Emission Estimate of Passport-Free Heavy Metal Mercury from Indian Thermal Power Plants and Non-Ferrous Smelters

By
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Preface of the Report

Globally coal is used for energy and the annual coal consumption has doubled in last three decades (from 2780 Mt to ~ 5000 Mt from 1980 to 2008 respectively) in the World. The consumption of coal is the most in Asia (2610 Mt) followed by North America (1050 Mt), others (540 Mt) and Europe (400 Mt) in year 2004. India is the third-largest producer of coal in the world. Coal production in India has risen from less than 1 Mt in 1880 to 456.4 Mt in 2007/08. Coal consumption and demand have grown enormously in India, primarily dominated by the power plants. In 1970, power generation consumed about 13 Mt (less than 20% of total coal consumption), which has increased to about 280 Mt in 2003 (TEDDY, 2009). In post 1980's, the power sector emerged as the largest consumer followed by other industries like smelting, cement etc. There are more than 50-coal based TPPs in India having installed capacity 14.6 GigaWatt (GW) in year 2008 where Central, state and private were having figures 6.6 GW, 3.8 GW and 4.2 GW respectively (Electricity Authority, 2008).

Zn and Cu production in India has been ~doubled from 278 Gg to 440 Gg and 394 Gg to 734 Gg respectively, whereas Pb production remain the same (119 Gg to 124 Gg) from 2003 to 2007.

To produce these non-ferrous metals the energy need mainly coal dependent. The coal consumption in these industries has increased from 31 million tonnes to 60 million tonnes between years 2004 to 2008. Though the energy consumption-share of these smelting industries was less than 12 % to total coal used in the country (TEDDY, 2009). But, the Hg-emission by burning of coals only add a part of the total emission since major contribution is from the dissociation of Hg-from the ore itself. During the smelting process, almost all Hg

The aim of this report is to review the current status of the available technology in these sectors, to make sector specific inventory of Mercury. Making future emission projection of Hg from thermal power plants. And Also to make species specific emission of Hg from these sectors.

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Chapter 1

Mercury release from Thermal power plant

1. Introduction

Mercury (Hg), a potential contaminant to the environment is of global concern because of its toxic nature, trans-boundary movement and ability of bioaccumulation etc. The residence time of elemental Hg in the atmosphere is 0.5 to 2-years (Schroeder and Munthe, 1998). Coal consumption is one of the prime anthropogenic sources of Hg in the biosphere (Pacyna et al., 2006). Hg content in the coal varies from place to place (0.01-0.5 mg/kg) and depends upon the coal-type in the world (Park et al., 2006).

Globally coal is used for energy and the annual coal consumption has doubled in last three decades (from 2780 Mt to ~ 5000 Mt from 1980 to 2008 respectively) in the World. The consumption of coal is the most in Asia (2610 Mt) followed by North America (1050 Mt), others (540 Mt) and Europe (400 Mt) in year 2004. India is the third-largest producer of coal in the world. Coal production in India has risen from less than 1 Mt in 1880 to 456.4 Mt in 2007/08. Coal consumption and demand have grown enormously in India, primarily dominated by the power plants. In 1970, power generation consumed about 13 Mt (less than 20% of total coal consumption), which has increased to about 280 Mt in 2003 (TEDDY, 2009). In post 1980's, the power sector emerged as the largest consumer followed by other industries like smelting, cement etc. There are more than 50-coal based TPPs in India having installed capacity 14.6 GigaWatt (GW) in year 2008 where Central, state and private were having figures 6.6 GW, 3.8 GW and 4.2 GW respectively (Electricity Authority, 2008).

Up to now only limited study has been conducted to test the mercury emission from any thermal power plants in India (CPCB), though some tests had been done for knowing the mercury content in the coal in India by BHEL, 2004. Mukherjee et al., 2008 attempted to prepare emission inventory of Hg-from various sources in India for the year 2000 and 2004.

Under the present report we will be making emission inventory for the period 2000 to 2008 on the emission factor (EF) approach for Indian thermal power plants. And also emission projection for the year 2009 to 2020 from this sector will be estimated.

2. Coal and Thermal Power Plants in India

Exploration, development, and sale of coal and lignite resources in India are completely under the oversight of the Indian Government, through the Ministry of Coal. The Ministry of Coal effectively determines all matters relating to the production, supply, distribution and sale price of coal. The Ministry is in administrative control of major coal-producing companies including Coal India Limited (CIL), Singareni Colliery Company Limited (SCCL), and Neyveli Lignite Corporation (NLC). The Geological Survey of India (GSI), the Mineral Exploration Corporation (MEC), SCCL, and CMPDIL map India's coal resources by undertaking prospecting surveys in areas with potential coal resources. The GSI and MEC are under the jurisdiction of the Ministry of Mines.

In addition to the Ministry of Coal, the Ministry of Power plays a key role in recommending coal linkages to power projects and in recommending coal block allocations for captive mining. The Planning Commission of India sets the long-term vision and priorities for the government and provides overall policy guidance and sectoral growth targets for all government ministries through its national plans. The Power and Energy Division of the Planning Commission also provides support to an Energy Coordination Committee under the chairmanship of the Prime Minister that addresses all key energy sector issues.

Among the other government entities involved in coal, the Ministry of Environment and Forests plays a key role in regulating the environmental impacts of mining and in providing clearances for mining in forestlands. The Ministry of Mines (through the GSI and MEC) also facilitates coal resource exploration. The Directorate General of Mines Safety, in the Ministry of Labor, helps protect occupational health and safety of mine workers in India through legislation, examinations, inspections and investigations. (http://www.pewclimate.org/docUploads/india-coal-technology.pdf).

The quality of Indian coal is poor and has gotten worse over the past decades. Indian coal has the general properties of the Southern Hemisphere Gondwana coal, whose seams are interbanded with mineral sediments (IEA, 2002). Run-of-mine coals typically34 have high ash content (ranging from 40–50%), high moisture content (4–20%), low sulfur content (0.2–0.7%), and low calorific values (between 2500–5000 kcal/ kg) (IEA, 2002). A comparison of Indian coals to Ohio and Chinese coals indicates the key differences like ash content in Indian coal is ~3-times than US and ~6-times than China (see Table 1). Selected coals from the U.S. and China have about twice the calorific value and carbon content of Indian coals. The low calorific value implies more coal usage to deliver the same amount of electricity. Indian coal, however, has lower sulfur content in comparison to other coals, although it has relatively high amounts of toxic trace elements, especially mercury (Masto *et al.*, 2007).

Table 1: Typical coal characteristics from few thermal power plants of India, China and US

Details (%)	India			Ohio (US)	Long (China)	Kou
	Kahalgaon	Simhadri	Sipat			
Carbon	25.05	29.00	30.72	64.2	62.8	
Hydrogen	2.95	1.88	2.30	5.0	5.6	
Nitrogen	0.50	0.52	0.60	1.3	1.4	
Oxygen	6.71	6.96	5.35	11.8	21.7	
Moisture	18.5	15.0	15.0	2.8	11.0	
Sulphur	0.17	0.25	0.40	1.8	0.9	
Ash	46.0	46.0	45.0	16.0	7.7	
Calorific value (kcal/kg)	2450	2800	3000	6378	6087	

(Source: Visuvasam et al., 2005)

Indian power sector comes under the Ministry of Power India. Earlier known as Ministry of Energy, it comprised of separate departments for power, coal and non-conventional sources of energy. In 1992, the Ministry of Power started working independently with work areas covering planning and strategizing the Indian power projects and policies. The power management and implementation of the various power projects undertaken, formulation and amendments of the power laws in India, management of the power supply in India, monitoring of the power plants in India, power companies in India, power generation in India and other power shortage problems etc. Central Electricity Authority (CEA) coordinates the Ministry of Power (MoP) in all technical and economic aspects. Along with the CEA, other subsidiary organizations of the Mop are:

- National Thermal Power Corporation (NTPC)
- National Hydro Electric Corporation (NHEC)
- Power Finance Corporation of India (PFCI)
- Nuclear Power Corporation of India Limited
- North Eastern Electric Power Corporation (NEEPC)
- Rural Electrification Corporation (REC)
- Damodar Valley Corporation (DVC)
- Bhakra Beas Management Board (BBMB)
- Tehri Hydro Development Corporation (THDC)
- Satluj Jal Vidyut Nigam (SJVN)
- Power Grid Corporation of India Ltd (Power Grid India)
- Power Trading Corporation (PTC)
- Bureau of Energy Efficiency (BEE)

The Power Ministry India has set up Power Finance Corporation of India that looks after the financing of the power sector in India. The Power Finance Corporation Limited provides finance to major power projects in India for power generation and conversion, distribution and supply of power in India. The power Ministry is concerned with perspective planning, policy formulation, processing of projects for investment decision, monitoring of the implementation of power projects, training and manpower development and the administration and enactment of legislation in regard to thermal, hydro power generation, transmission and distribution (http://www.indiahousing.com/infrastructure-in-india/power-sector-india.html).

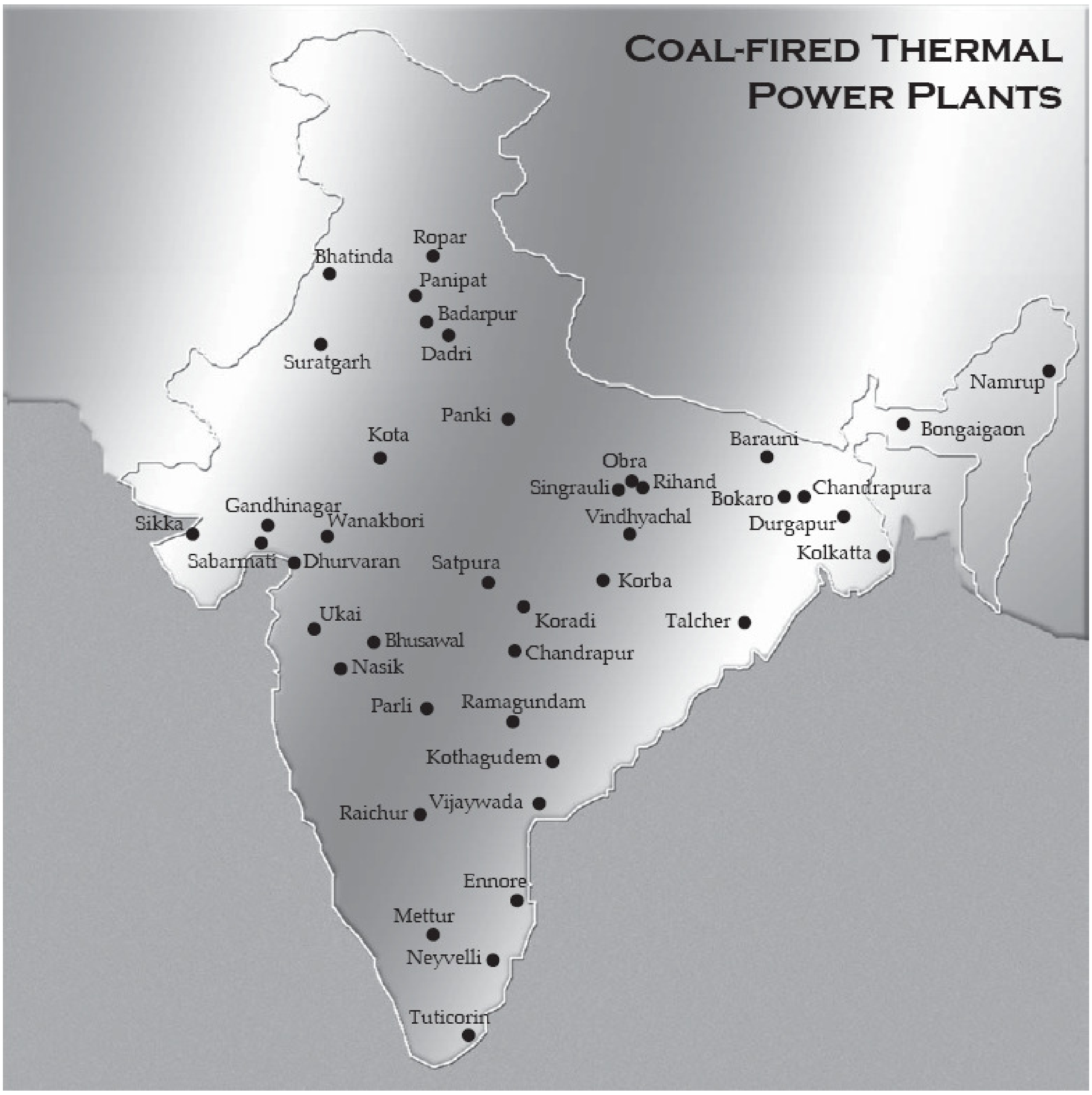


Fig. 1: Location of coal based thermal power plants in India

3. Methodology

3.1 Coal consumption in TPPs

Coal consumption in TPPs in India has increased from 273 Mt to 321 Mt in which contribution of imported coal were 7 to 8 Mt only from year 2006 to 2008 respectively (CEA, 2008). **Table 2** gives brief about the coal consumption in TPPs based upon regions. Details of plant specific coal consumption and amount of imported coal used could be seen in the **Annexure 1 and 2** respectively.

