removed from contaminated media; (2) questionable longevity of the solidified/stabilized materials; and (3) the need for future monitoring of heavy metals on site[97].

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[93] USEPA, 2007. *Treatment Technologies for Mercury in Soil, Waste and Water*. EPA-542-R-07-003.
[94] J Zhang, PL Bishop, *Stabilization/Solidification (S/S) of Mercury-containing Wastes using Reactivated Carbon and Portland Cement*. Journal of Hazardous Materials. 2002, 92(2), 199-212.
[95]XY Zhang, QC Wang, SQ Zhang, et al, *Stabilization/Solidification (S/S) of Mercury-contaminated Hazardous Wastes using Thiol-functionalized Zeolite and Portland Cement*. Journal of Hazardous Materials. 2009, 168(2-3), 1575-1580.
[96] USEPA, 2007. *Treatment Technologies for Mercury in Soil, Waste and Water*. EPA-542-R-07-003.
[97] G Dermont, M Bergeron, G Mercier, et al. *Soil Washing for Metal Removal: A Review of Physical/Chemical Technologies and Field Applications*. Journal of Hazardous Materials. 2008, 152(1), 1-31.

3.5.1.2 Soil washing

Soil washing refers to ex situ techniques that employ physical and/or chemical procedures to extract metals contaminants from soils. The processes including: 1) physical separation; 2) chemical extraction; or 3) a combination of both. Physical separation concentrates metal contaminants into a smaller volume of soil by exploiting differences in certain physical characteristics between the metal bearing particles and soil particles such as size, density, magnetism etc. Chemical extraction relates to techniques that try to solubilize the metal contaminants from the soil with an extracting aqueous fluid containing chemical reagents. The diluted acid, thiosulfate, EDTA, iodide and HNO3 had been tested for extracting mercury from soils[98]. Among these extractants, iodide, EDTA, and thiosulfate were found to be effective to remove mercury from soil with an efficiency at 30%. In addition, a mixture of 100 mM KI + 50 mM HCl (pH = 1.5) could remove nearly 77% mercury from soil[99]. The advantages of the method include that: (1) the processed soil can be returned to the site; (2) the process duration is typically short to medium-term compared to other metal extraction methods. The disadvantages of the method could be that: (1) the vast consumption of water required for making up the washing solution, and of clean water for the removal of the mobilized metallic species that have been retained in the soil after the remedial treatment; (2) The washing solution is rich with metal–chelant complexes, and must subsequently be treated before it can be safely discharged.

3.5.1.3 Thermal desorption

Thermal treatment usually involves application of heat and reduced pressure to volatilize mercury from the contaminated medium, followed by conversion of the mercury vapors into liquid elemental mercury by condensation[100]. The liquid elemental mercury collected from the condenser units can be reused or further treated. The soil types, organic contents, particle size, moisture content, amount of mercury in waste, operating temperature and pressure were the main factors that can affect the performance and capital cost of the technology. Obviously, the high efficiency removals of mercury were obtained with the operation conditions at relatively high temperature.

There are many advantages of this method, such as safety and less emission of treating substance as compared with other process[101,102]. However, the major disadvantages are high energy costs and effectiveness only at rather high mercury concentrations[103].

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[98] J Subires-Munoz, A Garcia-Rubio, C Vereda-Alonso, et al. *Feasibility Study of the Use of Different Extractant Agents in the Remediation of a Mercury Contaminated Soil from Almaden. Separation and Purification Technology*, 2011, doi:10.1016/j.seppur.2011.01.032.

[99] S Wasay, P Arnfalk, SR Tokunaga, *Remediation of a Soil Polluted by Mercury with Acidic Potassium Iodide*. Journal of Hazardous Materials . 1995, 44(1), 93-102.

[100] USEPA, 2007. *Treatment Technologies for Mercury in Soil, Waste and Water*. EPA-542-R-07-003.

[101] C. George, *Evaluation of Steam as a Sweep Gas in Low Temperature Thermal Desorption Processes used for Contaminated Soil Clean Up*, Elsevier, 1997.

[102] A Navarro, I Ca Adas, D Martinez, et al. *Application of Solar Thermal Desorption to Remediation of Mercury-contaminated Soils*. Solar Energy. 2009, 83(8), 1405-1414.

[103] R Kucharski, U Zielonka, A Sas-Nowosielska, et al. *A Method of Mercury Removal from Topsoil Using Low-thermal Application*. Environmental Monitoring and Assessment. 2005, 104(1), 341-351.

3.5.1.4 Electroremediation

The goal of electrokinetic remediation is to affect the migration of subsurface contaminants in an imposed electric field via electroosmosis, electromigration, and/or electrophoresis processes. During electrokinetic soil treatment, hydrogen ions (H^+) are generated at the anode due to water electrolysis, and migrate into the bulk of the soil (1) , (2). A low pH develops through the soil (except at the cathode where OH^- is generated), causing desorption of metallic contaminants from the soil solid phases. The dissolved metallic ions are then removed from the soil solution by ionic migration and precipitation at the cathode.

$$\text{At the anode: } 2H_2O \rightarrow O_2(g) + 4H^+ + 4e^- \quad (1)$$

$$\text{At the cathode: } 4H_2O + 4e^- \rightarrow 2H_2(g) + 4OH^- \quad (2)$$

The electroremediation efficiency is greatly affected by the soil properties, such as pH, carbonates and organic matters[104,105].

One of the most important advantages of the electrokinetic technique is its efficacy for the treatment of low hydraulic permeability soils. The major disadvantages of this method include: 1) time-consuming; 2) interfering of the results by non-target ions[106].

3.5.1.5 Nanotechnology

Nanotechnology involves using particles with dimensions in the range of 1–100 nanometers, to affect the mobility, toxicity and/or bioavailability of contaminants in soils. Nano-sized particles are characterized by a large surface area to volume ratio, which speeds up sorption kinetics[107]. Xiong et al[108] showed that the treatment of mercury contaminated substrate with FeS nanoparticles at a molar ratio of 26.5 (FeS-to-Hg), the Hg concentration leached into water was reduced by 97%. The major advantages of this method were safety, low cost, environmentally friendly, low energy demand, stable, as well as treating on site. However, the effect of nanoparticle on soil microorganisms was still yet to be investigated and the method should be tested in the field conditions.

3.5.1.6 Phytoremediation

(1) Phytoextraction

Phytoextraction is the use of plant to remove pollutants from the soil. The pollutants are

[104] KR Reddy, C. Chaparro, R.E. Saichek, *Removal of Mercury from Clayey Soils Using Electrokinetics*. Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering, 2003: 307-338.
[105] Z Shen, J Zhang, L Qu, et al, *A Modified EK Method with an I-/I 2 Lixiviant Assisted and Approaching Cathodes to Remedy Mercury Contaminated Field Soils*. Environmental Geology, 2009, 57(6), 1399-1407.
[106] J Virkutyte, M Sillanp, P Latostenmaa, *Electrokinetic Soil Remediation--critical Overview*. The Science of The Total Environment, 2002, 289(1-3), 97-121.
[107] E Cabrejo, E Phillips, D Mentor, et al, *In Situ Remediation and Stabilization Technologies for Mercury in Clay Soils*. Student summer internship technical report, 2010..
[108] Z Xiong, F He, D Zhao, MO Barnett, *Immobilization of Mercury in Sediment using Stabilized Iron Sulfide Nanoparticles*. Water Research, 2009, 43(20), 5171-5179.

absorbed by the roots and transported to the aboveground tissues of the plant. Then the pollutants were removed by harvesting the aboveground tissues. However, no plant species have been identified as mercury hyperaccumulators, thus the phytoextraction efficiency is limited.

(2) Phytovolatilization

Of the known bacterial heavy metal resistance systems, the Mer (mercuric ion resistance) determinant unique in terms of the orientation of the metal transporter it encodes. The mercuric reductase, which is encoded by the MerA gene could reduce mercuric ions (Hg^{2+}) to less toxic and volatile elemental mercury(3). Another important enzyme is organomercurial lyase (MerB), which catalyzes the protonolysis of the carbon-mercury bond. The products of this reaction are a less toxic inorganic species and a reduced carbon compound (4).

$$Hg^{2+} \xrightarrow{MerA} Hg^{0} \qquad (3)$$

$$R-CH_2-Hg^{+}+H^{+} \xrightarrow{MerB} R-CH_3+Hg^{2+} \qquad (4)$$

The plants *Arabidopsis thaliana, Liriodendron tulipifera, Arachis hypogaea, Populus deltoides, Oryza sativa, Spartina alterniflora* and *Chlorophyta* were integrated with MerA gene, and could resistant to high levels mercury[109]. However, the MerA modified plant fail to protect against the more toxic and environmentally relevant organic-Hg, and cause public anxiety due to the volatilization of mercury[110]. Therefore, on the one hand, both MerA and MerB genes are needed to protect cells from organic-Hg. MerA and MerB modified Arabidopsis thaliana could resist up to 5 mM PMA and 10 mM CH_3Hg[111].

3.5.2 Analysis and Conclusions

As remediation measures are costly, a risk-based approach should be adopted in accordance with the recommendations of a 2010 CCICED Special Policy Study on Soil Environmental Protection in China. This would involve selecting sites for remediation by giving priority to those posing the greatest risks to human health and the environment. Supporting measures would include establishing a transparent National Public Registry of mercury-related contaminated sites; establishing a government-wide legislative structure for the management of both current and legacy contaminated sites, including a financial mechanism to support the decommissioning and remediation of priority sites; supporting the creation/emergence of a domestic industrial sector capable of providing the various remediation requirements; and establishing a long term monitoring system at mercury-contaminated sites to protect public health and the environment.

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[109] M Czako, X Feng, Y He, et al, *Transgenic Spartina Alterniflora for Phytoremediation*. Environmental Geochemistry and Health. 2006, 28(1), 103-110.

[110] ON Ruiz, H Daniell, *Genetic Engineering to Enhance Mercury Phytoremediation*. Current Opinion in Biotechnology, 2009, 20(2), 213-219.

[111] SP Bizily, CL Rugh, RB Meagher, *Phytoremediation of Hazardous Organomercurials by Genetically Engineered Plants*. Nature Biotechnology. 2000,18(2).

4. INTERNATIONAL EXPERIENCE IN MANAGEMENT OF MERCURY POLLUTION

Developed countries have demonstrated that significant reductions can be made in mercury emissions from human activities without damaging their economies. They have used a wide range of strategies and approaches adapted to the particular circumstances of different industries that release or consume mercury.

4.1 Mercury Pollution Prevention and Control at the International Level

In 2002, the United Nations Environment Programme (UNEP) through its "Global Mercury Assessment Report"[112], described widespread mercury pollution in the environment and the resulting threats to human and animal health. In 2003, the 22nd Session of UNEP Governing Council considered the "Global Mercury Assessment Report", and the need for joint actions to address the mercury problem. The international community then discussed the merits of voluntary measures and international legally binding instruments to address the mercury issue. In the 25th Session of UNEP Governing Council in 2009, all parties reached a consensus on developing a separate mercury convention and initiated negotiations toward a legally binding international instrument on the mercury issue (referred to as Mercury Convention), to be concluded in early 2013. The first meeting of Intergovernmental Negotiating Committee was successfully held from June 7 to June 11 2010 in Stockholm, Sweden. International negotiations are currently underway to address the structure, substantive provisions, financial mechanism, technology transfer and assistance, as well as a compliance mechanism for the Mercury Convention. The substantive provisions are expected to address mercury supply, demand, trade, mercury-containing waste, contaminated site restoration, unintentional emissions and other topics. As the largest developing country and the largest mercury producer and discharger, China is an active participant in this above work.

With regards to the prevention and control of mercury pollution, UNEP has identified several priority areas including:

- technologies and approaches for prevention and control of mercury pollution (e.g., storage and disposal technologies and management measures for mercury-containing waste and mercury-containing compounds);
- reduction of the global mercury demands and usage (e.g., consideration of limiting original ore production and actively promoting the classifications of supply sources);
- promotion of control and restoration of existing mercury-contaminated sites; and
- popularization of the knowledge of the hazards of mercury on human health and the environment, and
- the management and disposal of mercury.

