Original Article

Future trends of excess mercury in Asia in response to Minamata Convention on Mercury

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Abstract

Owing to rapid industrialization, Asia has become the main source of mercury emissions and a significant net importer of mercury. Therefore, the situation regarding excess mercury in Asia needs to be better understood. In this study, mercury flows and excess mercury in 2010–2050 in Asian regions, with a particular focus on China, are assessed under updated assumptions. The excess mercury in China in 2030 and 2050 is estimated to be 125 and 284 tons, respectively. The cumulative excess mercury in China will reach around 10,000 tons in 2050 under the assumption of no export of it in the years 2010–2050. In addition, the year in which mercury reaches a surplus in Asia (excl. China) is estimated to be 2039. The mercury supply in Asia strongly depends on the usage of excess mercury in China. It is estimated that mercury supplies will be insufficient in Asia until at least 2017. These predictions should support decision-making and planning for long-term storage capacity, discussions of regional coordination, securing of technical support, and development of the basic design of related facilities.

Key Words Excess mercury・Long-term strategy・Scenario analysis・China・Asia

Introduction

Mercury is a heavy metal that is liquid at room temperature; it is a naturally occurring element that is found in the atmosphere, the aquatic environment, and the terrestrial environment [1]. Owing to its unique characteristics, mercury has been utilized in wide variety of products, including thermometers, dental fillings, batteries, electric switches and relays, light sources, manometers, and gauges [1–4]. Mercury is a toxic element, and some inorganic mercury in aquatic environments can be converted into organic mercury, which is highly toxic and can accumulate in biological tissues [5]. Methylmercury poisoning in Kumamoto and Niigata, Japan, during the 1950s and 1960s, caused severe damage to the environment and human health (Minamata disease) [5, 6]. Because mercury poses a significant threat to both the natural environment and human health, international efforts are required to reduce mercury pollution through anthropogenic emissions and their transport and transformation in the environment [7]. A reduction in the supply of mercury, its use in products, and long-term management have been identified as priorities of the United Nations Environment Programme (UNEP) Governing Council [8]. The Minamata Convention on Mercury (MCM), which was agreed upon in January 2013 and adopted by the Conference of Plenipotentiaries on 10 October 2013, in Minamata, is a global treaty to protect human health and the environment from the adverse effects of mercury [9]. The major highlights of the MCM include a ban on opening new mercury mines (mining is allowed for a further 15 years in currently active mines); phasing out of manufacturing processes using mercury or mercury compounds; control measures on air emissions, other releases, and the mercury content of products; and international regulation of the informal sector in artisanal and small-scale gold mining (ASGM) [10]. Therefore, it can be assumed that long-term management of mercury will change significantly when the MCM comes into force, and mercury can become excess in the near future.

The number of papers assessing excess mercury published in scientific journals is rather limited in comparison to the number of papers addressing other issues associated with mercury. Several reports [8, 11–14] discussing the supply, trade, and demand or the safe storage of surplus mercury have been published. UNEP [14] summarized the possible effects on human health and the environment in Asia and the Pacific of the trade of products containing lead, cadmium, and mercury. Studies on material flow of mercury, as well as its future prediction in response to MCM in China and Japan, respectively have been conducted [15, 16]. In addition, Maxson [8] conducted a scenario assessment of excess mercury in Asia over a 40-year period (2010–2050) by applying baseline data from 2005. Although, there have been the studies on the future prediction of excess mercury in response to MCM for individual countries, an improved understanding of the prospects for excess mercury in Asia under updated assumptions would greatly assist in understanding and dealing with long-term mercury management both nationally and globally, especially when the MCM comes into force.