Table 2: Region specific coal consumption (Gg) in Thermal Power Plants (TPPs) in year 2006 to 2008

	Year		
Regions	2005-06	2006-07	2007-08
Northern	76837	83072	89302
Western	88370	91346	106369
Southern	48855	55027.00	58399
Eastern	59382	65000	67147
North-East	0	0	
All Regions	273444	294445	321217

Source: CEA annual report, 2007-08.

3.2.1 The size and vintage of coal based units in India installed between 1965 to 2005

Coal-based thermal power plants in India could be sub-divided into 4-subgroups based on the installed capacity as follows: <100, 100 to 150, 200 to 250 and 500 MW respectively. **Table 3** shows the age of the coal-based units under the sub-group of above-mentioned sub-groups from the year 1965 to 2005.

Table 3: Size and vintage of coal based units in India from 1965 to 2005

Installation	**Age (year)**	**Installed capacity (MW)**				
Year		<100	100 to150	200 to 250	500	Total
2001-2005	<5	-	490	3165	4500	8155
1996-2000	5-10	75	740	5280	2000	8095
1991-1995	10-14	205	120	8060	3500	11885
1986-1990	15-19	332	890	8370	5500	15092
1981-1985	20-24	540	1670	8270	500	10980
1976-1980	25-29	120	2640	3290	-	6050

1971-1975	30-34	460	2710	-	-	3170
1966-1970	35-39	2210	720	-	-	2930
<1965	>40	1466	430	-	-	1896
	Total	5408	10410	36435	1600	68253

3.2.2 Installed capacity for the TPPs in India

Table 4: Region specific installed capacity of TPPs in year 31.10.2009

Region	**Coal based**	**Gas based**	**Diesel based**
Northern	20062.50	3563	12.99
Western	27015.50	8143.81	17.48
Southern	17822.50	4159.78	939.32
Eastern	16395.38	190.00	17.20
N. Eastern	60.00	766.00	142.74
Islands	0.00	0.00	70.02

Source: MNRE, 2009.

3.2.3 Sector wise plant load factor (PLF) of TPPs in India

Thermal generating units in India are under the ownership of following viz. Central, State and Private. Among all these sectors PLF achieved by Private Sector stations was the highest (91%) whereas state performed the least (72%) at the National level. Sector wise PLF of thermal units during the years 2006 to 2008 are given in **Table 5**.

Table 5: The installed capacity (MW) Versus plant load factor (%) under the central, state and private ownership from year 2005-06 to 2007-08 in India

Sector	Capacity (MW)			Plant Load Factor (%)		
	2005-06	2006-07	2007-08	2005-06	2006-07	2007-08
Central	25527.5	26470.0	28220.0	81.91	84.95	86.74
State	37846.5	38051.5	39274.5	67.30	70.84	72.09
Private	3075.0	3075.0	3075.0	85.37	86.35	90.77
Total	66449.0	67596.5	70569.5	73.71	77.03	78.75

Source: www.cea.nic.in

The all India PLF of thermal power plants has improved over the years 74 % to 79% respectively for the year 2005-06 to 2007-08. There are large inter-regional variations in the PLF. Thermal power station in the southern region have the highest PLF, of 85%, while those in the northern region have only 20% PLF. In fact, the PLF of thermal power station of eastern and the north- eastern region is lower than that in the other regions (TEDDY, 2009).

Table 6: The PLF (%) of TPPs in India as per their installed capacity in the year 2007-08

Installed capacity (MW)	Units commissioned up to 31st March 2008		Units reviewed		PLF (%)
	No.	Capacity (MW)	No.	Capacity (MW)	
500	39	19500	37	18500	87.58
300	4	1200	0	0	-
250	24	6000	17	4250	88.78
210	140	29400	138	28980	82.71
195-200	24	4795	24	4795	82.71
100-150	84	9442	81	9160	55.39
<100	85	4602	88	4884	54.33
Total	400	74939	385	70569.5	78.75

3.3 Mercury in Coal

Many studies across the globe have been done to quantify the content of Hg in coal. Pacyna, 1989 quantified Hg content in the bituminous coal from the developed countries whereas Park, 2006 analyzed different coals from countries like Korea, Australia, China, Indonesia, and Russia. Mukherjee et al, 2008 compiled Hg-concentration from many studies given in **Table 7**. There is dichotomy in the hypothesis behind the Hg-content in coal and sulphur content in the coal (Yudovich and Ketris, 2005) whereas coals having high density, e.g. are buried deep in the ground they often contain a high concentration of Hg. Broadly said then anthracite coals have higher Hg-content than bituminous coals. Hg-estimation in coal is technique sensitive, e.g. acid extraction and pyrolysis will provide different results for the same type of coal.

Table 7: Mercury (Hg) concentration in bituminous and other coal types across the world

Country	Hg in Bituminous coal (mg/Kg)	Hg in coal (mg/Kg)
Australia	0.026-0.40[a]	0.01-1.0[b]
Germany	0.70-1.40[a]	-
Japan	0.027-0.11[a]	0.045[b]
New Zealand	0.020-0.56[a]	-
Poland	0.050-0.07[a]	-
England	0.20-0.70[a]	-
USA	0.01-1.80[a]	0.17[b]
South America	-	0.20-0.96[b]
The former Soviet Union	0.074-0.18[a]	0.02-0.9[b]
China	-	0.15-0.303[b]
Europe	-	0.01-1.5[b]
Korea	-	0.012-0.048[b]

Where a: Pacyna, 1989; b: Mukherjee et al, 2008; -: not available

3.3.1 Mercury Content in Indian Coal

Indian coal contains Hg ranging from 0.11 to 0.80 μg of Hg per gram of coal reported by various researchers and organizations across the country. Hg total in the coal mg per kg,

Table 8: Mercury (Hg) concentration in Indian coal across the India

Locations	Hg in coal (µg/g)
GHTTP, Lehra, Mohabatt	0.26[a]
Anpara, UP	0.26[a]
North Chennai	0.33[a]
NLC-TPS II	0.18[a]
Chandrapura STPS	0.325[a]
Kolghat TPS	0.61[a]
Talchar TPS	0.33[a]
Gandhinagar TPS	0.42[a]
India	0.11-0.80[b]
India	0.11-0.14[b]
India	0.09-0.487[c]
India	0.2±0.007[d]
Current study (mean)	0.334[e]
Current Study (Max)	0.61[e]
Current Study (Min)	0.18[e]

Source: a: BHEL, 2004; b: Mukherjee et al., 2008; c: CPCB report; d: Reddy et al., 2005
e: average of BHEL, 2004 taken as study was conducted for the coal used in 8-coal based TPPs.

3.3.2 Estimation of Mercury from Indian TPPs

Mercury estimation from the Indian TPPs was done on the basis of consumption of annual consumption of coal and average emission factor (EF) of Hg in coal used in this sector.

$$(E_{Hg})_{year} = (\text{Coal Consumption})_{year} \times (EF)_{Hg} \text{ ------------------------------------ } (1)$$

Where, $(E_{Hg})_{year}$: Annual Emission of Mercury (Kg) from thermal power plants;

$(\text{Coal Consumption})_{year}$: Annual consumption of coal (Gg) in thermal power plants given in annexure 1;

$(EF)_{Hg}$: Emission Factor of Mercury used (0.334 g/Ton) from thermal power plants. Taking average result from the BHEL, 2004, derived emission factor under the current study. As BHEL, 2004 has done Hg-test in 8-thermal power plants across the country so mean value of emission factor from this study was taken for estimating Hg in the current study.

3.3.3 Estimation of the range of Hg-emission

Emission of Hg depends upon the type and quantum of coal in use. To see the upper and lower range of possible Hg-emission from the TPPs, lower and upper end of the coal EF for Hg was used. Under the current study we took the lower (0.18 g/Ton) and upper (0.61 g/Ton) limit of EF for coal based upon BHEL, 2004.

3.4 Species- specific Emission profiles of Hg from TPPs in India

Hg-in coal released into the exhaust gas as per elemental-Hg at the high temperature. Part of elemental Hg formed got oxidized to mercuric form in presence of SO_2, fly-ash etc. Physico-chemical properties of Hg depend upon their state. Like elemental is insoluble whereas mercuric is soluble in water. Because of the soluble nature of mercuric-form it has a tendency to get associate or adhered to the particles in the flue-gas as well (Wang et al., 2009). The residence time of Hg in the elemental state varies between 0.5 to 2-years whereas in the Hg^{+2} and Hg-particulate much less (few days to weeks). So, elemental Hg has contribution in the global circulation whereas other forms predominate in the regional one by atmospheric deposition.

Pirrone et al., 2001 factorize Hg-emitted from TPPs into elemental Hg-in gas, particulate and mercuric form in factor 0.5, 0.1 and 0.4 respectively. Based upon Pirrone et al., 2001 speciation of Hg was done for Indian TPPs for the year 2005 to 2008 estimated under the current study.

4. Mercury emission from Indian thermal power plants

4.1 Estimated range of Hg-emission

Total coal consumption (Gg) was taken from Table 2 to estimate Mercury emission from Indian TPPs by using equation 1. Hg-content in the coal varies from mine to mine and also place to place (Table 7 and 8). So, it was important to see the range (upper, mean and lower) of emission using lowest possible, mean and highest value of the emission factor (BHEL, 2004). Since mine specific emission factor data was currently unavailable and also sources of coal for each power plants varies and mostly many (Annexure 3). So, we have estimated the bandwidth of Hg-emission keeping emission factor as a variable. We have seen that emission estimation of Hg is very uncertain under the current situation for example the change in only one variable had given us the range between 59 Ton to 200 Ton for the year 2008 by taking lowest and highest studied emission factor by BHEL, 2004.

Base upon the BHEL, 2004, we found that there was only one TPP out of 8-chosen who had these extreme values and rest were in between. Based upon this evidence it could be concluded that in majority of cases the emission factor might be lying in between. So, out of emission range as discussed in Fig. 2 the most possible can be the estimated mean value, which has increased from 95 Ton to 112 Ton from 2006 to 2008 respectively.