International collaboration on scientific and technological research and the sharing of results has been promoted since 1990 through a series of International Conferences on Mercury as a Global Pollutant (ICMGP). Its regular meetings have been held every 2-3 years, with the number of participants having increased from over one hundred in the beginning to over one

[112] http://www.chem.unep.ch/mercury/report/1stdraft-report-25April.pdf

thousand now.

Several international actions on pollution prevention also includes measures on mercury releases. Although not targeting mercury specifically important aspects related to mercury are included. Some of these international conventions/agreements are:

- *Convention on Long-Range Transboundary Air Pollution, covering* Europe, the United States and Canada.
- *Helsinki Convention, on protecting the Baltic sea.*
- *Basel Convention*, on transboundary movement of hazardous waste and their disposal.
- *Waigani Convention* (Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Waste and to Control the Transboundary Movement and Management of Hazardous Wastes within the South Pacific Region).
- *Convention for the Protection of the Marine Environment of the North-East Atlantic* (known as the "OSPAR Convention"), on the protection of the marine environment of the North-East Atlantic
- *Rotterdam Convention*, establishing requirements for prior informed consent to govern the import and export of hazardous chemicals/pesticides.

An analysis of the relevant provisions of these international conventions/agreements led to the following preliminary conclusions:

(1) The geographical scope of the agreements has gradually widened. Initially focused on North America and Europe, they have gradually expanded to other regions and now the the global level, requiring signatories to make joint efforts. In support of their obligations the participating countries need to gradually advance their awareness and understanding of mercury sources, environmental transport, environmental impacts and mitigation measures.

(2) Control objectives require more and more attention to assessment of environmental hazards and risks, as well as to research and application of the best available technology (BAT) to reduce the damage of mercury on human health and the human living environment.

(3) Control strategies are shifting from a focus on point sources to life-cycle management.

4.2 Experiences of Other Countries with Mercury Pollution Management

4.2.1 Management Strategies with Clear Emission Reduction Objectives

The **United States**, for example, developed emission reduction objectives for different industries (Box 1). With implementation of its most recent rule, the power plant industry will achieve a mercury emission reduction of 78% between the baseline year of 2005 and the target year of 2015.[113, 114]

[113] http://epa.gov/mercury/pdfs/FINAL-Mercury-Roadmap-6-29.pdf (Accessed: Sept.7/2011).
[114] http://www.federalregister.gov/articles/2011/05/03/2011-7237/national-emission-standards-for-hazardous-air-pollutants-from-coal--and-oil-fired-electric-utility (Accessed Sept. 7/2011).

Box 1. US Management of Mercury Polluting Industries

The United States has introduced a series of control measures to address mercury emissions. Mercury is managed primarily under the *Clean Air Act*, which regulates hazardous air pollutants through a series of regulations and standards, including National Emission Standards for Hazardous Air Pollutants (NESHAP) Rules.

Between 1990 and 2005, the US promoted mercury emission reductions through the control of large mercury emission sources, such as domestic garbage, hazardous waste, medical waste and chlor-alkali production.

For the subsequent 10 years, the US will focus on smaller sources and industrial uses that collectively contributed over 20% of the nation's mercury air releases in 1999[36]. Through such efforts, mercury emissions in the US decreased from 220 tons in 1990 to 113 tons in 1999 – a 45% reduction.

The recently proposed Power Plant Air Toxics (NESHAP) Rule listed in the Federal Register in May 2011 expects mercury emissions to be further reduced from the 2005 baseline of 53 tons to about 11 tons by 2015 – a 78% reduction.

From 1970 to 2010 **Canada** reduced its mercury emissions by 90% using a mixture of mandatory and other instruments (Figures 10 and 11)[115]. The suite of instruments included (1) plant closures, (2) regulations, (3) national emission standards adopted by the federal government and all Provinces and Territories (Canada-Wide Standards), (4) guidelines, (5) a voluntary 'Accelerated Reduction/Elimination of Toxics Program'[116], (6) environmental codes of practice, (7) mandatory pollution prevention plans, and (8) the creation of the National Pollution Release Inventory[117].

From a co-benefit perspective, the Government of Canada is currently moving forward with the development of regulations to reduce greenhouse gas (GHG) emissions from coal-fired electricity generation in Canada, to take effect July 1st, 2015[118]. These regulations are expected to reduce mercury emissions from the electrical power generation sector by about 40% by 2020 and 65% by 2030 compared with 2005 levels, and could reduce mercury emissions by up to 96% by 2050.

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[115] *Risk Management Strategy for Mercury.* Environment Canada and Health Canada. October 2010. http://www.ec.gc.ca/doc/mercure-mercury/1241/index_e.htm (Accessed August 30, 2011).
[116] http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=A2A7F1B4-599A-47C3-BF0E-F075B8211D91 (Accessed: Sept. 7/2011).
[117] http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1 (Accessed: Sept 7/2011).
[118] *Risk Management Strategy for Mercury*. Environment Canada and Health Canada. October 2010 http://www.ec.gc.ca/doc/mercure-mercury/1241/index_e.htm (Accessed August 30, 2011).

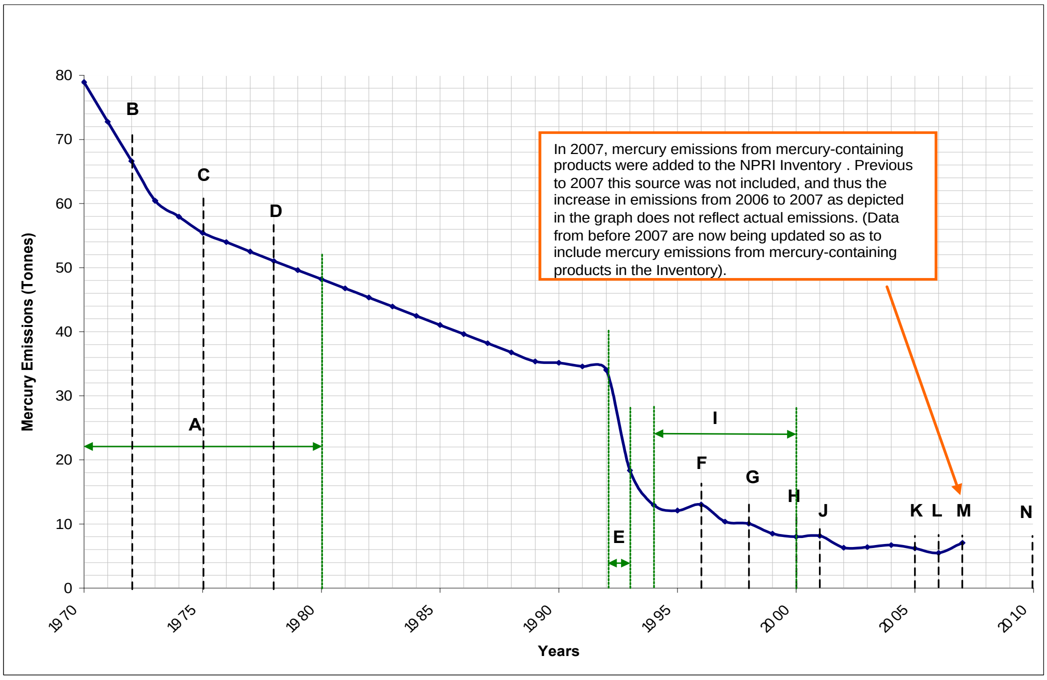

Figure 10. Canada's mercury emission have been reduced by 90% since the 1970's

A. 1970-1980: Closure of 10 of 15 mercury cell chlor-alkali facilities
B. 1972: Alkali Mercury Liquid Effluent Regulations
C. 1975: Closure of the Pinchi Lake primary mercury mine
D. 1978: Chlor-Alkali Mercury National Emissions Standards Regulations
E. 1992-1993: Process change by the Hudson Bay Mining & Smelting Co. facility in Flin Flon, Manitoba
F. 1996: National Guidelines for the Use of Hazardous and Non-Hazardous Wastes as Supplementary Fuels in Cement Kilns
G. 1998: National Emission Guideline for Cement Kilns; and mercury-based pesticide active ingredients no longer registered for use
H. 2000: Canada-wide Standards for Mercury Emissions from Incineration and Base Metal Smelting
I. 1994-2000: Accelerated Reduction/Elimination of Toxics program
J. 2001: Environmental Code of Practice for Integrated Steel Mills and Non-Integrated Steel Mills; and Canada-wide Standard for Mercury-Containing Lamps and Dental Amalgam Waste
K. 2005: Surface Coating Materials Regulations
L. 2006: Canada-wide Standards for Mercury Emissions from Coal-Fired Electric Power Generation Plants; Environmental Code of Practice for Base Metals Smelters and Refineries; and Pollution Prevention Plan for Base Metals Smelters and Refineries and Zinc Plants
M. 2007: Pollution Prevention Plan in Respect of Mercury Switches in End-of-Life Vehicles Processed in Steel Mills
N. 2010: Pollution Prevention Plans in Respect of Mercury Releases from Dental Amalgam Waste

Figure 10. Note use and impacts of plant closures, regulations, national emission standards (Canada Wide Standards), guidelines, a voluntary "Accelerated reduction/Elimination of Toxics Program", codes of practice, and mandatory pollution prevention plans. (Actions from 1970-2010)

Norway's efforts to minimize harm caused by hazardous substances include mercury. The national target is for releases and use of mercury and other substances that pose a serious threat to health or the environment to be continuously reduced with a view to eliminating them completely by 2020.

In 2008, Norway introduced a general ban on the use of mercury in new products, with only a few time-limited exceptions. The ban applies to the production, import, export and placing on the market of products containing mercury. The decision to introduce the ban was based on an overall evaluation of risks to people and the environment, and assessments of the availability of alternative products that do not contain mercury. The ban also applies to any new areas of use for mercury that may arise in the future. Norway was the first country to ban the use of mercury dental amalgam fillings. A summary of Norway's efforts in reducing and eliminating mercury pollution is available in English[119] and Chinese[120].

In 2005, the European Union launched a mercury strategy[121] containing 20 measures to reduce mercury emissions, cut supply and demand and protect against exposure, especially to methyl mercury found in fish. This strategy sits atop many specific EU regulations and directives established since 1990 to reduce the use and emissions of mercury to air and water. The strategy has resulted in restrictions on the sale of measuring devices containing mercury and a ban that came into force in 2011, on exports of mercury from the EU. New rules on safe storage will follow shortly. The EU's mercury strategy is a comprehensive plan addressing mercury pollution both in the EU and globally.

The EU reduced its mercury emissions by 67% between 1990 and 2009[122]. In 2009 the EU-27[123] had total mercury air emissions of 73 tonnes. The member states that contributed the most to these emissions were Poland, Spain, Italy, and the UK respectively, representing a total of 38 tonnes.

4.2.2 Collaborative Horizontal and Vertical Management

Due to the complexity and diversity of mercury pollution sources and impacts, prevention and control actions require collaboration amongst many institutions and interested parties. Multiple government agencies need to be engaged through several levels of jurisdiction, and several industry sectors have key roles to play in preventing and controlling mercury pollution. Citizens need to be engaged at the level of the general public but also as communities that may be at risk due to their location, occupation or susceptibility.

Horizontal Collaboration

Effective inter-agency collaboration requires the clear definition of roles and responsibilities

[119] http://www.klif.no/no/Publikasjoner/Publikasjoner/2010/Juni/Reducing-and-eliminating-mercury-pollution-in-Norway-The-mercury-problem
[120] http://www.klif.no/no/Publikasjoner/Publikasjoner/2011/Februar/Reducing-and-eliminating-mercury-pollution-in-Norway-pa-kinesisk
[121] *EU Community Strategy Concerning Mercury*. 28.01.2005. COM (2005) 20 Final. SEC (2005) 101. (Reviewed: Sept. 20/2011).
[122] *EU Emission Inventory Report 1990 - 2009*. EEA Technical Report No. 9/2011. (Reviewed: Sept. 20/2011).
[123] Twenty-seven member countries.

and the coordinated planning of operations and management. In most countries a lead Department assumes overall responsibility for environmental protection, while other departments contribute in accordance with their particular mandates (Box 2[124]).