As a consequence of rapid industrialization, Asia has become the main source of mercury emissions into the air, with East and Southeast Asia accounting for about 40% of the global total [7]. In addition, the Asian region is currently a significant net importer of mercury [8]. Thus, it can be expected that the demand and supply of mercury will fluctuate significantly in various fields in Asian countries when the MCM comes into force. The excess mercury might be illegally used by ASGM. Along with the most of the excess mercury will be stored in Asia, there is still no an effective framework for the storage and treatment of the excess mercury in Asia. Furthermore, final disposal and stable treatment system of the excess mercury haven't yet conducted. It may cause serious negative impacts on environment and human health when the excess mercury is improperly treated and disposed. Therefore, to capture the excess mercury in Asia can support decision-making and planning for long-term storage capacity, discussions on regional coordination, securing of technical support, and development of the basic design of related treatment facilities. Excess mercury in Asia thus needs to be better understood, so this issue is focused on in the current study. In the present study, excess mercury in Asia in 2010–2050 is assessed in response to MCM under updated assumptions, then a comparison is conducted between Maxson [8] and this study.

Materials and methods

Target area

The Asian region was targeted in this study, covering the sub-regions of East and Southeast Asia as well as South Asia. The East and Southeast Asian sub-regions include Brunei Darussalam, Cambodia, China, the Democratic People's Republic of Korea, Indonesia, Japan, the Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Papua New Guinea, the Philippines, the Republic of Korea, Singapore, Thailand, and Viet Nam. South Asia includes Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan, and Sri Lanka. It should be noted that countries in the Middle East and Oceania, including Australia and New Zealand, were outside the scope of this study.

Estimation of excess mercury in Asia

Excess mercury in Asia can be calculated based on the total supply and total demand in year t. The sources of mercury supply include primary mercury ore mining and mercury recovery. The sources of mercury demand include mercury usages in both manufacturing processes and products. The assumptions on the sources of mercury supply and demand are given in below. The cumulative amount of excess mercury can be calculated using Eq. (1). The assumptions of sources of mercury supply and demand were derived from Maxson [8] and MCM [10], and the baseline data were updated to the latest available from a range of reports and databases [17–20]. Normally, a linear prediction can be considered for the prediction if the future trend is uncertainty. Thus, a linear prediction was widely applied for calculation. The primary ore production in China, mercury usages in ASGM and VCM production in Asia in 2010-2030, as well as mercury usages in batteries, dental amalgam, fluorescent lamps, measuring devices and other products in Asia in 2005-2020 were calculated by linear prediction with conditions. China uses the most mercury and is the primary source of mercury ore mining, so a particular focus was placed on this region in assessing excess mercury in Asia in this study. The sources of mercury supply were mercury recovery from end-of-life products, vinyl chloride monomer (VCM) catalysis (recovery rate is 47%), and the non-ferrous smelting industry. Supply from chlor-alkali plants was excluded in this study.

$$Cumulative\ amount\ of\ Excess\ mercury = \sum_{t=2010}^{2050} (Total\ supply_t - Total\ demand_t) \qquad (1),$$

Assumptions on the sources of mercury supply in Asia: primary mercury ore mining and the mercury trade in Asia

(1) Primary ore was assumed to be mined until 2030 in China, according to the 15-year mining permit contained in Article 4 of the MCM. The production of primary ore in 2010–2030 can be calculated by linear prediction based on data from the past five years (2008–2012) [21].

(2) Excess mercury in China was assumed to be stored.

(3) The mercury trade is conducted between Asian countries, metallic mercury is imported only from China, there are no mercury exports outside Asia, and the excess mercury in the region was assumed to be stored.

Assumptions on the sources of mercury supply in Asia: mercury recovery

(4) Mercury is mainly recovered from non-ferrous (zinc and others) smelters. According to Maxson [8], the recovery rate in large zinc smelters (LZS) was assumed to be 93%, and at least 25% more mercury may also be recovered from other non-ferrous metal (especially gold, lead, and copper) processing activities in Asia. According to previous research [22], the non-ferrous metal smelting rate in Japan is constant; thus, the amount of recovery from the Japanese non-ferrous metal industry was assumed to be 36 tons per year.