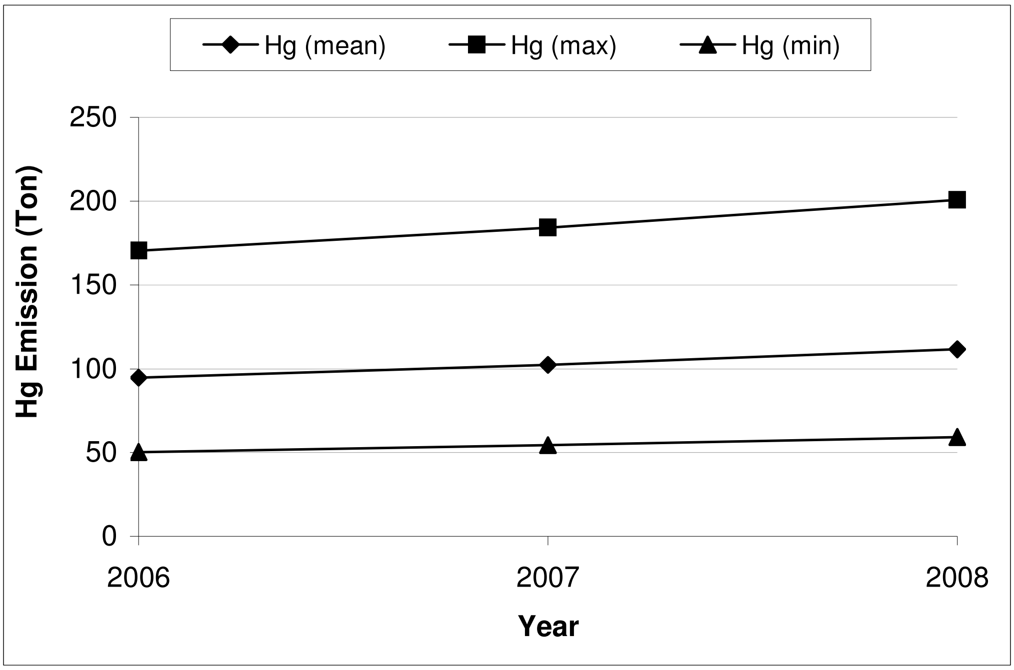


Fig. 2: Estimated range (minimum, mean and maximum) of emission for the Indian TPPs (2006-2008)

4.2 Species- specific Emission profiles of Hg from TPPs in India

Importance of fractionating Hg-emitted from the Indian TPPs were two-fold, 1) mainly has regional and or local deposition so as a result of regional to local concerns with respect to human health, vegetation and eco-system, and 2) its easier to capture Hg^{2+} and may be effectively done with the help of typical air pollution control devices (APCD) like electrostatic precipitators (ESP), fabric filter (FF) and flue gas desulfurization (FGD) devices. Though the efficiency of these devices varies and the emission speciation is an important source of uncertainty in assessing the atmospheric fate of the as a result of difference in the physico-chemical properties of these forms (Wang et al., 2009).

Based upon Pirrone et al., 2001 speciation of Hg was done for Indian TPPs for the year 2005 to 2008 estimated under the current study. **Table 9** shows estimated species-specific emission of Hg (Ton) from TPPs in India from year 2005 to 2007, estimated by taking values from the mean estimated Hg-emission **(Fig. 2)**. Based upon the above discussion we can say that it can be easy and cost effective to capture ~50% of total Hg-emitted from TPPs.

Table 9: Species-specific emission of Hg (ton) based upon estimated- mean value of from TPPs in India

Species of Hg	2006	2007	2008
Hg^0 (gas)	47.4	51.2	55.8
Hg^{+2}	37.9	40.9	44.6
Hg (particulate)	9.5	10.2	11.2

5. Projection for the Hg-emission for year 2008-2020 from Indian TPPs

The demand for coal in India's power plants has rapidly increased since the 1970s, with power plants in 2005–06 absorbing about 80% of the coal produced in the country. Other key coal consumers are the steel and cement industries. A large fraction of India's coal is transported using railways, and the future development of coal is linked to greater investments in coal transport infrastructure.

During the 11th Plan (year 2007-2012), a tentative capacity addition of 66,643 MW is planned comprising of 17,189 MW of hydro, 46,114 MW of thermal (44,000 MW coal/lignite, 2,114 MW gas/LNG) and 3,200 MW of nuclear capacity. During the 12th Plan (2013-2017), a tentative capacity addition of 86,500 MW is planned comprising of 30,000 MW of hydro, 44,500 MW of thermal and 12,000 MW of nuclear capacity.

Table 10: Proposed capacity addition (MW) in various power sectors including Coal based thermal power plants in India

5-yearly plan	Hydro (MW)	Thermal (MW)		Nuclear (MW)	Total capacity addition (MW)
11th (Year 2007-2012)	17,189	44,000 (Coal)	2,114 (Gas)	3,200	66,643
12th (Year 2013-2017)	30,000	44,500		12,000	86,500

Source: www.cea.nic.in, accessed on 21st Jan 2010.

The demand for coal in India is expected to increase rapidly in the future, dominated mainly by the power sector. It is projected that about 47 gigawatts (GW) of new coal-based power plants will be installed during the 2007–2012 period; total consumption of coal in the power sector is expected to be about 550 MT by 2012. Coal use for electricity generation in India is projected to grow by 1.9 percent per year (www.eia.doe.gov).

5.1 Methodology adopted in estimating Hg-emission projections (2009-2020)

Projection for the increase in annual coal consumption (1000 ton) estimated by taking into account the annual growth rate of coal consumption and base year taken for the extrapolation of was the year 2008 (**Table 11**). Further Hg-emission from TPPs was estimating by using equation 1 and keeping EF remain the same (0.334 g/Ton).

Table 11: Extrapolated coal consumption in power sector in India from 2009 to 2020

Year	Rate of increment in annual consumption (%)	Increase in annual coal consumption Projected (1000 ton)	Total projected coal consumption (1000 ton)
2009	1.9	6219	333539
2010	1.9	6337	339876
2011	1.9	6458	346334
2012	1.9	6580	352914
2013	1.9	6705	359620
2014	1.9	6833	366453
2015	1.9	6963	373415
2016	1.9	7095	380510
2017	1.9	7230	387740
2018	1.9	7367	395107
2019	1.9	7507	402614
2020	1.9	7650	410264

5.2 Projected Hg-emission from the coal based TPPs in India (2009-2020)

Using lowest and highest possible emission factor for Hg-emitted from TPPs we can see that the projected estimate for the 2020 can be between 68 Tons to 250 Tons. Apart from emission factor of coal there are certainly other factors like the actual growth rate in the coal consumption and use of typical air pollution control devices in future can chance the projected estimate under the current study.

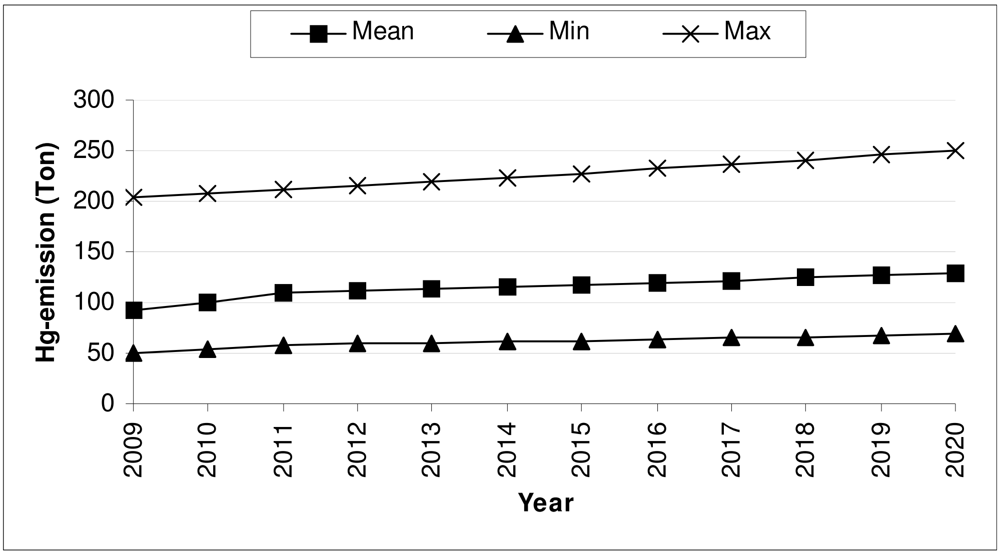


Fig. 3: Emission projection of Hg-from coal based TPPs in India (2009-2020)

6. Technologies to control Hg-emission from TPPs

Control-technology options for reducing Hg-releases may divide in the following three categories, (1) Pre-treatment measures; (2) Combustion modifications; and (3) Flue gas cleaning or end-of-pipe controls.

6.1 Pre-treatment measures

This typically includes Coal Beneficiations. Coal beneficiation is a generic term, used for washing of coal and is done to lower the ash by 8 to 12% and increase the Gross Calorific Value *(*GCV), Kcal/ Kg.

Processes and steps involved in coal beneficiation can be as follow-**1)** Raw Coal Input, **2)** Dense Media Processing Unit, **3)** Floats (Clean Coal) and **4)** Sinks

Offsite washing of coal can reduce the transportation cost as the coal is carried over a long distance along with environmental benefits (reducing green house effect and also mercury emission).

Table 15: Total Coal consumption (1000 Tonnes) Versus beneficiated (1000 Tonnes) between April to June 2008 from the respective TPPs of India

TPPs	Total (1000 Tonnes)	Beneficiated Coal (1000 Tonnes)
Badarpur	380	140
I.P. Station	80	80
Rajghat	60	60
Panipat	655	145
Bhatinda	180	35
Lehra Mohabat	380	40
Ropar	600	30
Kota	590	70
NCTPP	400	280

6.2 Combustion modifications

It acts to change the combustion process. These modifications may be used to reduce mercury concentrations in the process flue gas, or they may be used to change the characteristics of the flue gas stream so that mercury is more easily captured in downstream flue gas cleaning equipment. The modifications may include using technologies such as fluidized bed combustor, mass burn/waterwall combustor, low- (Oxides of Nitrogen) NOx burner, etc.

Examples, (1) Low- NOx technology-

It should reduce mercury emissions in the exhaust gases due to lower operating temperatures. Though very limited information is available on this technology hence its difficult to draw firm conclusions. While some sources indicate that a reasonable reduction can be achieved, other preliminary results of staged combustion in atmospheric fluidized bed combustion (AFBC) units indicated that low-NO_x had little effect on trace element emissions.

(2) By increasing Carbon content and subsequent Hg-adsorption capacity of fly ash-

It can potentially be used to improve capture of mercury by increasing the carbon content and subsequent mercury adsorption capacity of fly ash. Increased fly ash carbon content occurs during the use of low-NOx burners or the use of a NOx control technology called re-burning. This results from fuel-enriched regions within the combustion system. While increased Hg- capture has been shown to occur with increased fly ash carbon, this phenomenon has not been used in commercial practice for the control of mercury emissions, and it should be considered a potential control option that might be available in the future.

6.3 Flue gas treatment, or end-of-pipe controls

These are currently deployed for control of SO_2, NOx, particulate matter (PM) and hence also trace metals like Hg. SO_2 control technologies include a variety of wet and dry scrubbers; NOx may be controlled by selective catalytic or selective non-catalytic reduction; and PM might be controlled by fabric filters (FFs) or electrostatic precipitators (ESPs). There has been extensive testing of the Hg- removable capabilities of these systems on a wide range of coal-fired utility boilers in the USA. The average results ranged from 0% to 96 % dependent on a variety of factors.

Additional Hg-control can be achieved by injection of a sorbent (carbon- and/or calcium based) prior to the flue gas treatment system.