Box 2. Division of Responsibilities Amongst Federal Departments in the USA

The **US Environmental Protection Agency** develops standards related to air, water and soil pollution and controls mercury emissions from pollution to reduce the environmental risks caused by mercury; the **US Food and Drug Administration** is mainly responsible for the management of mercury in cosmetics, food and dental products; the **Occupational Safety and Health Administration** is mainly responsible for the management of mercury exposure in the workplace.

In Canada, Health Canada, the Department of Indian and Northern Affairs (INAC), the Canadian Food Inspection Agency (CFIA), Fishery and Oceans Canada and Environment Canada all contribute to regulations and other measures to protect the health of Canadians and the environment.

Health Canada, in particular, has determined mercury intake standards not adversely affecting the health of the people. The requirements of Environment Canada include protection and enhancement of the quality of the natural environment, including the water, air and soil. INAC makes sure that the people in Northern Canada have a balanced understanding of the health hazards of eating traditional food with a higher mercury content while also appreciating the importance of these natural food sources. CFIA is responsible for handling the commercial inspection of fish products before they are sold in Canada. Fisheries and Oceans Canada is responsible for marine and inland fisheries. Provincial governments have responsibilities for monitoring and inspection, including random inspections on the fish in various types of lakes and rivers, analyzing the pollutants in randomly inspected fish, if necessary, publishing the fish consumption report and informing these reports of the public.

<u>Vertical Collaboration</u>

In large countries and federations such as China, particular attention is required to ensure coherence and coordination of efforts by the central and regional levels of governments. Consistent application and enforcement of national standards is often a challenge in such cases.

In the USA, addition the the requirements of US-EPA, there are regulations at the State levels for the prevention and control of mercury pollution.

In the case of Canada, both the federal and Provincial/Territorial governments have

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[124] All three accessed on Sept 7/2011.
http://www.fda.gov/food/foodsafety/product-specificinformation/seafood/foodbornepathogenscontaminants/methyl mercury/ucm115644.htm
http://www.epa.gov/hg/
http://www.osha.gov/SLTC/mercury/index.html

jurisdiction over environmental protection and thus there are both federal and provincial or territorial organizations that develop policies and provide inspection and enforcement services in their respective jurisdictions. Coordination of efforts is done both at operational levels and policy levels through the joint development of Canada-Wide Standards. Several Canada-Wide Standards played a role in the reduction of Canada's mercury emissions[125].

4.2.3 Effective Legislation and Innovative Regulatory Approaches

In managing mercury pollution, developed countries generally use broad empowering legislation for environmental protection under which regulations are developed to control mercury emissions and releases and to limit mercury uses and exposure to mercury.

These countries use a standard regulatory life cycle of the kind depicted in Figure 12. The early stages of the cycle include issue identification and analyses that draw upon environmental risk assessments, cost-benefit analyses, and other techniques for regulatory impact assessments to support decision making that balances social, environmental and economic values.

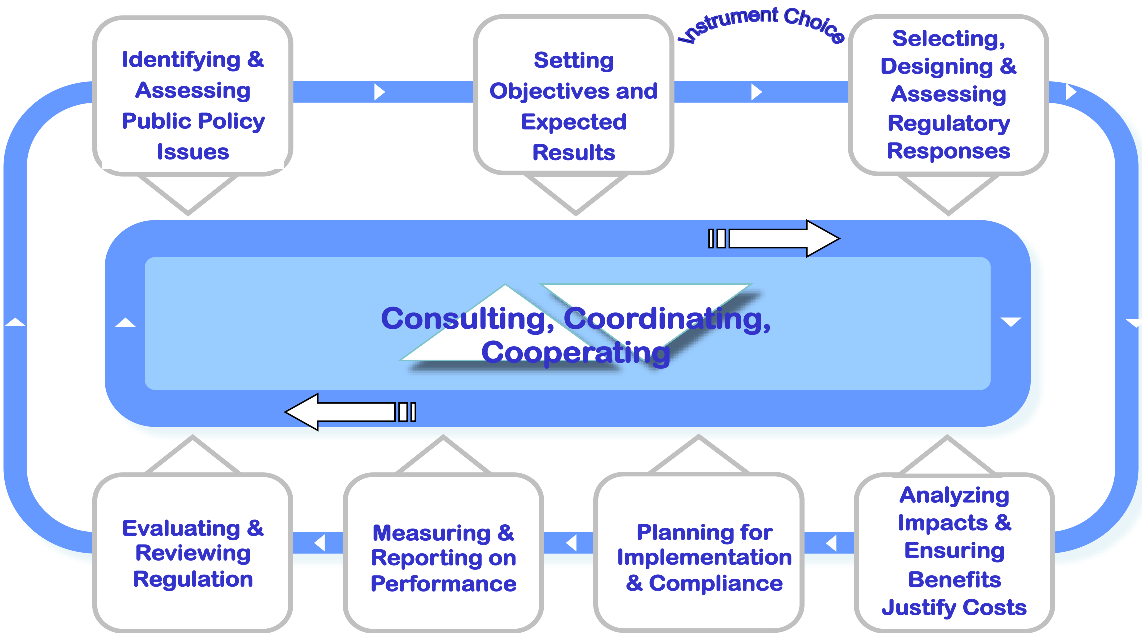

Figure 11. Lifecycle Approach to Laws and Regulations[126]

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[125] *Risk Management Strategy for Mercury*. Environment Canada and Health Canada. October, 2010 http://www.ec.gc.ca/doc/mercure-mercury/1241/index_e.htm (Accessed August 30, 2011).
[126] Figure 13 courtesy of Treasury Board of Canada Secretariat.

Box 3. Mercury Study Report to Congress: Overview 1997

A Mercury Study Report to Congress was prepared by the US-EPA. The Report provided a mix of strategies for the effective control of mercury emissions. The four major types of control techniques reviewed included: Pollution prevention measures, including product substitution, process modification and materials separation; Coal cleaning; Alternative approaches; and Flue gas treatment technologies. Additionally, the EPA provided the associated costs, the regulatory issues, and the financial impacts for a number of potentially affected industries if the proposal was to be successful.

Box 3[127] describes important work by US-EPA on the early stages of this cycle.

Instruments ranging from mandatory to 'voluntary', including market forces and information, may be used to change the behaviour of industries and consumers (Figure 13). Choosing amongst the many possible approaches requires collaboration amongst technical experts (who are familiar with the risks and measures that might be taken) and economists or policy experts who can assist with the assessment of the social and economic implications of possible actions[128].

With an expanded arsenal of tools many innovative approaches can be taken. Consider for example the use of mandatory, publicly accessible, facility-based inventories of pollutant releases[129]. These have a powerful regulatory effect[130] in the context of an open economy where public disclosure becomes an important environmental management tool. Rigorous mandatory reporting of mercury releases would provide China with credible data to support its national management decisions (e.g. to determine how much reduction is needed, or whether measures taken are having an impact) and for international negotiations. A system established initially for mercury could be extended eventually to include other heavy metals and other priority pollutants.

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[127] http://www.epa.gov/hg/report.htm (Accessed: Sept. 7/2011).

[128] Environment Canada uses an internal guidance document (Instrument Choice Framework for Risk Management under the Canadian Environmental Protection Act (1999) – March 2009) based on a document published by the Treasury Board of Canada Secretariat on *Assessing, Selecting and Implementing Instruments for Government Action* (http://www.tbs-sct.gc.ca/ri-qr/documents/gl-ld/asses-eval/asses-eval00-eng.asp). Accessed: Sept.14/2011.

[129] http://acts.oecd.org/Instruments/ShowInstrumentView.aspx?InstrumentID=44&InstrumentPID=41&Lang=en &Book=False (Accessed: Sept 7/2011).

[130] Archon Fung, Dara O'Rourke. *Reinventing Environmental Regulation from the Grassroots up: Explaining and Expanding the Success of the Toxics Release Inventory*. Environmental Management, 25(2): 115–127.

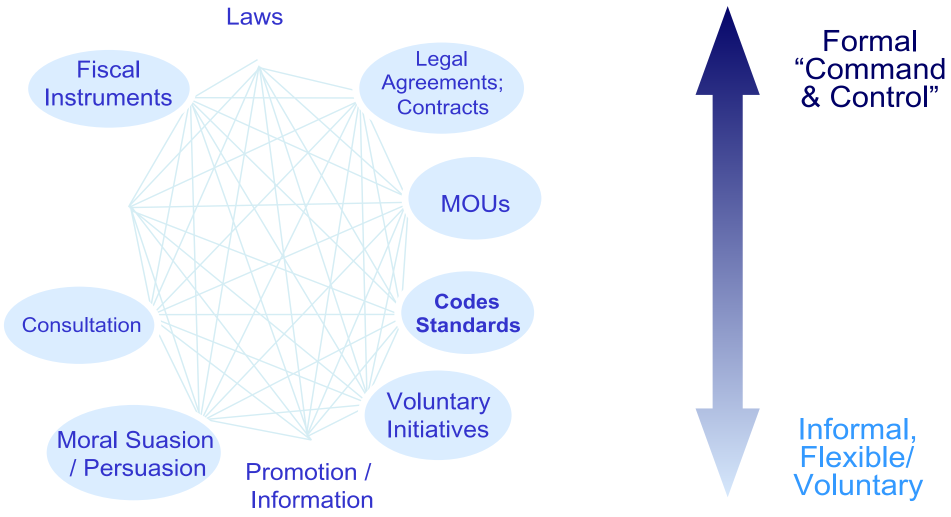

Figure 12. Innovative Approaches to Regulation Using Different Instruments[131]

Two tools developed in the USA deserve mention. The Toxics Release Inventory[132], a pioneering pollutant release and transfer registry, was developed in the mid-1980s following the tragic leaks of Methyl isocyanate gas from a Union Carbide plant in Bhopal, India**.** It provides communities with information about toxic chemical releases and waste management activities and supports informed decision making at all levels by industry, government, non-governmental organizations, and the public. As noted above, this has a powerful regulatory effect and was judged one of the most effective regulations ever produced by the US-EPA[133] due to the power of public disclosure in a society with an open economy and free press.

Another useful tool has been a standard known as "maximum achievable control technology" (MACT) that is based on emissions levels that are already being achieved by the better-controlled and lower-emitting sources in an industry sector[134], thereby taking cost and feasibility into account. Under the U.S. Clean Air Act Amendments of 1990, the MACT must not be less than the average emission level achieved by controls on the best performing 12 percent of existing sources, by category of industrial and utility sources[135].

In terms of economic instruments, a cap-and-trade (CAP) system was proposed to reduce mercury emissions from coal-fired power plants in the USA[136]. Under this system, those manufacturers who could not meet the new requirements would have had the opportunity to purchase emission rights for their excess emissions from the manufacturers who had met *and surpassed* the emission standards by improving and upgrading their equipment.

[131] Figure 14 courtesy of Treasury Board of Canada Secretariat.
[132] http://www.epa.gov/tri/ accessed October 24, 2011
[133] Archon Fung, Dara O'Rourke. *Reinventing Environmental Regulation from the Grassroots up: Explaining and Expanding the Success of the Toxics Release Inventory*. Environmental Management, 25(2): 115–127.
[134] http://www.scdhec.gov/environment/baq/Mact/
[135] http://www.ecomii.com/dictionary/maximum-available-control-technology-mact
[136] http://www.epa.gov/air/mercuryrule/ (Accessed: Sept 7/2011).

While this initiative was not successful for legal reasons[137], a cap-and-trade regime may nevertheless be a viable approach for mercury and the US-EPA did considerable work to design such a system. However it is a controversial approach that can be opposed by opponents as ‘trading in toxics’. If caps are sufficiently stringent they could lower emissions overall, but would do so at variable levels in different locations (less reductions from plants that would buy credits from those making the most reductions) – and it would of course be hard to explain to residents in the less-favoured locations why it is acceptable for their exposure to be higher than in other locations.