(5) The recovery of mercury in 2010 was assumed to be 200 tons in China, with the rate increasing by 10% per year. Mercury available in LZS will increase by 2% per year due to increasing zinc production worldwide [23].

(6) The rate of mercury recovery in Asia excludes Japan and China and the figures provided by Maxson [8] were used; a linear interpolation was used to obtain annual data, because only 5-yearly data are provided by Maxson. The recovery rate of plants is the same as that in China.

(7) In the case of Japan, the recovery rate was obtained from the value estimated by the Japanese Ministry of the Environment [24]; the recovery rates in other Asian countries were assumed to be 5%, 10%, and 25% in the years 2010, 2020, and 2040, respectively [8].

Assumptions on the sources of mercury demand in Asia: mercury usage in manufacturing processes

Manufacturing processes using mercury or mercury compounds are those involving ASGM, VCM, and chlor-alkali production. The assumptions used are listed below:

(1) Mercury usage in ASGM production by 2020 will decrease to 50% of that in 2010, and then decreased by 5% per year until 2050 [8].

(2) Mercury usage in VCM production by 2020 will decrease to 50% of that in 2010, and then be phased out by 2030, according to Annex B, MCM [10].

(3) Chlor-alkali production will be phased out by 2025 according to Annex B, MCM; the phase-out dates will be 2015 and 2020 for India based on Maxson [8], and 2015, 2020, and 2025 for other Asian countries. In addition, in accordance with Article 5(b) of the MCM, mercury recovered from chlor-alkali production will be stored.

Assumptions on the sources of mercury demand in Asia: mercury usage in different products

(4) Mercury usage in batteries in 2015 will decrease to 25% of that in 2005 [8]; according to the MCM, the mercury usage in batteries in 2020 will be reduced to 50% of that in 2015, and then reduced by 5% per year after 2020.

(5) Mercury usage in dental amalgam and fluorescent lamps in 2015 will decrease to 85% of that in 2005 [8]; according to the MCM, this type of mercury usage in 2020 will be reduced to 50% of that in 2015, and then reduced by 5% per year after 2020.

(6) Mercury usage in measuring devices in 2015 will decrease to 40% of that in 2005 [8]; according to MCM, this type of mercury usage in 2020 will be reduced to 50% of that in 2015, and then reduced by 5% per year after 2020.

(7) The mercury usage in electrical devices in 2015 will decrease to 45% of that in 2005 [8]; according to MCM, this type of mercury usage in 2020 will be reduced to 50% of that in 2015, and then reduced by 5% per year after 2020.

(8) The mercury usage in other products in 2020 will decrease to 75% of that in 2005 [8], and then be reduced by 5% per year after 2020.

Sensitivity (scenario) analysis

Sensitivity analysis is an important tool for validating the uncertainty of prediction results by changing the values of parameters that are dependent on certain assumptions. Uncertainties in assumptions were validated by changing the parameters (values). The sources of mercury supply include the formal mercury mining and mercury recycling in which the most is that recycled from LZS. In the sources of mercury demand, the mercury uses in ASGM remains large uncertainty. Therefore, in this study, the recycling rate of mercury in LZS, and the restriction of mercury use in ASGM and formal mercury mining are considered to be the most prominent factors that affect the prediction results. Therefore, several scenarios were set for predicting future excess mercury and the detail of these scenarios is given in Table 1. The assumptions for the future prediction in this study were based on the Maxson [8] and MCM as mentioned above, thus the values of them have been adopted as the baseline scenario. The values those the recycling rate of mercury in LZS and the restriction of mercury use in ASGM in Maxson [8] have been adopted as a baseline scenario. In addition, an assumption that primary ore is assumed to be mined until 2030 in China according to MCM has been adopted as a baseline scenario (Table 1). Considering the expected large amount of excess mercury might be stored in Asia, the behavior that recycling of mercury from LZS will possibly be stopped. Thus, as the alternative policy option 1, 0% was assumed to be the recycling rate of mercury in LZS in the future Asia. In option 2, 50% was assumed to be the recycling rate of mercury in LZS as the medium value in order to capture the sensitivity of the parameter showing as the recycling rate of mercury in LZS. Due to the serious negative impact on environment and human health coming from illegal uses of mercury in ASGM, option 1 that mercury uses by 2020 will decrease to 50% of that in 2010, and then totally phased out by 2050 was considered as the alternative policy option here. Likewise, considering the most of excess mercury will be stored in China [15], as only China contains primary mercury mines in Asia, it is assumed that Chinese formal mining will be completely phased out by 2020.