Research so far has indicated that the most cost-effective approach to mercury control may be an integrated multi-pollutant (SO_2, NOx, PM, and Hg) control technology.

The major Hg- capture mechanisms include the adsorption of Hg-onto solid surfaces and the solvation of Hg-in liquid scrubbers. Hg- can be adsorbed onto fly ash or entrained sorbent particles for subsequent capture in PM control devices. Hg- can also be captured in packed beds containing a variety of sorbents.

Distribution of Hg- within the various streams of wet flue gas desulfurisation (FGD) systems has been studied in a number of countries. These studies have shown that Hg-capture in wet FGD scrubber systems depends on the rank of coal burned, and the design and operating conditions and generally preceded by PM control devices (i.e., ESPs or FFs).

The total amount of Hg captured in a boiler equipped with a scrubber depended on the amount of Hg captured in the upstream PM control device and the soluble Hg2+ captured by the scrubber. Flue gas from the exhausts of units burning bituminous coals exhibited higher levels of Hg2+ than flue gas from burning of lower rank coals; this Hg can readily captured in the PM control device and downstream scrubber. Hg in the exhausts of units burning low rank coals tended to be Hg0, and Hg capture in these units tended to be minimal. The scrubber chemistry must also be controlled to insure that Hg2+ that is dissolved in the scrubber liquor is not converted back to Hg0 and re-entrained in the flue gas. Scrubber sludges must also be handled in an environmentally acceptable manner.

Pacyna reported that some wet FGD systems are unable to remove more than 30 % of the Hg in the flue gas, but in general the removal efficiency ranges from 30 to 50 % (Pacyna and Pacyna, 2000). Short-term tests in the USA have exhibited emission reductions for units firing bituminous coals that range from 40 to 95 %. The best capture was found for a unit equipped with a FF and a wet limestone (a type of FGD) scrubber.

Soluble forms of Hg like [Hg(Cl_2)] and other ionic forms can be captured in wet scrubbers. Hg0 is relatively insoluble in aqueous solutions and it must either be adsorbed onto a solid, or it must be oxidized to an ionic form that can be captured by scrubbing. Wet FGD systems used on units burning bituminous coal (which emit relatively more of the water soluble ionic Hg) perform much better than do such systems on units burning sub-bituminous coal (which emit relatively more non-soluble elemental Hg).

Table 12: Efficiency of common Hg- control technologies for utility

Control technology	Reduction (%) in Hg
1. Boiler emission control	
Electrostatic precipitator (ESP)	~10
Fabric filters (FF)	~29
Wet Flue gas desulfurization (FGD) System	30-40 (better performance on bituminous coal-fired boilers)
ESP/FF + Wet FGD	~85
High efficiency electrostatic precipitator (ESP)	~77 or less
FGD wet lime	

2. Boiler types and characteristics	
Wet bottom boiler	Produces higher Hg-emission than alternates
Full burner load	Produces similar than others
Fluidized bed combustion	Produces similar or lower Hg
Pulverized coal fired dry bottom boilers	Hg-emission depends upon coal type and control technologies used

(Source: Pirrone et al., 2001)

Hg is sometimes partly and occasionally up to 90% present in the vapor phase such that its collection by PM control devices is highly variable. Low temperature filtration helps to reduce the gaseous mercury off-gas content.

Filtration techniques have developed further, resulting in higher removal efficiencies. Electro-Static Precipitator (ESPs) or Fabric Filters (FFs) operated in combination with FGDs techniques, an average removal rate of 75% and 90% can be obtained for Hg when dust Selective Catalytic Reduction (SCR) devices are additionally employed. Emission control systems Flue Gas Desulphurisation (FGD) plus particulate control devices like (ESP) that use Fabric Filters generally achieves optimum levels of Mercury controls. The capture of mercury can be enhanced by introducing carbon/activated carbon into the flue upstream of the ESP or FF, or by distributing the flue gas throughout a carbon filter bed.

6.4 Current practices in controlling Hg-emissions

The Ministry of Environment and Forest (MoEF) insists on making space provision for Flue Gas Desulphurization (FGD). FGD Plant in the designs of thermal power units of 500MW and above capacity and also at stations with capacity of 1500 to 2000 MW to facilitate their retrofitting at a later stage in case the need for such plant is established. In sensitive areas the installation of FGD Plant may be insisted upon even for stations with smaller capacity.

Number of TPPs having installed capacity 500 has increased from 31 to 37 and their plant load factor (PLF) has also increased from 83 to 87% between fiscal year 2007 and 2008.

Table 13: Performance, number and capacity of 500 MW capacity group of TPPs in India

	2006	2007	2008
Number	31	33	37
Capacity (MW)	15500	16500	18500
PLF (%)	82.73	84.91	87.58

Source: cea, annual report 2007-08.

Dahanu from Reliance and Budge Budge from CESC have announced their PLF 100% for the year 2008.

Table 14: Following three Power Stations had achieved PLF above 100%

Station Name	Capacity (MW)	Organization	PLF (%)
Dahanu	500	Reliance	101.53
Sabarmati	300	Torrent Power	101.42
Budge Budge	500	CESC	100.43

Researchers has found that the overall efficiency of TPPs decline with the installation of emission control devices, since these devices are energy intensive.

6.4.1 Use of beneficiated coal

Coal Beneficiations has been made mandatory w.e.f June 2001 (http://envfor.nic.in/cpcb/newsletter/techind/therm.html). Generally the washed coal being supplied is having a GCV of 4700Kcal/kg and ash of 28-31% in Indian TPPs.

Table 15: Total Coal consumption (1000 Tonnes) Versus beneficiated (1000 Tonnes) between April to June 2008 from the respective TPPs of India

TPPs	Total (1000 Tonnes)	Beneficiated Coal (1000 Tonnes)
Badarpur	380	140
I.P. Station	80	80
Rajghat	60	60
Panipat	655	145
Bhatinda	180	35
Lehra Mohabat	380	40
Ropar	600	30
Kota	590	70
NCTPP	400	280

As per the results from the review of available Hg-controlling technologies Wet FGD System have efficiency to control mercury by 30 to 40% and even better if its bituminous coal.

6.4.2 Electrostatic Precipitators

Electrostatic Precipitators have been provided to control the emission of particulate matter with appropriate stack height for adequate dispersion of gaseous pollutants. For wider dispersal of SO_2, stack height of different capacity units have been stipulated. For units less than 500 MW the stack height has been stipulated as 220 meters whereas 500 MW units it is 275 meters. The details of generation capacity of TPPs and standard corresponding stack height (m) are given in the **Annexure 3**.

6.4.2 Wet ash disposal system (lean phase)

Wet ash disposal system (lean phase) has been adopted. Some of the plants have dry ash disposal/collection system vis-a-vis wet disposal in ash pond with wastewater recycling system.

6.5 Technology requirements

Though the Ministry of Environment and Forest (MoEF) insists on making space provision atleast for Flue Gas Desulphurization (FGD) for TPPs having capacity 500MW but yet this technology has to be functional in India.

There is need to install other pollution control devices which will not only control other emissions especially particulate matter but Hg-too.

1. High efficiency ESPs with EPIC controller should be provided. Further, based on background concentration or future development of power generation in cluster areas, space provision for installation of flue Gas Desulphurisation (FGD) system and DeNOx system, for control of SO_2 and NOx emissions are needed so that the same control be provided where needed. For controlling smaller particulate emissions from stacks i.e. PM10/PM2.5, bag filters may be used as ESP would not trap small particles efficiently. Bag filters may also be used in combination with mechanical collectors or ESPs.

2. Fluidised Bed combustion (FBC)/CFBC technology for the solid fuel containing higher ash and sulphur.

- Integrated Coal Gasification combined cycle (IGCC) technology should be tried.

3. Dense Phase wet ash disposal system. Ash pond wastewater should by recycled hundred percent by the new plants. To promote utilisation of flyash, provision for dry collection and storage (Silos) should be made an integral part of the ash management system.

4. In water scarce areas and in locations where power plants are sited near lakes/reservoir, cooling towers should be provided.

7. Limitation and further scope of the study

The current study provides the emission profile of Hg from TPPs in India but there are certain limitations of this and results must be interpreted with care. For example:

1) **Emission factor:** Average emission factor of Hg in coal used was 0.334 g/Ton based upon the BHEL, 2004. Across the world it's proved that Hg-content in coal varies with region and so with the study done by BHEL, 2004 as well. For

example coal from NLC-thermal power stations has least Hg (0.18 g/Ton) whereas Kolghat has the maximum (0.61 g/Ton). Still there is lack of TPP specific EF for the entire country. Also about 3% of imported coal is used in the country. These imported coals might have quite different EF than Indian one. Though the %age contribution of this imported coal is quite small but still should be taken into account for the better estimation.

8. Mercury (Hg) contamination from Indian TPPs

Release of Hg to air, water and through products may cause adverse impacts on environment and may pose significant risks to aquatic life and ultimately to human beings due to contamination of food chain. Metallic-Hg may also get converted to inorganic and organic-Hg (methyl-form). Organic-Hg could be more harmful to fetuses and young children as it may get entered through food chain.