Industry-led mercury management initiatives driven by societal and market pressures can also be effective. During a mission to Canada in July 2011, SPS Team Members heard from leaders of the Canadian chemical, mining and forestry industry associations. The global chemical industry’s ‘Responsible Care Program’ was launched in 1985 as a response to the Bhopal, India crisis and other events that had eroded public confidence in the industry to the point of threatening their ‘social license’ to operate. Under Responsible Care each facility operated by member companies is required to develop environmental and safety programs that are shared with local communities and subject to third party reviews[138,139].

Following reports of significant environmental damage inside and outside of Canada, the Canadian Mining Association created a similar program to protect their ‘social license’ to operate. Member companies establish targets above and beyond regulatory requirements, recognizing that the public wants to see transparent management and that local communities near mines and processing plants want to be informed and involved.

Members of the Canadian Forestry Products Association, not wanting to wait to be regulated by Governments or attacked in the marketplace where their brand can be seriously damaged, chose to get ahead of these threats by making the changes themselves. A leading example of this is the recently signed Canadian Boreal Forest Agreement under which the industry has committed to adopting good stewardship standards and to protecting a significant proportion of the forest from logging. In return environmental organizations agreed to cease media and market campaigns that were hurting the industry in the marketplace[140,141].

Evolving trade rules are also a major instrument to drive industries and governments to strengthen their management of environmental issues such as mercury pollution. There are newly emerging restrictions on the trade in mercury and mercury-containing products[142]. At the level of the WTO a dialogue continues to develop at the trade and environment committee on proposals to establish “border tax adjustments — to address competitiveness and leakage issues that may develop” as some countries, for example, fail to take sufficiently stringent

[137] http://www.cadc.uscourts.gov/internet/opinions.nsf/68822E72677ACBCD8525744000470736/$file/05-1097a.pdf (Accessed: Sept 7/2011).
[138] http://www.ccpa.ca/ResponsibleCareHome.aspx
[139] http://www.icca-chem.org/en/Home/Responsible-care
[140] For more information see: http://canadianborealforestagreement.com (Accessed: August 15 2011).
[141] For more information see: http://www.canadiangeographic.ca/boreal (Accessed: August 15 2011).
[142] Mr. Kees den Herder, an SPS Member from the Netherlands, presented the SPS Team with a large number of WTO restriction notices (for example) by the EU, Korea, and China alerting that those nations/regions were imposing border tariffs and/or import bans on certain mercury-added devices. Sept.4/2011.

measures to deal with green house gas emissions[143]. It is reasonable to think that mercury pollution could be the subject of similar discussions in the future given calls for global action, including, most recently, by the Arctic Council in its report on Arctic Pollution 2011[144].

As new regulations move their way through the development and approval stages it is often the case that a *Regulatory Impact Analysis Statement* (RIAS) be prepared so as to clearly outline the anticipated business and consumer impacts and the domestic and international governance impacts of the proposed regulation. An important part of the RIAS process is the cost-benefit analysis (CBA) statement wherein the social, economic, and environmental costs of the proposed regulation are discussed. In the case of pollution prevention regulations, the CBA will, in most cases, outline the environmental release reductions expected. In Canada[145], the USA[146], and the EU these RIAS and CBA procedures are open to public scrutiny. It is essential that evidence on implementation, impacts, and compliance be gathered to support these analyses. In the case of pollution regulations, the EC National Pollution Release Inventory[147] is built to provide essential information on impacts.

4.2.4 Upgrading of Industrial Structures and Making a Shift to a Green Economy

There are many sectors that use or produce mercury, and thus the matter is complicated. Japan, the US, Canada, Norway and the EU have adopted practical and feasible measures to stop or restrict mercury use in many sectors. Their experience is that these changes require adjustments to the industrial structure, often with significant capital investments for technological upgrading. Supporting policy measures that favour such investments, for example tax relief to encourage capital investments for cleaner production can facilitate these.

[143] *Climate Change Takes Centre Stage at WTO Environment Committee*. Bridges Trade BioRes. Volume 11 Number 13, 11 July 2011. International Centre for Trade and Sustainable Development. http://ictsd.org/downloads/biores/biores11-14.pdf (Accessed: August 30, 2011).
[144] AMAP, 2011. Arctic Pollution 2011. *Arctic Monitoring and Assessment Program (AMAP)*, Oslo. Vi + 38pp ISBN-13 978-82-7971-066-0 (http://www.amap.no/) (Accessed: August 30, 2011).
[145] http://www.gazette.gc.ca/rp-pr/p1/2011/2011-02-26/html/reg4-eng.html (Accessed: Sept 7/2011).
[146] http://www.epa.gov/ttn/ecas/regdata/RIAs/ToxicsRuleRIA.pdf (Accessed: Sept 7/2011).
[147] http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1 (Accessed: Sept 7/2011).

5. STRATEGY AND ACTION PLAN FOR MERCURY MANAGEMENT IN CHINA

China announced a program to address heavy metal pollution in its 12^{th} 5-Year Plan and is actively involved in multilateral negotiations on a proposed international mercury convention.

Both initiatives will require the improved management of mercury through a well-coordinated national strategy and action plan. This chapter describes what the strategy and action plan should include and examines the required supporting elements.

5.1 Nation-wide Mercury Management Strategy and Action Plan for China

The goal of this management strategy and action plan would be to protect human health and the environment from the dangers of mercury pollution and to reduce China's contribution to global mercury releases. Key features of this strategy and action plan would include:

- **Short and long-term goals to reduce mercury releases** consistent with the current 12^{th} 5-Year Plan for heavy metals for the period 2011-2015 and beyond;
- Strengthened measures to **protect the health of the Chinese population and the environment** from exposure to mercury;
- A compulsory **National Pollution Release and Transfer Inventory** information platform to support decision making;
- **Improved environmental performance in key mercury-dependent industry sectors and communities** consistent with national strategies for clean production and greening of the economy;
- **Strengthened regulatory policies and instruments** for the management of mercury;
- A **comprehensive management system** based on a continuous improvement approach with effective and consistent implementation throughout China;
- **Market-based mechanisms** gradually introduced as a supplement to enforceable command and control measures;
- Targeted **science and technology improvements** to provide the evidence base to support decision making for mercury risk management and control; and
- **Increased enforcement capacity** for the consistent national implementation of the action plan.

The following sections set out approaches and actions required to support such a robust Strategy and Action Plan.

5.2 A Sound Mercury Information Base to Identify and Manage Risks

The National Action Plan will need more timely and reliable information on the production, distribution, use, release, recycling, disposal and the resulting flows of mercury in China. Generating such information will require compulsory monitoring and reporting of mercury releases from key pollution sources. The ability to display this data by sectors, key regions, air sheds and water basins will allow managers and scientists to document the distribution and flows of mercury. It will further allow them to establish industrial emission factors that are appropriate for use by regulators in China and to identify, assess and reduce risks to the

health of the Chinese population.

Environmental risk and early warning systems need to be established along with industry-specific risk profiles.

Finally, adequate data are needed to support assessments of the social and economic impacts of mercury reduction measures.

To improve the evidence base for the cradle-to-grave management of mercury and the related risks in China, and to support China in its international mercury activities, key features of an information collection and analysis base need to include:

- A transparent, compulsory, nationally coordinated, facility-based, and regularly updated mercury release and transfer reporting system – designed to adopt the best practices from UNEP's inventory of tools and the pollutant release and transfer registry systems currently recommended by the OECD for implementation by its member states[148];
- An inventory of mercury movements into air, water, land, and waste streams to support the identification of human health and environmental risks to determine the priorities for control interventions; and
- An environmental risk information and early warning system to prevent environmental risks and to promote early identification and response to emergencies.

Note: The infrastructure and procedures used in a system of this kind for mercury could also be used to address other heavy metals, persistent organic pollutants and other pollutants of national concern.

5.3 Information and Actions to Reduce Risks to Public Health

There is a high degree of uncertainty in the estimates of China's mercury emissions and releases and consequently the distribution and fate of large amounts of the mercury released in China, is not clear. Therefore, studies on the speciation, molecular transformation and transport of mercury are needed along with a strengthening of monitoring and evaluation to support the assessments of risk to human health. This work would provide the key information needed for scientific evidence-based assessments of potential risks.
To reduce the impacts of both new and historic mercury pollution on human health it will be necessary to establish appropriate public advisories, and occupational health measures. Steps to address these needs should include:

- Strengthening monitoring for mercury in the environment, in foods, and in humans;
- Re-evaluating consumption standard limits for rice (and other crops), fish, cosmetics, etc. to provide guidance for cases where the levels are elevated;
- Developing appropriate communications messages particularly for populations in contaminated areas and in areas where food products are found to have elevated

[148] http://acts.oecd.org/Instruments/ShowInstrumentView.aspx?InstrumentID=44&InstrumentPID=41&Lang=en&Book=False

mercury, and for other vulnerable populations (e.g. pregnant women and young children); and

- Strengthening occupational health and safety monitoring and protection programs for persons in high-risk occupations (e.g. mining, smelting, PVC production, etc.).

5.4 Strengthened Risk-based Management of Contaminated Sites

Contaminated soils expose local populations to variable levels of mercury for extended periods through the consumption of mercury-contaminated crops. This differs from the situation in many countries where fish consumption is the major pathway for human exposure to mercury. In China, the foods most often contaminated by mercury are crops, such as rice, wheat and corn. Recent research found that methyl mercury could be highly accumulated in rice, thus posing a health risk to consumers[149].

A risk-based approach should be adopted for the management of contaminated sites[150]. Key actions required to do this are:

- Establishing a transparent National Public Registry of mercury-related contaminated sites to support the identification, assessment and categorization of such sites so that priorities can be set and decisions made concerning their remediation and future use;
- Establishing a government-wide legislative structure to clearly outline the division of responsibility and to determine the adequacy of laws for the management of both current and legacy sites contaminated by mercury, including financial mechanisms to support the decommissioning and remediation of priority sites;
- Remediating sites giving priority to those posing the greatest risks to human health and the environment;
- Supporting the creation/emergence of a domestic industrial sector capable of providing the various remediation requirements including supporting demonstration projects; and
- Establishing a long term monitoring system at mercury-contaminated sites to protect (local) public health and the environment.

5.5 Promote Green Transformations of Industries and Communities

China's technical capacity needs to be strengthened with further acquisition, development and application of cost-effective mercury pollution control techniques and alternatives to the use of mercury.

China's commitment to reduce GHGs by 40% per unit of GDP[151] will require industry sectors to adopt cleaner production methods. These will assist in reducing mercury use and releases. Such improved environmental performance will protect the health of the Chinese

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[149] H Zhang, X Feng, T Larssen, et al, *In Inland China, Rice, rather than Fish is the Major Pathway for Methyl Mercury Exposure*. Environmental Health Perspectives 118:1183 – 1188.
[150] Informed by the CCICED Special Policy Study on Soil Environmental Protection in China, 2010. http://www.sfu.ca/international-development/cciced/pdf/2010_ReportofSoil.pdf
[151] State Council announcement of 2020 commitments for reduced CO_2. 26th November 2009. http://finance.people.com.cn/GB/10461522.html [Chinese only].

workforce and local communities, aid in securing community acceptance, and protect global competitiveness.

Additional strategies will be needed to provide support for the economic diversification of communities faced with the closure of small plants, and faced with the end of practices such as small-scale mining and smelting and dangerous waste management practices.

Key features of these transformations would be:

- Promoting structural adjustment by industries that release or consume mercury, taking appropriate account of urban, rural and regional factors;
- Supporting the introduction and commercialization of mercury pollution-prevention technologies including the promotion of clean production process technologies, and the demonstration of best available and best achievable techniques and technologies (BAT[152]/BEP/MACT[153]) projects;
- Supporting industry to reduce the use of mercury in processes and products by using a range of financial incentives, and by compulsory and voluntary measures to encourage industry modernization and reform;
- Promoting alternate consumption choices and improving waste management and recycling; and
- Developing 'Green' economic diversification strategies for communities affected by the elimination of mercury-based industries[154, 155].

5.6 Strengthen China's Management and Regulatory Regimes for Mercury

China needs to systematically strengthen the management of its mercury pollution prevention and control activities at all stages of the regulatory lifecycle (Figure 10).