Results and discussion

Generation of excess mercury in Asia

Mercury flows in China

Mercury supply and demand, and excess mercury in China in 2010–2050, are shown in Fig. 1. Table S1 provides 5-year snapshots of the calculations of mercury supply and demand in China, showing the excess mercury that would likely be generated in the region during the period 2010–2050. There is no significant gap between mercury demand and supply in 2010 in China showing the excess amount of 57 tons (see Fig.1 and Table S1), under the assumption that China did not trade in this commodity with other countries in Asia. The excess mercury in 2030, and 2050 was estimated to be 125, and 284 tons, respectively.

The reduction in mercury usage up to 2020 is predicted to be larger than that of primary ore mining. The formal mercury mining will linear decrease from 1600 tons in 2010 to 18 tons in 2030 (see Fig.1 and Table S1). In addition, the excess mercury in China until 2020 will continue to increase due to increased amounts of mercury recovery from non-ferrous smelting industries, reaching 429 tons in 2020 (Fig.1). Then, excess mercury will decrease until 2030, due to a decrease in mercury usage and an increase in the proportional reduction of the primary ore. Mercury recovered from non-ferrous metal smelting will become the main supply source after the complete abolition of VCM by 2030. In addition, the proportion of the reduction in mercury usage will decrease; thus, excess mercury is estimated to increase again after 2030 (Fig. 1).

Mercury flows in Asia excluding China

Mercury supply and demand and excess mercury in Asia excluding China in 2010–2050 are shown in Fig. 2. Table S2 provides 5-year snapshots of the calculation of mercury supply and demand in Asia excluding China, showing the excess mercury that would likely be generated in the region during the period 2010–2050. It is difficult to capture mercury flows for the whole of Asia because of a number of data points lacking full information. For example, 512 tons of metallic mercury was imported into Malaysia in 2012, but less mercury than this was used in manufacturing processes or mercury-added products produced in Malaysia [15]. Because no primary mercury mining occurs in Asia outside of China, so mercury supply sources are limited. The total supply of mercury in Asia excluding China is estimated to be 59, 92, 97, 95, and 92 tons in the year 2010, 2020, 2030, 2040, and 2050, respectively (Table S2). Therefore, the period of fluctuation on supply amount will be 50–100 tons in Asia excluding China in 2010–2050. The mercury usage in 2010 was around 600 tons and gradually decreased in subsequent years. In 2050, the total uses of mercury will decrease to 52 tons (Table S1). The Asian (excl. China) annual excess mercury is estimated to be -537, -184, -47, 9, and 40 tons in the year 2010, 2020, 2030, 2040, and 2050, respectively. On the other hand, The Asian annual excess mercury is estimated to be -480, 245, 78, 238, and 324 tons in the year 2010, 2020, 2030, 2040, and 2050, respectively (Table S2). The first year in which excess mercury is estimated to occur in Asia excluding China is 2039, indicating that Asian countries outside China must import mercury to meet their demand. The first year in which excess mercury is estimated to occur in Asia including China is the year 2017 (Fig.2). Furthermore, excess mercury in Asia including China in the period 2010–2016 was estimated to be negative, so imports from outside Asia in this duration should be considered. It is estimated that excess mercury will increase between 2017–2020 and then decrease until 2030, due to significant decrease of mercury supply.