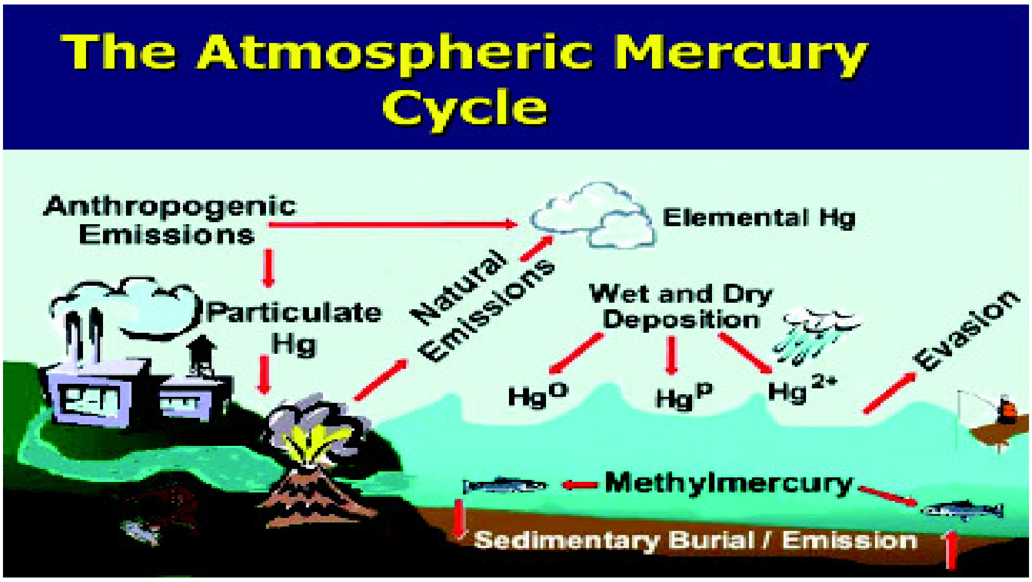


Fig 3: Hg-cycle in the atmosphere

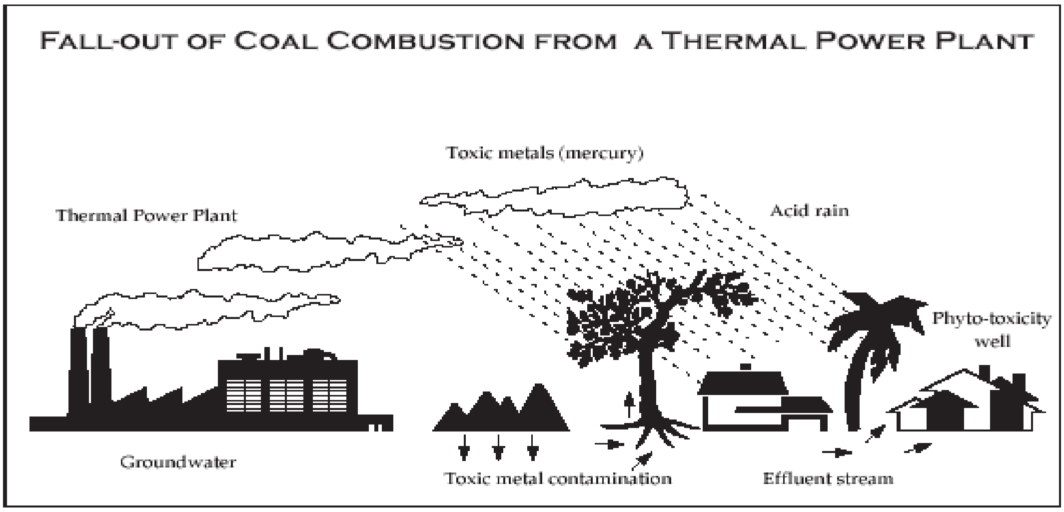
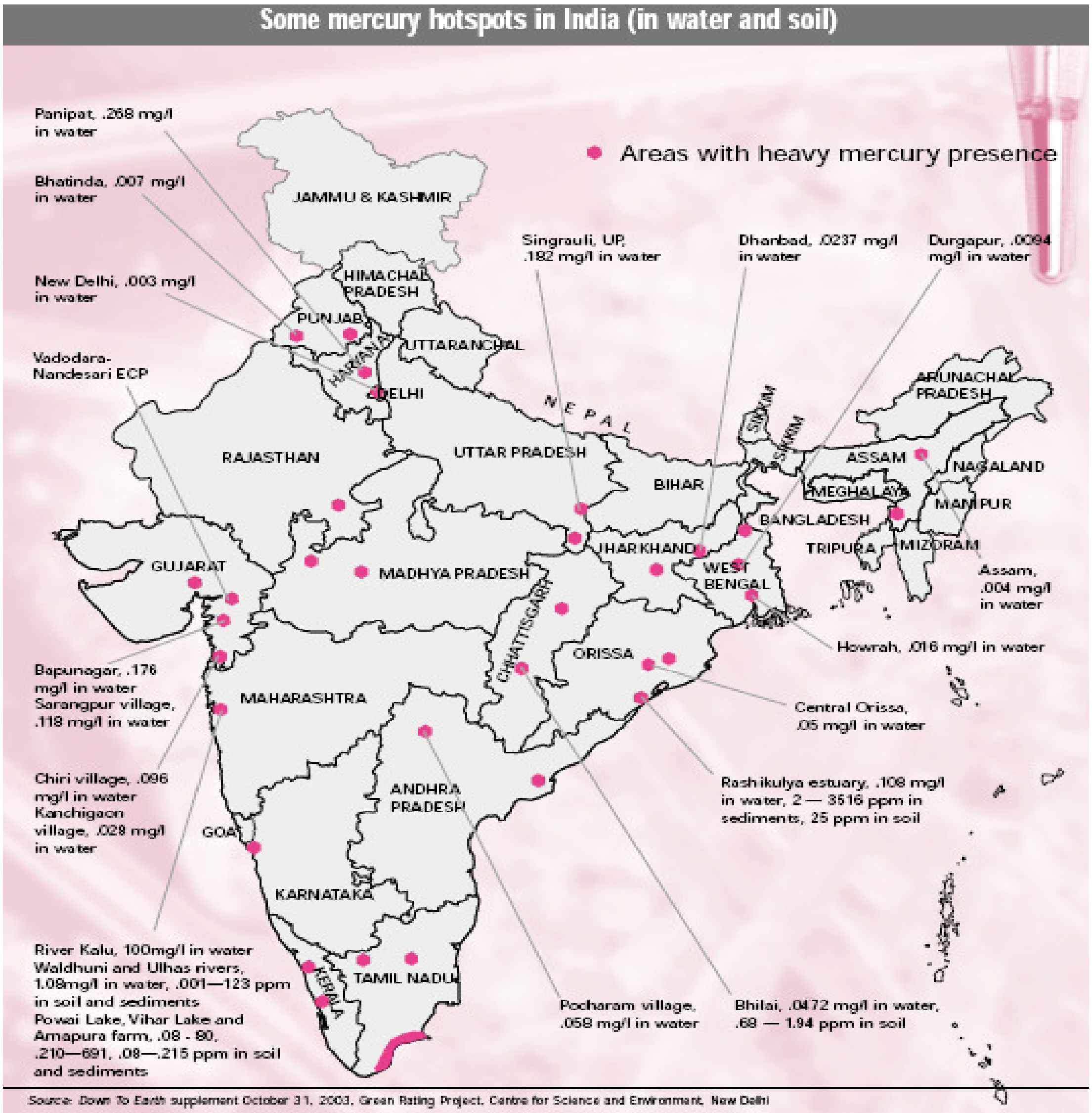


Fig. 4: Fall-out of the Hg-emitted from TPPs (source:toxiclink.org)

8.1 TPP based Hg-hotspots in India

8.1.1 Singrauli area

The Singhrauli area is a major site of thermal power generation in the country at Present. Govind Ballabh Pant Sagar lake is surrounded by the Super Thermal Power Plants (STPP) namely Singhrauli STPP, Vindhayachal SSTP, Rihand STPP, Anpara A & B STPP, Renusagar STPP. CPCB, chose four TPPs at 11 stack monitoring in Singrauli area for the stack monitoring to quantify the balance the Hg in various chemical forms. Singrauli area, though having an installed capacity of producing 9.5% of total thermal power in our country, stands responsible for 16.85 % of total mercury pollution through power generation. It was 58.05 % of Hg in gaseous and 2.4 % in particulate form are being emitted through stack and 32.5 % is retained in ashes (fly ash and bottom ash). The rest 7.05 % could not be accounted in balancing. Industrial Toxicology Research Centre (ITRC), Lucknow, undertook a project for quantitative appraisal of environmental risks due to mercury in Singrauli area. Over 1200 persons residing in the area have been clinically examined and their exposure to Hg assessed through analysis of hair and blood, along with local food land water samples collected from the area. Mean Hg-levels in blood (1055 subject) were significantly higher ($P<0.001$) in the subject as compared to that in controls. Percentage of Subjects from Singauli having more than 5 μg/ml in blood was found to be 66.3% as compared to 10.5% in controls. Mean values of Hg in hair (1183 subject) of the Singrauli subjects were also significantly higher ($p<0.001$) as compared to that in control subjects. Percentage of subjects having more than 1 µg/mg Hg in hair from Singrauli was found to be 47.9 compared to 24.5 in control subjects 19 milk samples out of 22 samples collected from this region had higher Hg levels than the permissible levels of 3µg/l. Mean values were also found to be significantly higher ($p>0.05$). The Hg-in water in this region was 0.182 mg/l (Down to Earth, 2003).


Some mercury hotspots in India (in water and soil)

● Areas with heavy mercury presence

Panipat, .268 mg/l in water

Bhatinda, .007 mg/l in water

New Delhi, .003 mg/l in water

Vadodara-Nandesari ECP

Bapunagar, .176 mg/l in water
Sarangpur village, .118 mg/l in water

Chiri village, .096 mg/l in water
Kanchigaon village, .028 mg/l in water

River Kalu, 100mg/l in water
Waldhuni and Ulhas rivers, 1.08mg/l in water, .001—123 ppm in soil and sediments
Powai Lake, Vihar Lake and Amapura farm, .08 - 80, .210—691, .08—.215 ppm in soil and sediments

Singrauli, UP, .182 mg/l in water

Dhanbad, .0237 mg/l in water

Durgapur, .0094 mg/l in water

Assam, .004 mg/l in water

Howrah, .016 mg/l in water

Central Orissa, .05 mg/l in water

Rashikulya estuary, .108 mg/l in water, 2 — 3516 ppm in sediments, 25 ppm in soil

Pocharam village, .058 mg/l in water

Bhilai, .0472 mg/l in water, .68 — 1.94 ppm in soil

Source: Down To Earth supplement October 31, 2003, Green Rating Project, Centre for Science and Environment, New Delhi

Fig. 5: Some Hg-hotspots in India (source: Down to Earth, 2003)

8.1.2 Tuticorin, India

A coal fired thermal power plant commissioned during 1979, is located along the Coastal region of Tuticorin, India, near Bay of Bengal. East and Southeast of this area is bound by Gulf of Mannar, which is the first Marine Biosphere Reserve in South and Southeast Asia. There are five TPPs each having the installed capacity of 210 MW and using 17–18 Gg of coal per day. The Hg concentration in respirable suspended particulate matter (PM_{10}) was found to be $0.02\pm0.01 \mu g/m^3$ (Jayasekher, 2009).

9. Comparison of Hg-emission from Indian TPPs with other countries

Under the present study Hg-emission estimated was compared with other studies. We found that Hg-emission for the year 2004 by Mukherjee et al., 2009 were exceeding in comparison to the mean-estimated value under the current study. Difference could be as a result of emission factor taken by Mukherjee et al., 2009 was 0.376 g/Ton whereas it was 0.334 g/Ton.

Table 15: Comparison of Hg-estimated under current study with other countries

Year	India (Ton)		China (Ton)	South Africa (Ton)	Europe (Ton)
2000	-	-	-	-	63.5 [b]
2004	121[a]	-	114 [c]	-	-
2005	-	95[e]	125 [c]	112[d]	-
2006	-	102[e]	-	-	-
2007	-	111[e]	-	-	-

Where, a: Mukherjee et al, 2009; b: Pacyna et al., 2006; C: Streets et al., 2009; d: Leaner et al., 2009; e: Current study

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List of Annexure:

Annexure 1: Coal consumption (1000 Tonnes) in respective Thermal power plants from year 2005 to 2007

NORTHERN REGION	2005-06	2006-07	2007-08
DELHI			
Badarpur	3768	3739	4021
I.P.Stn.(DVB)	934	942	982
Rajghat (DVB)	503	529	736
Sub-Total	**5205**	**5210**	**5739**
HARYANA			
Faridabad	797	663	859
Panipat	5829	6852	6910
Yamuna Nagar			50
Sub-Total	6626	7515	7819
PUNJAB			
Bhatinda	1777	1615	2160
Lehra Mohabat	1820	2009	2190
Roper	6179	6494	6801
Sub-Total	**9776**	**10118**	**11151**
RAJASTHAN			
Kota	5342	5445	6019
Suratgarh	5933	6154	6714
Sub-Total	**11275**	**11599**	**12733**
UTTAR PRADESH			
Anpara	8497	8757	8214
Harduaganj	533	754	752
Obra	4821	4785	4982
Panki Extn	848	871	986
Paricha	704	1808	2051
Tanda	2567	2670	2691
Unchahar	4736	5022	5982
Rihand	6696	10157	10547
Singrauli (STPS)	10394	9783	11154
NCTPP (Dadri)	4159	4023	4501
Sub-Total	**43955**	**48630**	**51860**
TOTAL	**76837**	**83072**	**89302**