Policy advice needs to be founded on greater capacity for risk assessment and analysis of management options to prevent and control mercury pollution in key sectors. Enhanced capacity is needed to select and apply appropriate technologies and clean production

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[152] In EU BAT is defines as best available techniques and hence includes BEP (best environmental practice. For a specific sector a BAT reference document (BREF) gives detailed information on available and emerging techniques in the sector. BREFS are available at: http://eippcb.jrc.es/reference.

[153] MACT is a US-EPA standard. "When developing a MACT standard for a particular source category, the EPA looks at the current level of emissions achieved by best-performing similar sources through clean processes, control devices, work practices, or other methods. These emissions levels set a baseline, often referred to as the "MACT floor" for the new standard. At a minimum, a MACT standard must achieve, throughout the industry, a level of emissions control that is at least equivalent to the MACT floor. The EPA can establish a more stringent standard when it makes economic, environmental, and public health sense to do so. http://www.cdphe.state.co.us/ap/mact.html (Accessed September 10, 2011).

[154] A helpful example is the small scale economic development work of UNDP in Kyrgyzstan found at the following link (accessed September 22, 2011) .
http://www.unep.org/hazardoussubstances/Mercury/InterimActivities/Partnerships/SupplyandStorage/PrimaryMercurySupplyProject/tabid/3547/language/en-US/Default.aspx

[155] The UNIDO office in China is developing a project proposal with MEP/FECO to seek GEF funding, focusing on the zinc smelting industry (UNIDO Representative, personal communication). This project could provide an opportunity to explore ways to support the adaptation of communities affected by the closure of small smelters

mechanisms and to monitor releases and oversee facility operations for key sectors and regions. Many of China's existing standards and specifications lag behind modern requirements for pollution control and management. Consistent national application of mercury pollution prevention and control measures is needed at a time of Township Industrialization to avoid risks of an East-to-West transfer of polluting industries.

Despite important high-level economic policies to support environmental protection in China, economic instruments do not yet play a significant role in the control and prevention of mercury pollution. Measures could include tax provisions to promote environmental protection beyond basic compliance with the laws, as well as supportive investment and financing mechanisms. The funding of mercury pollution prevention, control or remediation activities have yet to be fully explored.

Not least amongst the challenges for the regulatory system are the governance issues identified in OECD reports on China's environmental performance[156] and on regulatory governance in China[157]. With regard to policy, opportunities were identified to improve regulatory impact assessments and the integration of environmental and economic policies. An operational priority for the management of mercury and other heavy metals is the need to increase national consistency in the implementation of standards and regulations through provincial and local levels of government.

In order to strengthen its capacity for effective and efficient regulation of industries which release or use mercury, and the pollution resulting from past practices, China will need to:

- Strengthen all aspects of the regulatory life cycle as described in Chapter 3 (Fig 10);
- Improve Regulatory Impact Analysis in line with the recommendations of the OECD Review[158] and use the OECD checklist[159];
- Strengthen the chain of command from National to Local levels to ensure consistent implementation, compliance, and enforcement of regulations and the application of other measures. This can be advanced by completing a transition now underway for Provincial Environmental Protection Bureau Directors to report directly to MEP Headquarters;
- Ensure that adequate operational capacity exists for inspection, enforcement and management of emergency responses;
- Promote voluntary initiatives by industrial sectors, for example, adoption of the international industry-led 'Responsible Care' program by the chemical industry; and
- Enforce national standards in rural regions and Western China to prevent the migration of polluting industries from more developed regions.

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[156] *OECD Environmental Performance Reviews: CHINA*. OECD 2007. http://www.oecd.org/document/24/0,3343,en_2649_201185_38952984_1_1_1_1,00.html (Accessed August 30).

[157] OECD Reviews of Regulatory Reform. China. *Defining the Boundary between the Market and the State.* OECD 2009. http://www.oecd.org/document/36/0,3746,en_2649_37421_42222884_1_1_1_37421,00.html (Accessed August 30, 2011).

[158] OECD Reviews of Regulatory Reform. China. *Defining the Boundary between the Market and the State.* OECD 2009. http://www.oecd.org/document/36/0,3746,en_2649_37421_42222884_1_1_1_37421,00.html (Accessed August 30, 2011).

[159] *The OECD Reference Checklist for Regulatory Decision Making.* OECD 1995. http://www.oecd.org/dataoecd/20/10/35220214.pdf (Accessed August 30, 2011)

5.7 Develop and Apply Knowledge to Reduce Mercury Use, Releases and Impacts on Public Health and the Environment

Public information, awareness and education are needed on practical measures to reduce exposure to mercury and on the release of mercury, especially for those vulnerable populations, such as indigenous people, women, children, and workers living close to industrial and mining activities. Thus it is important to improve the current knowledge base and to begin reducing the knowledge gaps in environmental impact assessment processes, environmental management tools, and the scientific advice available to government, industry and the public.

To reduce knowledge gaps and the levels of uncertainty in the technical and scientific advice available to government, industry, and the Chinese people, actions should include:

- A thorough national review of current status and knowledge on mercury similar to those completed or underway in other nations and regions[160];
- Improved monitoring and reporting of the various species of mercury in the environment, foods and humans, recognizing the differences between China and other regions of the world where such research has been carried-out;
- Establishing and refining dose response relationships for human health impacts, as current data are based on locations that may not be reflective of the Chinese situation[161;]
- Improving the understanding of the fate and effects of mercury emissions and their biogeochemical cycles;
- Confirming that the methylation of mercury following the flooding of lands for the creation of hydro-reservoirs in China does not represent a problem, given the experience of other countries;
- Developing and importing innovative emission-reduction technologies;
- Improving communications that promote mercury product recycling and the use of alternate products and devices; and
- Strengthening occupational safety training for persons (including management, technologists and operators) in mercury-dependent industries.

5.8 Strengthen International Cooperation and Actively Support the Global Campaign to Eliminate Mercury Pollution.

As China develops its capacity for mercury management, a strengthening of international

[160] For example:

- AMAP, 2011. Arctic Pollution 2011 (Mercury in the Arctic). *Arctic Monitoring and Assessment Programme (AMAP)*, Oslo, Norway. vi+38 pp. http://amap.no/documents/
- The US-EPA mercury risk Assessment http://yosemite.epa.gov/sab/sabproduct.nsf/fedrgstr_activites/A&N%20Hg%20Risk%20Assessment%20TSD!OpenDocument&TableRow=2.2
- Canadian Mercury Science Assessment http://www.ec.gc.ca/scitech/default.asp?lang=En&n=1890C965&xsl=articlesservices,viewfull&po=3CEEE8E1#9

[161] The Seychelles and the Faroe Islands.

cooperation will secure support for improved mercury management in China. Such cooperation will also increase the introduction of capital and technology, develop personal and technological collaboration, and strengthen overall international cooperation for environmental protection. There is great reputational value in strengthening China's international image through the promotion of a global campaign to prevent mercury pollution. As China is in the midst of negotiations on a global mercury convention, strengthened international cooperation will assist the formulation of practical provisions for the mercury convention and will guide China's mercury management policies in the future.

Key features of this task should include actions to:

- Establish policy dialogues and information exchanges with key international partners to promote the global strategic campaign on mercury;
- Promote cooperation and communications with developing countries and countries with economies in transition;
- Strengthen bilateral communications and cooperation on management, technology, international trade, capital investments, human resource capacities and governance of the mercury problem;
- Promote the introduction of best available and best achievable techniques and technologies for mercury pollution and control from other countries, and spur the development of domestic technologies to improve mercury management; and
- Monitor and contribute actively to discussions on trade and environment at the WTO as it may relate to mercury in the future.

5.9 Improve the Environmental Performance of Industries that Use or Release Large Quantities of Mercury - Sector Specific Strategies

Regulation of each of the major sectors, which are described in detail in Section 2.3, will require strategies that take account of technical options, economic and social factors, trade strategies, international norms and the interplay with broader national policies, for example, on energy. Mercury reduction strategies will be needed with short-term strategies focused on early returns – i.e., the most mercury reduction at the lowest cost, and long-term strategies focused on more complex and costly reductions that will require time for careful investments.

Such approaches require discussions and collaboration amongst leaders from the industry sectors, academia, energy and industry ministries and central policy agencies to ensure that opportunity for innovation, future energy supply, and economic, industrial and social strategies and impacts, are fully considered in such key decisions. It will also be necessary to engage the provinces and local governments to the extent that their support will be needed for effective implementation and enforcement.

There will be requirements for command-and-control types of mercury emission regulations that progressively implement more demanding standards. Standards to be set in China should take account of international examples and factors ranging from the protection of the environment and human health in China to assuring the continuing access of Chinese

products to international markets that are currently, and may become, sensitive to environmental performance.

The industries targeted for priority attention based on their impact on human health and the environment can be divided into two categories: those that release mercury, and those that use mercury in their processes or produce mercury-containing products.

The Key Sources of Mercury Releases

- Coal-Fired Power Plants and Industrial Boilers
- Non-Ferrous Metal Smelting
- Cement Production

The Key Mercury Users/Producers

- VCM/PVC Production (using the Calcium Carbide Process)
- Mercury Mining and Smelting
- Recycling and disposal of Mercury-Containing Wastes
- Mercury-Added Products
    a. Battery Producers
    b. Compact and Fluorescent Lamp Producers
    c. Medical Devices Producers

Proposals for actions in these industries are set out in the following sector-specific strategies. These should form the basis for comprehensive consultations with the industries concerned and with other Ministries and stakeholders as regulatory impact assessments are prepared, leading to appropriate 'Made in China' management and regulatory measures. A summary of the anticipated benefits from actions in these sectors is set out in Figure 11.

As part of its ongoing work the MEP should assign a national team leader to each of the key sectors to lead the building of the required sector-specific strategies and plans.

5.9.1 Coal-Fired Power Plants and Industrial Boilers

China's resource and energy strategies dictate that coal will continue to be an important energy source, even in the long-term. Mercury emissions from the use of coal will be reduced as China improves its energy efficiency and increases its use of renewable and alternate energy sources. On the other hand, while desulfurization and de-dusting facilities have been installed in most coal combustion industries in China, techniques dedicated to the removal of mercury remain absent.

In order to reduce mercury emissions from these sources the following steps are required:

- Promote cleaner production such as advanced coal processing techniques and the use

of low-mercury coal[162];

- Reduce mercury emissions by measures to control other air pollutants (SO_2, NOx, PM) through timely national implementation of the new standards released on September 21/2011 to take affect on January 1/2012[163], and by improving the stability and availability of existing devices. Simultaneously, it is necessary to promote the development and the demonstration of approaches to establish best available and best achievable techniques and technologies (MACT, BAT/BEP)[164];
- Establish mercury pollution controls for the coal-combustion industries, including an industry-wide regulatory regime, appropriate emission standards[165] (Box 4) and some necessary economic incentives;
- Improve the plan of action and the enforcement of mercury pollution regulations to ensure mercury emissions standards are met;
- Discontinue small high-polluting industrial boilers or shift to natural gas where available; and
- Improve the management flow of mercury-containing waste products such as fly ash, FGD gypsum, and wastewater.

5.9.2 Non-Ferrous Metal Smelting[166]

Box 4. Possible emissions reductions from coal-fired power plants and boilers.

Estimates are that emissions from coal-fired power plants in China can be significantly reduced from 2005 levels by 2020 using BAT. The SPS Team suggest that a target of <5 μg/m^3 is doable by 2015 and <3 μg/m^3 could be doable by 2020.

Estimates are that emissions from industrial boilers in China can be significantly reduced from 2005 levels by 2020 using BAT. The SPS Team suggest that small inefficient boilers of less than 14 mega-watt capacities should be discontinued. Boilers up to 75 mega-watts capacities should have an emission target of <10 μg/m^3 and boilers larger than 75 mega-watts should have an emission target of < 3 μg/m^3 by 2020.