The mercury supply in Asia depends strongly on the usage of excess mercury in China. It is estimated that mercury supplies will be insufficient in Asia until at least 2017, and thus the import and/or export of mercury used in mercury-containing products should be possible, as defined by the MCM. In addition, an excess of mercury in Asia (excl. China & Japan) will occur from 2030 if the mercury usage of ASGM is excluded (see Table S2).

Cumulative amount of excess mercury storage in Asia

The excess mercury storage in 2010–2050 is shown in Fig. 3. The maximum excess mercury storage scenario occurs when the cumulative excess mercury in China reaches 10,000 tons in 2050, under the assumption of no export between

2010 to 2050. The cumulative excess mercury in China is estimated to be 57, 2781, 5519, 7379, and 9995 tons in the year 2010, 2020, 2030, 2040, and 2050, respectively (Table S1). The cumulative excess mercury in Asia excluding China, only taking into account the annual excess mercury from chlor-alkali decommissioning, is estimated to be 471, 584, 599, 875 tons in the year 2020, 2030, 2040, and 2050, respectively (Table S2). The cumulative excess mercury in Asia under the assumption of export from China is estimated to be 1152, 3025, 4750, and 7643 tons in the year 2010, 2020, 2030, 2040, and 2050, respectively (Table S2). Thus, even the export of mercury and mercury-containing products will be prohibited according to MCM, but considering huge mercury storage in China and insufficient supply sources of mercury in Asian countries outside China, the export with conditions should be discussed.

Parameter sensitivity

In the case of the recycling rate of mercury from LZS, the alternative policy option considered here is that 0% (option 1) and 50% (option 2) recycling rates of mercury from LZS lead to a decline in the mercury supply (see Table 1). The impact of these reductions in the recycling rate of mercury from LZS are shown in Fig. 4 and Online Resource (OR) Fig. S1. In the case of China, the total supply sources of mercury in the year 2030, will reduced to be 226 tons in option 1, which is almost 60% of the supply amount in the baseline scenario (Fig.4). The total supply sources of mercury in the year 2030, will reduced to be 40 tons in option 2, which is almost 10% of the supply amount in the baseline scenario (Fig.4). Then, the total mercury supply sources will be reduced to 95% and 44% of those in the baseline scenario after 2030 in option 1 and option 2, respectively (Fig.4). Because mercury mining and mercury recovery from VCM in China play important roles before 2030, these recycling rate reduction scenarios (option 1 and option 2) have only a weak effect on mercury supplies before 2030 (see Fig. 4). In addition, there will be no excess mercury after 2025, and the mercury shortage will be 1743 tons in option 1 of the recycling rate of mercury in LZS (Fig.1). Besides, in option 2, the Chinese cumulative excess mercury will be 4475 tons, which is almost half of that in the baseline scenario. In the case of the whole of Asia, especially considering the point in time at which excess mercury occurs, there are no prominent differences among the three scenarios. In the case of Asia excluding China, the time point at which mercury reaches a surplus will be later than that of the baseline scenario (see OR Fig. S1).

In the case of the limitation of mercury use in ASGM, the alternative policy option considered here is that the mercury usage in ASGM by 2020 will be decreased to 50% of that in 2010 and then phased out by 2050 (option 1). There are no obvious differences in total mercury use, Chinese annual excess mercury, and Asian annual excess mercury between the baseline scenario and the alternative scenario (see Fig. S2 and S3).

In the case of the restriction of formal mercury mining in China, the alternative policy option considered here is that formal mining will be completely phased out by 2020 according to Chinese regulations (option 1). The impact of this scenario is shown in Fig. 5. In this scenario, the total mercury supplies will be reduced by 6500 tons and excess mercury would occur a few years later compared with the baseline scenario. This will lead to a mercury shortage of approximately 1600 tons, mainly in the period before 2030.