WESTERN REGION			
GUJARAT			
Ahemedabad	1186	1266	1503
Gandhinagar	2455	2427	3400
Sikka	813	732	831
Ukai	3561	3200	4023
Wanakbori	6787	7274	8426
Sub-Total	**14802**	**14899**	**18183**
MADHYA PRADESH			
Amarkantak	980	1063	926
Birsingpur	3717	4027	4387
Satpura	6852	6610	6686
Vindhyachal	11678	12986	16973
Sub-Total	**23227**	**24686**	**28972**
CHHATTISGARH			
Korba East	2845	2705	2785
Korba East (Extn)			553
Korba West	4314	4451	4654
Korba STPS	11408	11789	12496
Sipat STPS			2
Sub-Total	**18567**	**18945**	**20490**
MAHARASTRA			
Bhusawal	2393	2400	2698
Chandrapur	10260	10194	13353
Koradi	4915	5480	5521
Khaperkheda	4420	4593	4969
Nasik	3808	4626	4818
Parli	3799	3420	4389
Paras	389	351	547
Dahanu	1790	1752	2429
Sub-Total	**31774**	**32816**	**38724**
TOTAL W.R.	**88370**	**91346**	**106369**
SOUTHERN REGION			
ANDHRA PRADESH			
Kothagudem	6009	6433	7040
Ramagundam	280	255	332
Vijayawada	6808	6937	7116
Ramagundam	11700	12363	13057
Rayalaseema	1526	2226	3215
Simhadri	4633	5237	5695
Sub-Total	**30956**	**33451**	**36455**
KARNATAKA			
Raichur	6012	7529	8051
Sub-Total	**6012**	**7529**	**8051**
TAMIL NADU			

Ennore	576	1291	1971
Mettur	3547	4282	3989
Tuticorin	5643	5516	5383
North Chennai	2121	2958	2550
Sub-Total	**11887**	**14047**	**13893**
TOTAL	**48855**	**55027.00**	**58399**
EASTERN REGION			
BIHAR			
Barauni	131	42	134
Muzaffarpur	0	0	0
Kahalgaon	5773	5378	4930
Sub-Total	**5904**	**5420**	**5064**
JHARKHAND			
Patratu	810	588	669
Tenughat	1068	1769	1244
Bokaro	2018	2490	3020
Chandrapura	1495	1542	1701
Sub-Total	**5391**	**6389**	**6634**
WEST BENGAL			
Durgapur (DVC)	1213	1349	1105
Mejia (DVC)	3718	4044	4236
Bandel	1284	997	1315
Sagardighi			68
Santaldih	842	1048	1243
Kolaghat	5086	5820	6158
Bakreswar	2489	2986	3083
Calcutta (CESC)	400	431	449
Titagarh (CESC)	1163	1155	1176
S.G.St (CESC)	681	697	771
Budge Budge (CESC)	2517	2520	2521
Durgapur (DPL)	1744	1473	1349
Farakka	8830	9072	8892
Sub-Total	**29967**	**31592**	**32366**
ORISSA			
Talcher Old	2837	2838	2801
Talcher STPS	12676	16022	17632
Ib Valley	2607	2739	2650
Sub-Total	**18120**	**21599**	**23083**
TOTAL E.R.	**59382**	**65000**	**67147**
N.E. Region			
ASSAM			
Bongaigaon	0	0	0
Sub-Total	0	0	0
TOTAL(ALL INDIA)	**279456**	**301974**	**329268**

Annexure 2: Amount of imported coal (1000 tonnes) used in the thermal power plants in India

Name of power plant	2005-06	2006-07	2007-08
Badarpur			
I.P.Stn.(DVB)		4	
Panipat			
Roper			
Ahemedabad	588	535	470
Gandhinagar	718	721	797
Budge Budge ((CESC)			0
Lehra Mohabat			0
Ukai	0	0	0
Wanakbori	71	76	0
Nasik			0
Trombay	1802	1978	2030
Dahanu	522	586	408
Mettur	632	321	507
Tuticorin	25	387	808
North Chennai	365	324	455
Raichur			0
Kota			
Suratgarh	155	218	0
Titagarh (CESC)	0		0
Sikka	128	246	249
Bhusawal			0
Khaperkheda	49	263	68
NCTPP (Dadri)	129	301	32
Talcher STPS	1490	784	804
Simhadri	470	251	151
Farakka STPS	611	554	755
Ramagundam STPS	77	139	0
Kahalgaon	52	201	521
Vijayawada	0	0	0
Kolaghat	0		0
Santaldih			0
New Cossipore			0
Durgapur (DPL)	0		

Rihand STPS		90	132
Vindhyachal STPS		115	145
Parli			0
TOTAL IMPORTED	7884	8094	8415

Source: cea, annual report, 2007-08

Annexure 3: **List of thermal power plants, which have dry flyash collection facilities in India**

1. Dahanu, Maharashtra
2. Sabarmati, Gujarat
3. Budge-Budge, West Bengal
4. Titagarh, West Bengal
5. Vizaywada, AP
6. Rayalseema, AP
7. Kothagundem, AP
8. Ramagundem ‘B', AP
9. Nellore , AP
10. Rajghat, Delhi
11. Raichur, Karnataka
12. Singrauli NTPC, UP
13. Vindhyachal, MP
14. Ramagundem, AP
15. *Farakka, West Bengal
16. *Kahalgaon, Bihar
17. *Korba, Chhatisgarh
18. *Talcher (old), Orissa

19. Talcher (Kaniha N), Orissa
20. Badarpur, Delhi
21. Dadri, U.P.
22. Unchahar, U.P.
23. DPL, West Bengal
24. Nasik , Maharashtra
25. Chandrapur, Maharashtra
26. Kota , Rajasthan
27. Ropar, Punjab
28. Bhatinda, Punjab
29. Lehra Mohabbat, Punjab
30. Sabarmati, Gujrat
31. Suratgarh, Rajasthan
32. *Neyveli Lignite Corporation,TN
33. North - Chennai , TN
34. Ib Valley, Orissa
35. Meizia ,WB
36. ** Faridabad , Haryana
37. **Panipat, Haryana
38 Sikka, Gujrat

* : Facility is being provided

**: PFC has sanctioned the scheme, same is being developed

Chapter 2

Mercury release from non-ferrous smelting plants

1. Introduction

Mercury (Hg), a potential contaminant to the environment is of global concern because of its toxic nature, trans-boundary movement and ability of bioaccumulation etc. The residence time of Hg in the atmosphere is 0.5 to 2-years (Schroeder and Munthe, 1998). Metallurgical processes are one of the important anthropogenic sources of Hg (Nriagu 1989, Pirrone et al., 1996). Non-ferrous metal smelting industries mainly includes, (1) [Zinc (Zn), (2) Lead (Pb) and (3) Copper (Cu).

The Ministry of Mines is responsible for the survey and exploration of minerals, for mining and metallurgy of non-ferrous metals like Cu, Zn, and Pb etc., and for the administration of the Mines and Minerals (Regulation and Development) Act, 1957, in respect of all mines and minerals, other than coal, natural gas, petroleum, and atomic minerals. The following organizations operate under the jurisdiction of the Ministry of Mines; Survey and exploration of these minerals been taken care by Geological survey of India (GSI) and Mineral Exploration Corporation Limited; regulation and conservation by Indian Bureau of Mines, whereas Mining and Processing by corporations like Hindustan Zinc Limited, Hindustan Copper Limited and Sikkim Mining Corporation. The GSI is the principal agency responsible for the assessment of geological and regional mineral resources of the country. GSI was established in 1851 and is one of India's oldest investigative agencies in the field of earth sciences. Its areas of operation encompass scientific surveys and research, for locating mineral resources. GSI operates through six regional offices and four specialized wings - marine, coal geophysics, airborne surveys and training._Indian Bureau of Mines (IBM) is the principal government agency responsible for compiling exploration data and mineral maps and for providing access to the latest information is respect of mineral resources in the country. IBM has both regulatory as well as service functions.

Zn, Pb and Cu had common property with Hg, which is affinity with Sulphur (sulphophilic) in nature. So, Hg gets easily associated with sulfide ores of these metals. The Hg-content in these ores varies from metal types and also from place to place (Nriagu and Pacyna, 1988, Streets et al., 2005). At ~1000°C Hg- in the ore get emitted to the atmosphere during the process of smelting.

Zn and Cu production in India has been ~doubled from 278 Gg to 440 Gg and 394 Gg to 734 Gg respectively, whereas Pb production remain the same (119 Gg to 124 Gg) from 2003 to 2007.

To produce these non-ferrous metals the energy need mainly coal dependent. The coal consumption in these industries has increased from 31 million tonnes to 60 million tonnes between years 2004 to 2008. Though the energy consumption-share of these smelting industries was less than 12 % to total coal used in the country (TEDDY, 2009). But, the Hg-emission by burning of coals only add a part of the total emission since major contribution is from the dissociation of Hg-from the ore itself. During the smelting process, almost all Hg in the ore gets evaporated from the matrix, go into the flue gases primarily as elemental Hg (Hg0) with small portion as divalent Hg (Hg^{2+}) and particulate Hg (Hg^{p}) (Pacyna and Pacyna, 2002), and eventually be emitted into the atmosphere, if there are no pollution control technologies applied.

2. Mining and Processing of non-ferrous metals in India

Hinudstan Zinc Limited incorporated on 10th January, 1966 after the Govt. of India took over erstwhile Metal Corporation of India to own, manage and develop the mineral and smelting capacities for the strategic zinc and lead metals in the country. Hindustan Copper Limited incorporated in November, 1967 is presently the sole indigenous producer of primary copper in the country. Sikkim Mining Corporation (in which Central Govt. has 49% equity participation), produces polymetallic ore which is treated in the concentrator plant producing copper, lead and zinc concentrates.

2.1 Hinudstan Zinc Limited

Hindustan zinc Limited is the India's largest and world's second largest integrated producer of zinc & lead, with a global market share of approximately 6.0% in zinc. It has four mines and three smelting operations: mines are situated at Rampura Agucha, Sindesar Khurd, Rajpura Dariba and Zawar in the State of Rajasthan, while the smelters are located at Chanderiya and Debari in the State of Rajasthan and Vizag in the State of Andhra Pradesh.

2.1.1 Mines under Hinudstan Zinc Limited

Rampura Agucha Mine is the world's largest zinc mine with an annual ore production capacity of 5.0 million tonnes. It is situated 230 kms north of Udaipur, Rajasthan, India. In fiscal year 2009, Rampura Agucha produced 591,743 tonnes of contained zinc and 56,946 tonnes of contained lead. The current ore production capacity would likely to increase from 5.0 million tonnes per annum to 6.0 million tonnes per annum. Rampura Agucha is also one of the lowest cost zinc producer globally. Rampura Agucha is an open-pit mine, commissioned in 1991. Rampura Agucha is stratiform, sediment-hosted, high grade zinc & lead deposits. The ore body is massive and lens shaped. Ore grade is consistent and is not deteriorating as we move down. Total Reserves & Resources as on 31 March 2009 are 118.8 million tonnes containing 19.1 million tonnes of contained zinc-lead.

The mine is highly mechanized with 34 m^3 excavator and 240 ton dumpers, for excavation of ore and waste. The mine is equipped with the world-class infrastructure facilities including the latest generation slope monitoring radar system; truck dispatch system; in-house central workshop and heavy vehicle service center and repair shop equipped with requisite facilities.
The management system of Rampura Agucha comprises of: the Quality System ISO 9001:2008, the Environmental System ISO 14001:2004 and the Occupational Health, Safety Management System OHSAS 18001:2007, SA 8000:2008 and 5S Certifications.

Sindesar Khurd Mine, Rajasthan is the second largest ore body in the portfolio of Hindustan Zinc mines with reserves and resources base of over 56 million tonnes after Rampura Agucha. Sindesar Khurd has Underground Mining Method, Blast hole open stoping Products, Zinc Concentrate and Lead Concentrate Ore Product Capacity, 0.30 milion tonnes per annum Certification, ISO 9001:2008, ISO 14001:2004, OHSAS 18001:2007, SA 8000:2008 & 5S. The annual ore production capacity of 0.30 million tonnes and achieved a production level of 11,870 tonnes of contained zinc and 5,350 tonnes of contained lead in FY 2009. We plan to increase the current ore production capacity of Sindesar Khurd from 0.30 mtpa to 1.50 mtpa.