There are many medium and small-sized enterprises operating at different technical levels in the non-ferrous metal smelting industry in China. In order to reduce mercury releases, the following measures should be adopted:

- Phase in binding production-based emission limits based on BAT from international sources (Box 5) to improve the environmental performance of this industry sector

[162] Which can be further aided by utilizing coal washing techniques, low-order coal extraction, and CWS preparation.
[163] Statement by Wu Xiaoqing, Deputy Environment Minister [MEP]; China Daily, page 1, September 22/2011. Relates to new more stringent standards targeting SO_2, NOx, Mercury, and soot discharged from coal-fired power plants.
[164] Activated carbon injection, addition of bromine or bromides before combustion, in flue gas additives, or at points in the generation process, and others.
[165] For example: the currently proposed emission standard of 30 μg/m^3 is considered far too high. A new standard should be set taking into consideration levels being targeted by the USA [1.5 μg/m^3] and the EU [3 μg/m^3].
[166] In particular: zinc, lead and copper.

while encouraging further research and development of domestic technologies;

- Strengthen research and the introduction of relevant core technologies for mercury pollution control within the industry;
- Promote the application of mercury removal technologies to enable enterprises to collect, process or release mercury for further use or resale;
- Reduce from the current 10 ppm[167] to 1 ppm the upper limit for mercury in sulphuric acid as it may be used as a raw material for the production of other materials including fertilizers, which could then re-introduce mercury into the crop food chain.;
- Close small inefficient and highly polluting plants. Current regulations banning the operation of small-scale facilities need to be better enforced. Structural change in the non-ferrous industry will require government support for adaptation by the communities affected; and
- Improve requirements to track and control mercury entering the sulphuric acid streams of these plants and other reclaimed mercury wastes.

5.9.3 Cement Production

The mercury emissions from cement production are highly dependent on the mercury content of the raw material used and also the mercury content of the coal. Currently very little information is available on the mercury content of this raw material. Mercury emissions from cement production should be reduced by actions to:

- Seek co-benefits from other pollution control measures, including energy saving and air pollution control[168] and from strengthening mercury control technologies in this area;
- Establish binding emission limits[169] and mercury management[170,171];
- Phase in improved requirements to track and control waste mercury entering the cement industry from gypsum and fly ash (as outputs from the coal combustion industry), and other waste streams; and
- Improve the availability of information on the content of mercury in the raw material in order to help guide the selection of low-mercury feedstock.

5.9.4 VCM/PVC Production

In China, the acetylene production process — using a mercury catalyst — still dominates the VCM/PVC industry, accounting for more than 70% of the total, which leads currently to a

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[167] *Sulphuric Acid for Industrial Use*, Standards Press of China, GB/T 534-2002. 2002-09-24.

[168] Including changing particle emission control from ESP to FF.

[169] By applying BAT, a limit of mercury emission of < 0.05 mg/m^3 is achievable. [http://www.environment-agency.gov.uk/static/documents/Business/How_to_Comply_-_Cement_EPR3_01a.pdf]. There is also a new US production standard of: 55lbs/million tons clinker for existing sources and 21lbs/million tons clinker for new sources: www.epa.gov/ttn/atw/pcem/pcempg.html - Table 1 of the final rule [page 55052]. The emission standard is 10 μg/m^3 for existing sources and 4 μg/m^3 for new sources.

[170] Management measures are described in the Reference Document on BAT in the cement, lime and magnesium oxide manufacturing industries, European Commission, May 2010. (ftp://ftp.jrc.es/pub/eippcb/doc/clm_bref_0510.pdf).

[171] The replacing materials are added as powder after milling of the clinker in a cold mixing process with other additives such as gypsum.

huge demand for mercury. The following steps should be taken to accelerate mercury reduction in the VCM/PVC sector:

- Priority must be assigned to achieving mercury-free PVC production processes. Recalling the 2007 guidance provided by the NDRC, the industry should actively seek opportunities to shift from the coal-based acetylene process to the ethylene process, which is more energy efficient;
- Facilities using the acetylene process should be encouraged to further invest in the transformation to lower-mercury processes and eventually to mercury-free methods of production. Binding regulations and improved enforcement measures should be phased-in to track and control mercury entering the waste streams and by-products;
- Research on mercury-free technologies and processes should be strengthened[172];
- Explore the extent to which a shift away from the acetylene method will provide co-benefits in reduced GHG emissions[173] and thereby reduce pressure on other industrial sectors that share a GHG cap with the VCM/PVC industry; and
- Work should be done to strengthen the control and management of the whole process, establishing economic incentives to reduce the use of mercury, and to promote the recycling of low mercury catalyst. Authorities should also explore 'cap and trade' systems or fees for mercury use.

5.9.5 Mercury-Added Products

The following recommendations should be considered to reduce mercury in the mercury-added products sectors:

- Promote the development and use of mercury-free or low mercury-added products as alternatives to the current mercury-added products;
- Establish mercury content limits on production, import, export and consumption of mercury-added products;
- Develop an action plan to reduce the use of mercury-added products including the industrial structural adjustments required;
- Encourage, through regulatory measures, the gradual transition of mercury-added products at the poorest level of mercury content to meet the same limits of products at the best level of mercury content;
- Improve the development, introduction and promotion of recycling technologies for existing mercury-added products industries;
- Adopt a production license system that favours extended producer responsibility measures, cleaner production, circular economy initiatives, and voluntary industry sector measures to reduce the mercury-added content of their products.

[172] Such as: new molecular sieve fixed-mercury catalysts and integrated large-scale chloride fluidized bed reactors.
[173] The production of one metric ton of PVC by the acetylene process produces twice the CO_2 emissions than the ethylene process used in Europe and North America.

5.9.6 Recycling and Disposal of Mercury Wastes

There is a wide range of mercury-containing wastes that need special attention, such as batteries, mercury-added lamps, medical devices, dental amalgam, VCM mercury catalysts, gas cleaning sludge, and smelting wastes. Currently, in China most used mercury-containing products are sent to landfills along with municipal solid waste. The absence of an effective recycling system and proper hazardous waste handling therefore poses a high risk of mercury pollution to the environment. It will therefore be important to properly enforce China's hazardous waste management regulations. The following steps should be taken to improve recycling, handling and disposal of mercury-containing waste:

- Strengthen the introduction and development of mercury wastes recycling and disposal technologies;
- Strengthen collection, storage, recycling and disposal systems for mercury-containing waste;
- Establish strict recovery efficiency and pollutant discharge standards for the mercury waste handling industries; and establish evaluation methods and indicators;
- Promote the use of cost-benefit analyses to determine whether it is more efficient and effective to promote the use of mercury-free products or the recycling of mercury-added products;
- Establish market-based incentives for recycling of mercury-containing wastes; and
- Enhance consumer awareness and set up special recycling sites at convenient locations in the community. Engage government, manufacturers, recycling professionals and communities in the development and operation of an effective recycling system for waste mercury-containing products.

<u>Note</u>: Dental amalgam can easily and cheaply be removed from dental wastewater. Action might be initiated through a national dental association as a prelude to eventual binding regulations to remove dental amalgam from waste streams.

5.9.7 Mercury Mining and Smelting

Mercury mines and smelting facilities release mercury to the environment through a number of pathways. The long-term legacy of these mines and smelters is an accumulation of mercury in humans, animals and plants in the surrounding environments. The risk of mine tailing collapses poses an additional risk. The following recommendations should be considered to reduce mercury pollution from both the operating and legacy mines and smelters:

- Strengthen national government oversight of this industry for the approval, control and reporting of production;
- Undertake risk-based management based on human health impacts and impacts to the environment for contaminated sites resulting from closed mines, smelters, and their waste sites;
- Strengthen enforcement and emergency response capacity and establish financial mechanisms to support the identification, decommissioning and remediation of both legal and illegal mines and mercury processing plants; and

- In order to optimize the use of funds for remediation and protect the environment, food supply and public health, collaboration should be strengthened among authorities responsible for the general security, safety and emergency response capacity (e.g. related to risks of mine tailing collapse).

5.10 Overview of the Effects of Mercury Pollution Controls on Pollution from other Heavy Metals

Many measures to reduce mercury releases will directly or indirectly reduce pollution from other heavy metals.

Combustion processes that release mercury also emit other heavy metals such as lead, cadmium, thallium and zinc. Hence measures by coal-burning sectors targeting mercury and conventional air pollutants, especially particulate matter, will also reduce those other heavy metal emissions. Similarly, proper treatment of the waste streams in these sectors will not only reduce mercury releases but also the releases of other heavy metals.

In the non-ferrous metals sector, several heavy metals other than the metal being produced are commonly also present in the ore. Pollution control measures will thus reduce the release of mercury and other heavy metals. The closing of small, inefficient and highly polluting non-ferrous metal smelters will be particularly efficient in preventing pollution by mercury and other heavy metals, both to air and water.

Furthermore, the management regime and regulatory capacity established to prevent and control mercury pollution will support the development and implementation of measures required to reduce and prevent pollution from other heavy metals. Table 8 indicates qualitatively some of the benefits and co-benefits one could expect following the implementation of improved mercury pollution prevention measures across the sectors previously discussed.

5.11 Benefits and Costs

A comprehensive analysis of the socio-economic benefits and costs of the proposed action plan exceeded the time and resources available to the SPS Team. However some work was initiated and a path forward is offered for more complete analyses.

Table 8. Qualitative View of Anticipated Benefits from Actions by the Various Sectors

Sector	Quantity of Mercury Involved[174]	Opportunities for Early Actions	Benefits for Health and the Environment		Co-Benefits for other Heavy Metals
			China	Global	
Coal Fired Power Plants	++				
Coal Fired Boilers	+++				
Non-Ferrous Smelters	++				
Cement Production	++				
VCM/PVC Production	++++				Zero
Battery Production	++				
Thermometers	++				Zero
Blood Pressure Monitors	+				Zero
Compact & Fluorescent Lamps	+				Zero
Dental Amalgam	+				Zero
Mercury Mining	++++				

Good	Better	Best

[174] Qualitative scale of 'Use' of mercury or the 'Release' of mercury. += Not Much ++= Medium Amount +++= Large Amount ++++= Very Large Amount.

As a basis for selecting the priority actions set out in section 6 of this report, an expert group of international and Chinese team members prepared Table 8 to offer a qualitative overview of the benefits that could be anticipated from action by the various sectors that were considered.

A helpful review of economic studies on the benefits of reducing mercury pollution was provided by Swain et al in 2007[175].

For an overview of the costs and effectiveness of control measures the reader is referred to a recent report prepared by UNEP's Chemicals Branch at the request of the UNEP Governing Council[176]. An important conclusion of this report was that "estimating costs for control of mercury emissions requires knowledge of the current status of the emissions sources including technological descriptions of current and planned air pollution control". To do this in China will be require major efforts that engage the regulatory officials from MEP and the industry officials who manage operations of the various sectors concerned. Some work to this end was initiated under the SPS Project by experts at Peking and Renmin Universities and should assist with the regulatory work, including regulatory impact assessments, for the scenarios that we are recommending.

With the exception of the mercury-free catalysts now being developed and field tested for the PVC/VCM sector in China, all of the methods proposed in Chapters 5 and 6 of this report have passed practical tests of cost-effective application in other countries.

5.12 Estimation of Possible Reductions in Emissions and Uses of Mercury

Based on the foregoing scenarios, estimates of the reductions in emissions and uses of mercury were calculated as described below. The results are presented in Table 9.

Coal-Fired Power Plants

The baseline emissions of 123 tonnes in 2007 was derived from research conducted for this SPS project by Prof. Duan Lei et al – Tsinghua University[177]. This represents 19% of the total emissions to the atmosphere of 643 tonnes. Assuming the adoption of a new target of <5 $\mu g/m^3$ by 2015 and <3 $\mu g/m^3$ by 2020 and even assuming a 10% annual growth in coal consumption by these plants, these targets would reduce mercury emissions in 2015 by about 10% and in 2020 by a further 30% from 2007 levels.

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175 Socioeconomic Consequences of Mercury Use and Pollution. Edward B. Swain, Paul M. Jakus, Glenn Rice, Frank Lupi, Peter A. Maxson, Jozef M. Pacyna, Alan Penn, Samuel J. Spiege;l and Marcello M. Viega. Ambio Vol. 36, No. 1, February 2007. Royal Swedish Academy of Sciences. http://www.ambio.kva.se

176 *Study on Mercury Sources and Emissions and Analysis of Cost and Effectiveness of Control Measures*. Division of Technology, Industry and Economics (DTIE), Chemicals Branch, UNEP. November 2010 (UNEP(DTIE)/Hg/INC.2/4.