Comparison of Asian annual excess mercury between Maxson and this study

From the results of analysis on parameter sensitivity, the formal mercury mining plays a vital role for the prediction results in this study. Thus, the Asian annual excess mercury with maximum/ reduced mercury in China as reported by Maxson and in this study is compared, as shown in Fig. 6. The estimations of excess mercury differ because the assumptions and baseline data were updated according to the constraints of the MCM and various reports and databases in this study. The baseline data applied in this study is the year 2010 compared with the year 2005 applied in Maxson. In addition, the constrains in MCM have been considered in this study. The amounts of excess mercury in 2020–2025 in this study are greater than those maximum mercury mining in China reported by Maxson; in contrast, the excess mercury in 2030–2050 in this study is less than that reduced mercury mining in China reported by Maxson. The time point at which mercury reaches a surplus as reported by Maxson was estimated to be 2015 under the assumption of maximum mercury mining in China and 2030 under the assumption of reduced mercury mining in China. The time point at which mercury reaches a surplus in this study was estimated to be the year 2017 under the assumption of a Chinese mining permit of 15 years under the MCM. In addition, the excess Asian mercury in 2050 in the work of Maxson was estimated to be 658 tons under the assumption of maximum mercury mining in China and 358 tons under the assumption of reduced mercury mining. Excess mercury in 2050 is estimated to be 324 tons in this study.

Conclusions

In the present study, the excess mercury in Asia in 2010–2050 was estimated under updated assumptions. From the estimation results described above, the following main conclusions can be drawn:

The excess mercury in China in 2030 and 2050 was estimated to be 125 and 284 tons, respectively. Up to 2020, the reduction in mercury usage will be greater than that of primary ore mining, and the excess mercury in China will continue to increase. The mercury recovered from non-ferrous metal smelting will become the source of mercury supply after the complete abolition of VCM up until 2030. The proportion of the reduction in mercury usage will decrease, and thus excess mercury is estimated to increase again after 2030. The cumulative excess mercury in China will reach around 10,000 tons in 2050 under the assumption of no export of it between 2010 and 2050.

The point at which mercury reaches a surplus in Asia (excl. China) was estimated to be the year 2039. The excess mercury in Asia including China in 2010–2016 was estimated to be negative, and thus imports from outside Asia should be taken into consideration. The mercury supply in Asia strongly depends on the usage of excess mercury in China. It is estimated that mercury supplies will be insufficient in Asia at least until 2017, so it should be possible to consider the import and/or export of mercury-containing products defined by the MCM. The point at which mercury in Asia (excl. China & Japan) reaches a surplus will be the year 2030 if the mercury usage of ASGM is excluded. The cumulative excess mercury in Asia (excl. China) taking into account only the annual excess mercury from chlor-alkali decommissioning was estimated to be 875 tons in 2050; in addition, the cumulative excess mercury in Asia under the assumption of export from China between 2010 and 2050 was estimated to be 7643 tons in 2050. Thus, a long-term strategy for excess mercury management will be necessary.

The size of the surplus of mercury and the time at which this surplus will start to arise markedly depend on different scenarios (or assumptions), based on policies and regulations associated with the prevention of mercury pollution. There will be no excess mercury after the year 2025 and a mercury shortage will occur in the scenario where the recycling rate of mercury from LZS in China is 0% (option 1). In the scenario where the recycling rate is 50% (option 2), the Chinese cumulative surplus of mercury was estimated to be almost half of that in the baseline scenario. In the case of the whole of Asia, especially the time point at which mercury reaches a surplus, there are no prominent differences between the recycling rates from LZS scenarios. There are also no obvious differences in total mercury use, Chinese annual excess mercury, and Asian annual excess mercury between the baseline scenario and the restriction of mercury use in ASGM scenarios. For the scenario of a restriction of formal mercury mining in China, total mercury supplies will be reduced and mercury will reach a surplus a few years later compared with the baseline scenario.

The results of this study will support decision-making and planning for long-term storage capacity, discussions of regional coordination, securing of technical support, and development of the basic design of related facilities.