Rajpura Dariba Mine, Udaipur, Rajasthan has annual ore production capacity of 0.90 million tonnes and achieved a production level of 19,700 tonnes of contained zinc and 4,930 tonnes of contained lead in FY 2009. From December 2008, Rajpura Dariba's concentrator has partially switched over from the existing differential concentrate production for lead and zinc to bulk concentrate, which has resulted in higher metal recovery of 2.5% in zinc, 6.0% in lead and 4.0% in silver. Like Sindesar Khurd Mine it is also an Underground mining-type. It has ore production capacity 0.9 million tonnes per annum and have ISO 9001:2008, ISO 14001:2004, OHSAS 18001:2007, SA 8000:2008 & 5S certifications.

Zawar: 40 kms south of Udaipur, Rajasthan, India

2.1.2 Smelters under Hinudstan Zinc Limited

Chanderiya Smelting Complex (CSC) is the single largest zinc-smelting complex in the world. Its current metal production capacity is 610,000 tonnes per annum (525,000 tonnes per annum of zinc and 85,000 tonnes per annum of lead). The main products are special high grade (SHG) zinc, continuous galvanizing grade (CGG) Zinc, prime western (PW) zinc and pure lead. It also produces a number of valuable by-products including silver and cadmium. Chanderiya Smelting Complex is located 110 Kms North of Udaipur in the State of Rajasthan, India. It was commissioned in the year 1991 with an initial production capacity of 70,000 tonnes per annum of Zinc and 35,000 tonnes per annum of Lead. In the past 6 years, the capacity of the plant has been expanded five folds to its current capacity of 525,000 tonnes per annum of Zinc and 85,000 tonnes per annum of Lead. The Chanderiya Smelting Complex has Imperial Smelting Technology Roast Leach Electro-winning Technology Ausmelt™ Technology and produces
SHG Zinc and Zinc Alloys, PW Zinc, Lead and Silver. The Annual Production Capacity The annual production of Chanderiya Smelting Complex are as follows: Zinc, 525,000 tonnes, Lead 85,000 tonnes and Silver 150 tonnes. It has ISO 9001:2000, ISO 14001:2004, OHSAS 18001:2007 & 5S certification.

Zinc Smelter Debari is a Hydrometallurgical zinc smelter situated at Debari, about 13 kms from Udaipur, in Rajasthan, India. The primary product of Debari is High Grade (HG) zinc and it also recovers cadmium as by-product. It has Roast Leach Electro-winning Technology and produces 88,000 tonnes per annum of Zinc and also have ISO 9001:2008, ISO 14001:2004, OHSAS 18001:2007, SA 8000:2008 & 5 certifications.

Zinc Smelter Vizag is a hydrometallurgical zinc smelter situated at Vizag, in the State of Andhra Pradesh, India. The primary product of Vizag is High Grade (HG) zinc and it also recovers cadmium as by-product. It follows Roast Leach Electro-winning Technology. Zinc Smelter Vizag was commissioned in the year 1978 with an initial production capacity of 30,000 tonnes per annum of zinc. In the year 2003 the capacity of the plant had been expanded to 56,000 tonnes per annum of zinc through de-bottlenecking. It has ISO 9001:2008, ISO 14001:2004, OHSAS 18001:2007 & SA 8000:2001and 5S workplace management system certification.

2.2 Hindustan Copper Limited (HCL)

HCL is a public sector undertaking under the administrative control of the Ministry of Mines, was incorporated on 9th November 1967. It has the distinction of being the nation's only vertically integrated copper producing company as it manufactures copper right from the stage of mining to beneficiation, smelting, refining and casting of refined copper metal into downstream saleable products. (http://www.hindustancopper.com/CompanyProfile.asp?lnk=1&plnk=1).

The Company markets copper cathodes, copper wire bar, continuous cast copper rod and by-products, such as anode slime (containing gold, silver, etc.), copper sulphate and sulphuric acid. More than 90% of the sales revenue is from cathode and continuous cast copper rods. In concluded financial year 2006-07, as per provisional estimates, the Company has earned a all time highest net profit pf Rs 331 crore (~USD 75 million) against a sales turnover of Rs 1800 crore (~ USD 420 million). HCL's mines and plants are spread across four operating Units, one each in the States of Rajasthan, Madhya Pradesh, Jharkhand and Maharashtra as named below:
(1) Khetri Copper Complex (KCC) at Khetrinagar, Rajasthan, (2) Indian Copper Complex (ICC) at Ghatsila, Jharkhand, (3) Malanjkhand Copper Project (MCP) at Malanjkhand, Madhya Pradesh and (5) Taloja Copper Project (TCP) at Taloja, Maharashtra

2.2.1 Khetri Copper Complex (KCC) at Khetrinagar, Rajasthan

Khetri is situated at the foothills of the Aravalli Range, which hosts copper mineralization, giving rise to a 80 km long metallogenetic province from Singhana in the north to Raghunathgarh in the south, popularly known as Khetri Copper Belt. The belt comprises of tightly folded Proterozoic metasediments that rest over basement gneisses and is a part of the North Delhi fold belt. Prominent deposits of the belt are: Khetri, Kolihan, Banwas, Chandmari, Dhani Basri, Baniwali Ki Dhani (Neem Ka Thana, Rajasthan). Other deposits are: Dholamala, Akwali, Muradpura - Pacheri (Jhunjhunu, Rajasthan), and Devtalai (Bhilwara, Rajasthan). Regular mining ceased in this area by 1872. With the advent of 20th century, the geologists of Geological Survey of India. Indian Bureau of Mines undertook explorations. Development of Khetri Mine was started by National Mineral Development Corporation (NMDC) and the project was handed over to HCL in 1967 when HCL was formed. Subsequently, smelting and refining facilities were added. Khetri comprises of Khetri town and Khetrinagar. Khetri town was founded by Raja Khet Singhji Nirwan, and Khetrinagar, which is about 10 km away from Khetri town, is developed and maintained by Hindustan Copper Limited.

Existing Infrastructure are as follows:

- Established in 1967
- Mechanized underground mines namely 'Khetri' and 'Kolihan' (capacity 1.0 million tonnes of ore per annum)
- Beneficiation plant (capacity 1.81 million tonnes per annum)

Process plants to produce 31,000 TPA of refined copper

Table 1: Ore Reserves including resources Khetri Copper Complex (KCC) at Khetrinagar, Rajasthan

Khetri Mine	26 million tonnes @ 1.13 % Cu
Kolihan Mine	20.64 million tonnes @ 1.35 % Cu
Banwas Block	25.02 million tonnes @ 1.69 % Cu
Chandmari-Kolihan	

Intervening block	12.10 million tonnes @ 1.03 % Cu

2.2.2 Indian Copper Complex (ICC) at Ghatsila, Jharkhand

Singhbhum Copper Belt comprises of a Proterozoic volcano-sedimentary rock that creates a shear zone known as Singhbhum shear zone. Copper mineralization in SCB is localized along this shear zone. Prominent deposits of the belt are Chapri, Rakha, Surda, Kendadih, Pathargora and Dhobani. Other deposits are: Turamdih, Ramchandrapahar, Nandup, Bayanbil and Dhadkidih (Singhbhum, Jharkhand). Indian Copper Corporation Ltd was established by a British company in 1930 at Ghatsila consisting of a cluster of underground copper mines, concentrator plants and smelter. On 25.09.72 the Govt. of India nationalized the company under provisions of the Indian Copper Corporation (Acquisition of Undertaking Act) and merged the same with HCL. Today it falls under the sate of Jharkhand, under the jurisdiction of east Singbhum district.

Existing Infrastructure at ICC:

- Established in 1930
- Operating Mine: Surda~26 MT @ 1.20% Cu
- Process plants to produce 19,000 TPA of refined copper

Ore Reserves including resources:

Table 2: Additional mining reserves (old mines)

Rakha mine	47.19 million tonnes @ 0.97% copper
Kendadih Mine	12.85 million tonnes @1.73% copper
Chapri Block	63.50 million tonnes @1.14% Cu

2.2.3 Taloja Copper project (TCP) at Taloja, Maharashtra

The Taloja Copper Project was set up in December 1989, based on technology sourced from Southwire, USA. The plant produces Continuous Cast Copper Rods (CCR) and has a capacity of producing 60,000 TPA. The inputs, i.e. cathodes are sourced from the Company's own unit at Khetri and Ghatsila (i.e. KCC and ICC) as well as through direct purchase of cathodes. The unit also undertakes tolling of cathodes. The Project has an installed capacity to produce 60,000 MT per year of Continuous Cast Copper Wire Rods of 8mm, 11mm, 12.5mm and 16mm diameters. The product is offered for sale in the form of coils, each coil weighing 3.5 MT, 2.5 MT and 1.00 MT.

The technology used is the SC 2000 system of the world-renowned Southwire Co., USA. The Southwire Continuous Rod System (SCR) is accepted as the world's leading technology for producing premium quality continuous cast rods. Rods produced by this technology meet the most exacting standards conforming to ASTM B 49/98 &/or IS 12444/1988.

Existing Infrastructure

» Established in 1990
» Plant to produce 60,000 TPA of continuous cast wire rod.

Taloja in Navi Mumbai falls sunder Raigarh district of Maharashtra. Only 43 km drive from Mumbai airport, Taloja enjoys almost all the facilities of a metro. Vashi is also another important commercial hub close by. The district HQ, Alibagh, is a popular tourist spot.

2.2.4 Malanjkhand Copper Project (MCP) at Malanjkhand, Madhya Pradesh

Malanjkhand Copper Belt comprises of a large body of copper ore in granitic rocks varying from diorite to granite in composition. Prominent deposits are: Malanjkhand, Shitalpani (Balaghat, Madhya Pradesh), Gidhri Dhorli, Jatta and Garhi Dongri. Malanjkhand Copper Project was established in 1982.Initial project has been set up by Hindustan Copper Ltd to exploit the copper ore through an open pit mine. Geological Survey of India took systematic geological exploration at this deposit during 1969. Mining lease of the ore was granted to HCL during 1973. With advancement of time this project was enhanced with viable operational developments.

At present besides the open pit mine and concentrator plant the project has also been provided with auxiliary facilities such as Tailings Disposal and Water Reclamation System, Repair Shops, Maintenance Garage, Water Treatment Plant, Warehouses, Fuelling Stations, 132 KV Power Sub-station, Waste Treatment Facilities and Township with modern amenities.

Existing Infrastructure at MCP:

- Established in 1982
- Single largest copper deposit of India
- Open pit mine with a capacity of 2 million TPA of ore with a matching concentrator plant, Tailing Disposal System and other auxiliary facilities.
- Ore Reserves including Resources
- Malanjkhand Mine: 221.00 million tonnes @ 1.31% copper

Malanjkhand copper deposit, located 20 km away from the Kanha National Park is the single largest copper deposit of India with nearly 70% of the country's reserve and contributing around 80% to HCL's total copper production.