177 Updated Emission Inventory Data provided for this project [background report from Prof. Duan Lei et al – Tsinghua University, Beijing, China. Atmospheric Mercury Emission Control Measures, 2011]. lduan@tsinghua.edu.cn

Coal-Fired Boilers

The baseline emissions of 213 tonnes in 2007 was derived from research conducted for this SPS project by Prof. Duan Lei et al – Tsinghua University [178]. This represents 33% of the total emissions to the atmosphere of 643 tonnes. Taking account of international practices, boilers above 75 mega-watts capacities could have an emission target of 10 $\mu g/m^3$ by 2020 thereby reducing the emissions of this sector by about 40%.

Non-Ferrous Metals

The baseline emissions of 116 tonnes in 2007 was derived from research conducted for this SPS project by Prof. Duan Lei et al – Tsinghua University [179]. This equals 18% of the total emissions to the atmosphere of 643 tonnes. By adopting production level emission limits, for example, of 0.2 gram of mercury per ton of finished zinc or lead, or 1 gram of mercury per ton of finished copper - this along with the closure of the small highly polluting smelters would reduce non-ferrous smelter emissions from 116 tonnes [2007] to about 5 tonnes, a reduction of 96%.

Cement Production

The baseline emissions of 90 tonnes in 2007 was derived from research conducted for this SPS project by Prof. Duan Lei et al – Tsinghua University [180]. This equals 14% of the total emissions to the atmosphere of 643 tonnes. By adopting a new standard of 10 $\mu g/m^3$ these emissions can be reduced by 25% (23 tonnes) by 2015 and by adopting a further improved standard of 4 $\mu g/m^3$ in 2020 emissions will be reduced by a further 30% (27 tonnes) from 2007 levels.

VCM/PVC Production

The baseline of 780 tonnes of mercury being used by the industry in 2010 was determined from two sources[181]. The projected reductions in the industry's use of mercury in future years were based on the industry completing the reduction programs as outlined by the three ministries [NDRC, MIIT, MEP]. They established the following goals:

- By 2012: achieve 50% of the VCM industry to use low mercury catalyst that is expected to reduce mercury use by 208 tonnes annually. Therefore use is expected to be [780-208] 572 tonnes;

[178] Ibid.
[179] Ibid.
[180] Ibid.
[181] Data compiled from these sources: D Liu, H Fan, *Strengthen Mercury Contamination Prevention and Treatments Promotecalcium Carbide Process PVC Industry Health Sustainable Development*. China Chlor-Alkali. 2011, 4: 1-3.
X Jian, Y Shen, W Yao, et al. *Status Analysis and Reduction Countermeasures of China's Mercury Supply and Demand*. Research of Environmental Sciences. 2009, 22 (7): 788-792.

- By 2015: only use low-mercury catalyst [mercury use per tonne of PVC produced to drop 50%] and full recycling of the spent low-mercury catalyst[182]. Therefore use would be reduced to [572-572*50%] 286 tonnes; and
- By 2020: promote mercury-free catalyst and gradually achieve mercury-free across the VCM/PVC industry[183]. Therefore use would be reduced by a further 286 tonnes.

The method does not take increased production rates into consideration nevertheless the mercury used by the industry will drop to zero by 2020 if and only if, the industry achieves mercury-free production across the total PVC industry sector by 2020.

Battery Production

The baseline of 140 tonnes of mercury being used by the industry in 2009 was reported by MIIT[184]. The MIIT Heavy Metal Pollution Comprehensive Prevention Plan[185] amongst other things calls for the Chinese battery industry to reduce its use of mercury by 80% by 2015. Hence 140x80% = 112 tonnes reduction.

The method assumes the industry will achieve the reductions expected by the Plan.

Thermometers

The baseline of 109 tonnes being used by the industry sector in 2008 was reported by the industry association[186]. It is anticipated that as importing nations ban the import of mercury containing products and as electronic equivalent devices become less costly for Chinese domestic users, then it is conservatively assumed that production will drop by about 50% in the mid-term.

Blood Pressure Monitors

The baseline of 118 tonnes being used by the industry sector in 2008 was reported by the industry association[187]. It is anticipated that as importing nations ban the import of mercury containing products and as electronic equivalent devices achieve the same accuracy as these analog products at less cost for Chinese domestic users, then it is conservatively assumed that production will drop by 30 – 40% in the mid-term.

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[182] *Cleaner Production Technologies Program in the PVC Industry,* MIIT (Ministry of Industry and Information Technology of the People's Republic of China), 2010. http://www.dhp.gov.cn/upload/2011/3/2412262376.pdf *Mercury Prevention and Control in respect to Industries related to PVC Produced by Calcium Carbide Method Program*, MIIT (Ministry of Industry and Information Technology of the People's Republic of China), 2010. http://baike.baidu.com/view/3717369.htm

[183] *Mercury Prevention and Control Planning in the VCM Industry*. CPCIF (China Petroleum and Chemical Industry Federation), CCAIA (China Chlor-Alkali Industry Association). http://wenku.baidu.com/view/4188021ba8114431b90dd883.html

[184] http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/13505234.html [Chinese only]. Accessed on Sept 21/2011.

[185] Ibid

[186] China Association for Medical Devices Industry (CAMDI). http://www.camdi.org/

[187] Ibid.

Compact Fluorescent Lamps

The baseline of 78.2 tonnes of mercury being used on a production of 4.8 billion lamps in 2008[188] was reported by MEP/FECO. To move this baseline to 2010 with a production of 6.7 billion lamps it is assumed that the production process:

(1) Using manual pipetting to deposit the mercury where the pipetting drops can range from 20 – 60 mg per lamp made-up 0% of the industry in 2010.
(2) Factories with automatic dosing of the mercury. The range of mercury dosing can range from 10 – 20 mg per lamp made-up 35% of the industry in 2010.
(3) BAT dosing technology via mercury-amalgam glass capsules plus special glass preparation. The range of mercury dosing can range from 3.5 - 5 mg per lamp made-up 65% of the industry in 2010. This leads to the calculation that the baseline in 2010 was 68 tonnes of mercury.

The industry already has a goal to achieve 5 mg per lamp for 100% of production but it is expected it will take until 2013 to achieve this. When achieved, the consumption will drop by 35 tonnes to 33 tonnes of mercury. When the EU limit of 3.5 mg per lamp is achieved **[unsure of date but certainly before 2020]** this will provide another reduction of 12 tonnes dropping consumption to 23 tonnes of mercury.

Fluorescent Lamps

There are no definitive data on the production level or the mercury usage of this industry sector. However, SPS members[189] who are familiar with this industry sector have provided the following best assumptions:

(1) Of the total lamp sector; CFLs make-up 70% and FLs make-up 30%.
(2) If the CFL sub-sector produced 6.7 billion lamps with an estimated total mercury use of 68 tonnes then the average mercury use per lamp was near 10 mg per lamp.
(3) It is estimated that the FL sub-sector used 30 – 60 mg per lamp therefore this produced an average of 45 mg per lamp.
(4) With an estimated production level of 2.9 billion FL lamps, the annual mercury used by the sector will be about 130 tonnes[190].
(5) Since it is anticipated that the FL sub-sector will achieve a BAT of 10 mg per lamp in the near term, to suit upcoming import restrictions by some nations, then it can be conservatively assumed that the total mercury used by the FL sub-sector will drop to 29 tonnes.

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188 *Mercury Related Industries Inventory Report*, 2008, MEP/FECO.
189 Mr. Kees den Herder (Netherlands) and Dr. SUN Yangzhao (China/MEP/FECO).
190 2.9 billion is 44% of 6.7 billion. Therefore 68 tonnes x 44% = 29.04. Then 45 mg is 4.5 times greater than 10 mg. Therefore 29.04 x 4.5 = 130.68

6. RECOMMENDATIONS FOR PRIORITY ACTIONS

Europe and then North America were for centuries the major sources of anthropogenic mercury releases. Following substantial reductions of mercury releases from these two regions over the past three decades, Asia is now by far the largest source, and China the largest national producer, user, and releaser of mercury. Indeed, China now accounts for more than 50% of global use.

China's economic development efforts over the past 30 years have spurred significant industrial growth. During this period, as described in previous chapters, China's connection to mercury has grown on three fronts: (1) With the expansion of its heavy industries such as non-ferrous metals smelting, cement production, coal-fired power generation, and industries relying on coal-fired industrial boilers, mercury emissions from smelting and coal combustion have made China the biggest emitter of mercury to the atmosphere. (2) For the production of PVC in China, coal rather than oil or natural gas is used as a feedstock in a process that demands a significant amount of mercury as a catalyst for the chemical reaction, making this the biggest mercury-use industrial sector in the world. (3) The growth in production of batteries, fluorescent lights, and mercury-added medical instruments has been such that China now produces most of the global supply, thereby contributing significantly to waste streams around the world created as these products reach the end of their useful life.

China now has an opportunity to address these problems through innovation and modernization of its industrial base. As a world leader in international trade and economic growth, and consistent with its green development strategy, it is in China's interest to significantly reduce its use and production of mercury and releases to the environment while strengthening recycling and waste management systems. Now is the time to act as the world is focused on international cooperation to control mercury pollution.

Based on the opportunities set out in Chapter 5 of this report and in particular the sector-specific analyses (section 5.9), recommendations are made for early and longer-term actions consistent with the 12^{th} 5-Year Plan for heavy metals for the period 2011-2015 and beyond. In addition to the specific priority recommendations that follow, this report identifies several other actions that can usefully be taken by China in the near and long term to reduce mercury pollution and its impacts. Table 9 provides an overview of the estimated reductions in mercury emissions and mercury demand that China could expect to achieve if the recommendations provided in this report are implemented over the next decade.

The overall approaches that we recommend are to: 1) strengthen the management and regulatory systems to control the use mercury and other heavy metals, including measures to protect the health of the Chinese population; 2) establish ambitious but feasible targets for reduced use of mercury and reduced releases of mercury to the environment, drawing upon experiences of other countries; and 3) foster the development of closed-loop systems for the management of mercury as a resource to reduce and eventually eliminate the demand for new mercury in China.

While this report has focused on mercury, many of the proposed actions will contribute directly or indirectly to the control of pollution from other heavy metals. For example

measures to reduce mercury pollution from non-ferrous metal smelters, mining, coal-fired boilers and cement production will also reduce pollution from other heavy metals such as lead and cadmium. Furthermore, the regulatory systems and capacity established for mercury pollution control will support the development and implementation of measures required to reduce and prevent pollution from other heavy metals. A similar CCICED Special Policy Study would be helpful to develop appropriate strategies and action plans for these other pollutants.

In its 12th 5-year plan China has made clear commitments to address pollution by mercury and other heavy metals and is moving forward with early actions. This will require dedication and continued effort that should start immediately and accelerate over the next decade.

Table 9. Overview of Estimated Possible Reductions by 2020 (Tonnes)[191]

Sector	Baseline Emissions	Anticipated Emission Reduction	Baseline Use	Anticipated Use Reduction
Coal-Fired Power Plants	123 [2007]	12+37= 49 (40%)		
Coal Fired Boilers	213 [2007]	85 (40%)		
Non-Ferrous Smelters	116 [2007]	111 (96%)		
Cement Production	90 [2007]	23+27=50 (55%)		
VCM/PVC Production			780 [2010]	208+286+286= 780 (100%)
Battery Production			140 [2009]	112 (80%)
Thermometers			109 [2008]	54 (50%)
Blood Pressure Monitors			118 [2008]	40 (34%)
Compact Fluorescent Lamps			68 [2010]	35+12=47 (70%)
Fluorescent Lamps			130 [2010]	101 (78%)
Total[192]	542	295 (55%)	1345	1134 (84%)

[191] See Section 5.11 of this report for methods used to prepare these estimates.
[192] Be mindful that there is rounding of numbers for display purposes.