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References

1. NWMOA (Northeast Waste Management Officials' Association) (2008) Trends in mercury use in products: Summary of the interstate Mercury Education & Reduction Clearinghouse (IMERC) Mercury-added Products Database. http://www.newmoa.org/prevention/mercury/imerc/factsheets/mercuryinproducts.pdf
2. MOE (Ministry of the Environment) (2010) Material Flow of Mercury in Japan (in Japanese)
3. MNRE (Ministry of Natural Resources and Environment) and DOE (Department of Environment) (2006) Substance flow analysis of mercury in Malaysia
4. A. Cain, S. Disch, C. Twaroski, J. Reindl, and C. R. Case (2007) Substance Flow Analysis of Mercury Intentionally Used in Products in the United States. *J. Ind. Ecol.*, 11(3): 61–75
5. M. Takaoka (2004) Mercury and mercury-containing waste management in Japan. *J. Mater. Cycles Waste Manag.*, 17 (4): 665–672
6. M. Harada (1995) Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. *Crit. Rev. Toxicol.*, 25 (1) 1–24
7. UNEP _a (United Nations Environment Programme) (2013) Global Mercury Assessment 2013: Sources, emissions, releases, and environmental transport
8. P. Maxson (2009) Assessment of excess mercury in Asia, 2010-2050. UNEP (United Nations Environment Programme) Concorde report. http://wedocs.unep.org//handle/20.500.11822/11764. Accessed 11 July 2017
9. Website of the Minamata Convention on Mercury. http://www.mercuryconvention.org/. assessed 8 March 2016
10. UNEP _b (United Nations Environment Programme) (2013) Minamata Convention on Mercury
11. Concorde (2006) Mercury Flows and Safe Storage of Surplus Mercury
12. UNEP (United Nations Environment Programme) Chemicals Branch (2006) Summary of Supply, Trade and Demand Information on Mercury
13. SHINKO RESEARCH CO., LTD (2011) Survey on material flows, supply and demand of mercury-containing products (in Japanese)
14. C. B. UNEP DTIE (2011) Study on the possible effects on human health and the environment in Asia and the Pacific of the trade of products containing lead, cadmium and mercury
15. Habuer, Y, Zhou., and M. Takaoka (2018) Time-series analysis of excess mercury in China. *J. Mater. Cycles Waste Manag.,* 20 (3): 1483–1498
16. R. Sodeno and M. Takaoka (2017) Outlook for Future Material Flows of Mercury in Japan in Context of the Minamata Convention on Mercury (in Japanese). *Mater. Cycles Waste Manag. Research.*,28(0): 128-139
17. UNEP (United Nations Environment Programme) Global Mercury Cell Production Data. assessed 29 April 2015
18. World Chlorine Council Report to UNEP on Chlor-Alkali Partnership. assessed 29. April 2015
19. CCICED（China Council for International Cooperation) (2011) Special Policy Study on Mercury Management in China. presented at the CCICED 2011 Annual General Meeting, Beijing, China
20. Mercury Watch: Global database. http://www.mercurywatch.org/. assessed 8 June 2015
21. USGS _a (United States Geological Survey) (2013) 2013 Minerals Yearbook: Mercury [Advance Release]
22. N. Yoshimoto, M. Takaoka, K. Oshita, and T. Mizuno (2011) Estimate of the amount of recovered mercury from nonferrous metal smelting (in Japanese). *Proc. Annu. Conf. Jpn. Soc. Mater. Cycles Waste Manag.*, 22: 247–247
23. USGS _b (United States Geological Survey) (2013) 2013 Minerals Yearbook: Zinc [advance release]
24. MOE (Ministry of the Environment) (2013) Material flow and air emissions inventory of mercury (Announcement) (in Japanese)
25. Habuer, N. Yoshimoto, M. Takaoka, T. Fujimori, K. Oshita, N. Sakai, and S. A. Syed Abd Kdir (2016) Substance flow analysis of mercury in Malaysia, *Atmospheric Pollut. Res.,* 7(5): 799–807. http://dx.doi.org/10.1016/j.apr.2016.04.005