6.1 Take Early Actions that Offer Public Health and Environmental Benefits

There are a number of actions that can be taken quickly to protect human health and the environment from mercury.

6.1.1 Non-Ferrous Smelters

Governments, and in particular Environmental Protection officials, should take immediate steps to close the remaining small, inefficient and **highly polluting non-ferrous metal smelters** by strengthening and ensuring the implementation and enforcement of regulations banning the operation of such facilities.

These measures will serve not only to protect the health of workers and nearby communities, but will provide a substantial portion of the emission reductions from this sector (see II.3 below) with limited impact on productivity. Taking the zinc industry as an example, over 80% of the mercury emissions come from these small smelters that produce less than 20% of the zinc.

These actions will also reduce pollution from other heavy metals such as lead and cadmium. Structural change in the non-ferrous industry will require government support for economic diversification and adaptation by the communities affected.

6.1.2 Coal Combustion

To reduce mercury emissions from the **coal combustion sectors** China should:

(1) Promote implementation of best available techniques for mercury-specific controls (e.g. activated carbon injection, addition of bromine or bromide) with support for early uptake through training and financial incentives;

(2) Reduce demand for coal combustion through continued efforts to improve energy efficiency and to increase the use of renewable and alternate energy sources; and

(3) Further strengthen requirements for action by the coal combustion sectors to control other air pollutants and thereby increase the co-benefits of reduced mercury emissions, an approach that in recent years has contributed to decreased mercury emissions despite an increase in coal consumption by this sector.

6.1.3 Protecting Citizens

Health, Labour, Environmental, Safety and Emergency Authorities should collaborate on measures to:

(1) Protect citizens at risk from exposure to mercury as a result of their occupations, food or place of residence (e.g. near contaminated sites). Measures needed include: 1) food consumption advisories based on monitoring and standards appropriate to China,

2) effective occupational health and safety programs, and 3) information, advice and support to people living in proximity to contaminated sites;

(2) Ensure secure management of hotspots near abandoned mercury mines and mercury mine tailings to prevent further water, soil and air-pollution and to prevent possible mine tailing collapses; and

(3) Strengthen inspection and enforcement to ensure that illegal activities such as artisanal small-scale gold mining or illegal waste disposal are prevented.

6.2 Make Major Reductions in Mercury Emissions and Releases to Protect Public Health and the Environment in China and Reduce China's Contribution to Global Emissions

Major reductions in mercury emissions can be achieved in the following sectors (Figure 12) through capital investments over the next decade.

6.2.1 Coal Combustion Sectors

(1) **Industrial boilers** should shift to natural gas where available and feasible. Where coal must be used, advanced coal processing techniques and the use of low mercury coal should be encouraged. Small and inefficient coal-burning boilers of less than 14 mega-watt capacities should be discontinued. Taking account of international practices, boilers above 75 mega-watts capacities could have an emission target of 10 $\mu g/m^3$ by 2020 thereby reducing their emissions by about 40%.

(2) Emissions from **coal-fired power plants** in China can be significantly reduced from 2010 levels by 2020 using modern technologies. A target of <5 μg/m3 seems feasible by 2015 and <3 μg/m3 could be achieved by 2020. Even assuming a 10% annual growth in coal consumption by these plants, these targets would reduce mercury emissions in 2015 by about 10% and in 2020 by a further 30% from 2007 levels.

6.2.2 Non-Ferrous Smelter Sector

The sector should be required to phase in binding emission limits taking account of technologies available from international sources while encouraging further research and development of domestic technologies. For example, an achievable emission limit of 0.2 grams of mercury per ton of finished zinc or lead, or 1 gram of mercury per ton of finished copper could be implemented. These limits, along with the closure of the small highly polluting smelters, would reduce non-ferrous smelter emissions from 116 tons [2007] to about 5 tonnes, a reduction of 96%. More stringent emission limits should be phased in for new smelters since, with the current best available technology, emissions of less than 0.01 grams per ton of zinc are already realistically achievable.

A regulation limiting the maximum mercury content in sulphuric acid produced as a by-product from this sector should be strengthened by reducing the maximum limit from the

current 10 ppm to 1 ppm and actively enforced especially where this by-product may be used to produce fertilizers for food crops.

6.2.3 Cement Sector

Binding emission limits should be phased in for the cement sector based on best available technologies and management measures used in North America and Europe. A standard of 10 $\mu g/m^3$ could reduce emissions in 2015 by about 25% and in 2020 a standard of 4 $\mu g/m^3$ could reduce emissions by a further 30% from 2007 levels. Co-benefits can be achieved from other pollution control measures, including energy saving initiatives and air pollution control.

6.3 Reduce Mercury Use and Demand and Recycle Waste Mercury in a Closed Loop

China can reduce and eventually eliminate the demand for new mercury for its manufacturing sectors by fostering the development of closed-loop systems that manage mercury as a valuable resource, and by reducing the requirement for mercury in manufacturing processes and products.

6.3.1 VCM/PVC Sector

Priority must be assigned to achieving cost-effective mercury-free PVC production processes.

Recalling the 2007 guidance provided by the National Development and Reform Commission for the Chlor-alkali (caustic soda, PVC) Industry [193], the sector should actively seek opportunities to shift from the coal-based to oil- or gas-based processes, that use no mercury and are more energy efficient.

Every effort should be made to achieve the government's announced goals for this sector, which are as follows:

- By 2012 achieve 50% of the sector adopting the low-mercury catalyst process to reduce mercury use by an estimated 208 tonnes annually;
- By 2015 achieve 100% of the sector adopting the low-mercury catalyst process (mercury use per metric ton of PVC produced to drop by 50% or an estimated reduction of 286 tonnes) and implement the full recycling of the spent low-mercury catalyst;
- By 2020 promote mercury-free catalyst use and gradually achieve mercury-free production across the PVC industry.

Facilities that continue using the coal-based process should invest in the transformation to lower-mercury and eventually to mercury-free methods. Additionally, binding regulations and improved enforcement measures should be phased in to track and control mercury entering the VCM/PVC sector's waste streams and by-products.

[193] NDRC [2007]74. http://www.sdpc.gov.cn/zcfb/zcfbgg/2007gonggao/t20071106_170922.html (Accessed by Sep. 26th/2011).

If a promising new mercury-free catalyst now undergoing commercial trials should prove effective, steps should be taken to encourage its uptake by early adopters while continuing efforts to develop competing methods. There is an urgent need for significant investments in research on mercury-free technologies and processes for PVC production.

The government should foster these technologies by instituting financial mechanisms to assist the sector's transformation to mercury-free processes.

Considering industry forecasts that the sole mercury mine in China could be exhausted within 5 years, and given the need to drive innovation and adaptation in the sector, a policy of preventing fresh mercury from entering China's industrial system as early as 2015 would be an important step toward achieving mercury-free production across the PVC industry.

6.3.2 Closed-Loop Systems for Mercury Consuming Industries

Develop closed-loop systems that capture and recycle mercury to eliminate the need for inputs of new mercury, thus fostering resource conservation and reducing waste. This approach can be applied broadly to capture and reuse mercury from many sources ranging from non-ferrous smelters to medical products.

This will require development of an effective mercury recycling system and proper hazardous waste handling regimes. This will require the strengthening and proper implementation and enforcement of China's hazardous waste management regulations.

China should consider establishing a cap on the available supply of mercury by 2015 to accelerate reduced dependence on the mining of mercury and to promote innovation and adaptation by the PVC sector and other mercury-consuming industries.

6.3.3 Improved Standards for Mercury-added Products

Encourage producers of mercury-containing products to use less — or zero — mercury by:

(1) Developing and implementing regulations to gradually require producers of high mercury-added products (e.g. lamps) to meet the same standards as products with the lowest mercury content available internationally;
(2) Developing and using mercury-free or low-mercury-added products and by encouraging their use in place of current mercury-added products (e.g. through free exchange programs for medical devices);
(3) Adopting a production licensing system that favours extended producer responsibility, cleaner production, circular economy initiatives, and voluntary industry measures to reduce the mercury-added content of their products; and
(4) Improving recycling technologies and promoting the creation of the necessary industries.

China should promote, develop and implement the Heavy Metal Pollution Comprehensive Prevention Plan for the battery industry issued for comment by the Ministry of Industry and Information Technology on November 25, 2010. The Plan proposes to phase out alkali

manganese button batteries with mercury exceeding 5 ppm by 2013. By 2015 mercury consumption by the battery industry in China would be reduced by 80% from a baseline of 140 tonnes.

As the producer of 80% of the world's compact fluorescent lamps, China has an opportunity to lead the development of a global standard for the mercury content in these lamps. The government working with the industry association has established a limit of 5 mg that it expects to achieve by 2013; this will decrease the industry's mercury demand by about 35 metric tons from 2010 levels. Further reductions of an estimated 12 tons could be made by moving to a limit of 2.5 mg in lamps < 30 watts and a limit of 3.5 mg in lamps >30 watts.

Additionally, China produces a large number of regular fluorescent lamps for use in residential, commercial, and industrial settings. In 2010 this fluorescent lamp sector used about 130 tonnes of mercury. For these products, the government is considering a standard limit of 10 mg. This standard would reduce the total mercury used by the fluorescent lamp sector to about 29 tonnes.

6.4 Build Strong Foundations for a Mercury-Free Green Economy

Key foundations required for successful actions to reduce pollution from mercury and other heavy metals are the national systems for regulation and management of these pollutants and the knowledge base required to protect public health and the environment and to foster innovation in green technologies that eliminate or significantly reduce pollution.

6.4.1 Regulation and Management

(1) Establish a mandatory, transparent, facility-based and quality-controlled national inventory of mercury transfers and releases to support evidence-based cradle-to-grave management of mercury and the related risks in China;

(2) Strengthen regulatory capacity at all stages of the life cycle from issue identification and regulatory impact assessments to implementation, enforcement and evaluation, and increase the range of 'instruments' used, including market-based and industry-led approaches. Accomplishing these ends will require building specialized capacity for example in the use of alternate instruments, cost-benefit analysis and regulatory impact assessment;

(3) Strengthen understanding and oversight of the key sectors for continuous mercury reduction. This will require dedicated staff to lead this work at the Ministry of Environmental Protection; and

(4) Strengthen management and regulatory systems for mercury and other heavy metals, including increased capacity for timely and effective emergency responses and for consistent application and enforcement of national standards and regulations throughout the country to prevent development of pollution havens in remote and developing regions and to prevent mercury from entering the food supply and other routes of exposure that put the population at risk.

6.4.2 Knowledge and Innovation

(1) Improve monitoring for mercury in foods, humans, and the environment to support risk assessment and management measures;

(2) Foster new technologies suited for use in China (e.g. a mercury-free catalyst for the PVC acetylene industry, addition of bromine or bromide for coal-burning power plants, and small and clean industrial boilers). Support such efforts through a technology evaluation and verification system;

(3) Promote education and increased awareness amongst the public, government, industry, and medical personnel, including senior leaders, and build capacity for action in these areas.

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As part of the research process, five meetings of the Special Policy Study Team were held including one in Canada. The Canadian study tour included a visit to the TECK zinc smelter in British Columbia, a visit to the ATCO coal-fired power plant in Alberta, and a visit to a contaminated site remediation contractor in Nova Scotia. These visits were for the most part organized by Environment Canada to whom our special thanks are extended. The SPS Team is also grateful to the following executives of Canadian industry associations who shared with us their experiences and lessons learned from industry-led initiatives to improve environmental performance: Richard Paton, President and CEO, Chemistry Industry Association of Canada, Paul Lansbergen, Secretary and Lead Director, Regulatory Affairs, Forest Products Association of Canada, and Gordon Peeling, President and CEO (retired), Canadian Mining Association.

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The front cover photo-ribbon includes a photograph of a cooling tower and men carting bags of spent mercury catalyst courtesy of Prof. Uwe Lahl of the SPS Team; a photograph of a young child playing with a container of mercury courtesy of Prof. Thorjorn Larssen of the SPS Team; and a public domain photograph of a small mercury smelter. The Abstract page includes a public domain photograph of mercury droplets.

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The Special Policy Study Team on Mercury Management in China submits this Report.