2.3 The Sikkim Mining Corporation

It was established by a proclamation of the then Darbar of Sikkim in February 1960 as a joint venture having 51% equity from Government of Sikkim and 49% equity from Government of India. After a gestation period of about 6 years, production of the complex ore from Bhotang Mine started since 1966-67 onwards. This was the only mine till recently in the country, which produced three metals (copper, lead and zinc) from a polymetallic complex ore. There is also the presence of appreciable amount of silver and some amount of gold in the ore. As on 1.4.98 the mine is estimated to have (proved & probable) reserves of about 3.28 lakh tonnes and has already produced about 4.11 lakh tonnes of ore since its inception. Currently Bhotang mine is producing about 54 TPD (tonnes per day) of ore and the other exploratory mine called 'Pacheykhani', located about 15 km away from the former in the East Sikkim district, is also producing about 18 TPD. The cumulative production would be enhanced to 90-100 TPD after the major repair of the existing Cone Crusher of the Mill plant by the end of the financial year 1998-99. The copper concentrate produced by the corporation is sold of to M/s Hindustan Copper Ltd., zinc concentrate to M/s Hindustan Zinc Limited and lead concentrate is not saleable at present due to high bismuth (0.6 to 0.7%) content which contains appreciable amount of silver. The performance of the

Corporation has never been good due to various reasons but recent capital re-structuring proposal already approved by the Board of Directors for enhancing the Share Capital from Rs.6.00 crores to Rs.10.00 crores is expected to result in improvement of its productivity and financial performance in near future.

Table 3: Location of Mines along with capacity under the Sikkim Mining Corporation

Location of Mines	**ORE Capacity (TPD)**
1. Bhotang Multimetal Mine	100 TPD (Currently 54 TPD)
2. Pacheykhani Copper Mine (Both located in East Sikkim)	20 TPD (Currently 18 TPD)

The production of Sikkim Mining Corporation during the year 1997-98 and 1998-99 are given below:

Table 4: Production of ore and respective concentrate (in Tonnes)

Product	**1995-96**	**1996-97**	**1997-98**	**1998-99 Target**	**1998-99 Actuals (Prov.)**
Ore	11026	9685	15698	20020	18000
Concentrate					
1. Copper	206	321	791	1020	1020
2. Lead	499	372	90	100	100
3. Zinc	359	337	289	20	12

Source:http://mines.nic.in/archp6smc1.html

3. Methodology

Mercury estimation from the non-ferrous smelting industries was done on the basis of annual production of these metals and average emission factor (EF) of Hg produced in making unit metal.

$(E_{Hg})_{year}$ = (Non-ferrous metal production)$_{year}$ × $(EF)_{Hg}$ ----------------------------- (1)

Where, $(E_{Hg})_{year}$: Annual Emission of Mercury (Kg) from non-ferrous metal smelting;
(Non-ferrous metal production)$_{year}$: Annual production (Gg) of non-ferrous metal;
$(EF)_{Hg}$: Emission Factor of Mercury in gram per Mg production of non-ferrous metals.

3.1 Metal production in India

There are four Cu-smelters in which the Flash Smelting process, the Ausmelt process and the Imperial Smelting mainly used. In the Flash-smelting Furnace the pre-heated air and oxygen heated to produce Cu. In Ausmelt process, the feed materials are fed through a port located in the roof of the furnace and fall into the molten bath. Air and oxygen are necessary for combustion, and molten metal and slag are removed and off-gases from the furnace are cooled and cleaned in gas clean up systems before discharge. Zn production follows other metallurgical process like Zn production in Udaipur, Rajasthan follows hydrometallurgical process which has following steps: roasting, leaching, solution purification, Zn electro-winning, melting, casting, and alloying. Blast Furnace Process produces pb-production in Tundoo, Jharkhand whereas at Chhattisgarh the Imperial Smelting Process has been chosen. The smelting procedures depend on ore types. Zinc ores are divided into two major categories, one is sulfide ore as sphalerite (ZnS) and the other is oxide ore mainly as calamine ($ZnCO_3$). For oxide ores, only one step is needed. Zinc ores and coal are filled in small ceramic jars, and then the jars are heated to ~800 ^{o}C for a few hours in a furnace using coal as fuel. At reduction condition, zinc ore will be reduced to liquid metal zinc by carbon in coal. For sulfide ores, two steps are required. First of all, de-sulphurization is applied. The mixture of zinc ore and coal are baked in the air at high temperatures (~800 ^{o}C) in a furnace with coal as fuel, and ZnS will be oxidized to $ZnCO_3$. The final step is the same as the smelting of oxide zinc ore. There were no pollution control devices applied during all smelting process at all, and both the smelting residues and flue gas were directly discharged into the environment.

The non-ferrous metal production in India between 2003 to 2007 is given in **Table 5**. Zn and Cu metal production in India has almost doubled whereas Pb production kept the same from year 2003 to 2007. A small amount of Zn, Pb and Cu are also done by secondary smelting process where mainly scraps of these metals are used. Mainly informal industries in India are involved in the secondary metal production. In this process insignificant amount of Hg- produced because it's a more of physical process where molting and re-shape of these metals took place. In our study we have not considers the secondary metal production of these non-ferrous metals because of the stated reason.

Table 5: Production data of non-ferrous smelters (1000*Tonnes) in India

Metal Production (1000*Tonnes)	**Year**				
Zinc (Zn)	**2003**	**2004**	**2005**	**2006**	**2007**
Primary	253.9	238.4	266.2	420.9	416.8
Secondary	24.0	24	23.0	23.0	23
Total Zn	278	262	289.0	444.0	440
Lead (Pb)					
Primary	77.5	40	56	77.7	88.8
Secondary	41	25	35	35	35
Total Pb	118.5	65	91	112.7	123.8
Copper (Cu)					
Primary	391	401	486.6	610	500.4
Secondary	3	18	30.4	34	233.6
Total Cu	394	419	517	644	734

Sources, USGS, 2007

3.2 Emission Factor

Various researchers (Nriagu and Pacyna, 1988, Pirrone et al., 1996, Streets et al., 2005) across the world have worked out the emission factor (EF) of Hg-emission in producing per unit of these metals. Since Hg-in the ore-content varies specially and generally it's more in the developing countries than developed one. Also the metallurgical process and other involved technologies used in the developed countries are better than developing one. Various researchers from across the world has documented emission factor as low as 8 mg/kg and as high as 156 mg/kg for producing unit of Zn metal. In developed countries, smelting companies not only recover Hg as a by-product, but also utilize modern flue gas cleaning devices to prevent Hg emission to the atmosphere (i.e. Mukherjee et al., 2000). Therefore Hg emission factors from non-ferrous smelting industries in developed countries are generally quite low.

Based upon the literature review Li et al. (2008) has used a range between 20 to 25 mg of Hg per Kg of Zn-metal produced for the developing countries whereas 7.5 to 8 mg/Kg for the developed one. Hylander and Herbert, 2008 has arrived at the global mean emission factor as 12 mg/Kg whereas for the developing country like China many researchers including Li et al. (2008) got higher value than him (Table 6).

Table 6: Mercury (Hg) content in non-ferrous across the India

Metal	Hg (mg/Kg)	Reference countries	Source Reference
Zn	12.09	Global mean	Hylander and Herbert, 2008
	8 to 25	Developing	Pai et al., 2000; Feng et al., 2004
	8 to 45	Global	Nriagu and Pacyna, 1988
	13.8 to 156	China	Street et al., 2005
	86.6	China (National average)	Jiang, 2004
	20 to 25[a]	Developing	Li et al., 2008
	7.5 to 8[a]	Developed	Li et al., 2008
Cu	5.81	Global	Hylander and Herbert, 2008
	15		Pirrone et al., 1996; Nriagu and Pacyna, 1988
Pb	15.71	Global	Hylander and Herbert, 2008
	43.6		Li, 2007; Feng et al., 2004

Where, a: on the basis of Nriagu and Pacyna, 1988; Pirrone et al., 1996; Prasad et al., 2000; Pacyna and Pacyna, 2002; Pacyna et al., 2003, 2006; Streets et al., 2005

Based upon these studies we took the minimum, mean average and maximum value for the emission factor under the current study (Table 7). Unlike Zn-smelting industries very limited study across the world has been done for estimating Hg- from Cu and Pb smelting industries. Mean variation found between minimum and maximum Emission Factors were ~3-times, so it was important to calculate range of emission for non-ferrous smelting industries for India using these emission factors from years 2003 to 2007.

Table 7: Emission factor used under the current study

Metal	Hg (mg/Kg)	Scenarios	Source Reference
Zn	12.09	Country mean average	Hylander and Herbert, 2008
	8	Minimum	Pai et al., 2000; Feng et al., 2004
	25	Maximum	Pai et al., 2000; Feng et al., 2004
Cu	5.81	Minimum	Hylander and Herbert, 2008
	15	Maximum	Pirrone et al., 1996; Nriagu and Pacyna, 1988
Pb	15.71	Minimum	Hylander and Herbert, 2008
	43.6	Maximum	Li, 2007; Feng et al., 2004

3.4 Species- specific Emission profiles of Hg from Zn smelting industries in India

Pacyna and Pacyna, 2002 factorize Hg-emitted from non-ferrous smelters into elemental Hg-in gas, mercuric and particulate form in factor 0.8, 0.15 and 0.05 respectively. Based upon this study we estimated the various species of Hg-emitted from Indian non-ferrous smelting industries. As already stated in Chapter 1 (Hg-Emission from Thermal power Plants) of this report about the differential chemical nature and hence residence time of these species.

4. Estimated Mercury emission

The estimated Hg-emission range was between 2 Ton to 6.3 Ton in year 2003 and has increased to 3.3 to 10 Ton respectively in year 2007 from the Zn-smelting industries. The variation accounted as a result of the range of emission factor used under the current study. Share increase in Hg- emission from this sector could be well co-related to the increase in the Zn-metal production in the same year (Table 5) followed by slight decline in year 2006 to 2007.

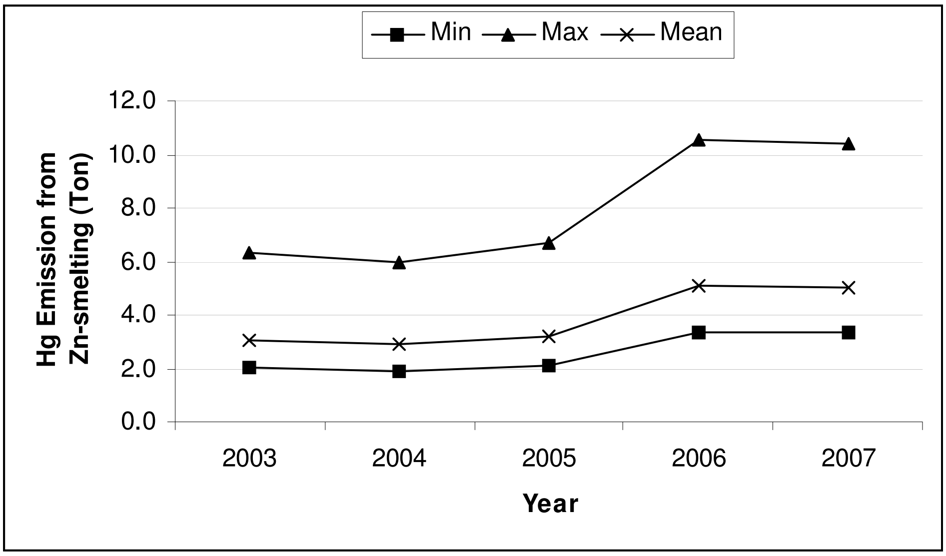

Fig. 1: Estimated emission of Hg from Zn-smelting between year 2003 to 2007 in India

Estimated upper end of Hg-emission from Pb-smelting industries had ~50% declined (from 3.3 To to 1.7 Ton) between 2003 to 2004 and had reached to 3.8 Ton by year 2007. The reason behind this change was as a result of decline in production figure in year 2004 and steady growth in later years (Table 5). The emission factor chosen for the max. and min. were ~3-fold so similar trends and same could be seen in the estimated range of Hg-emissions for any year.

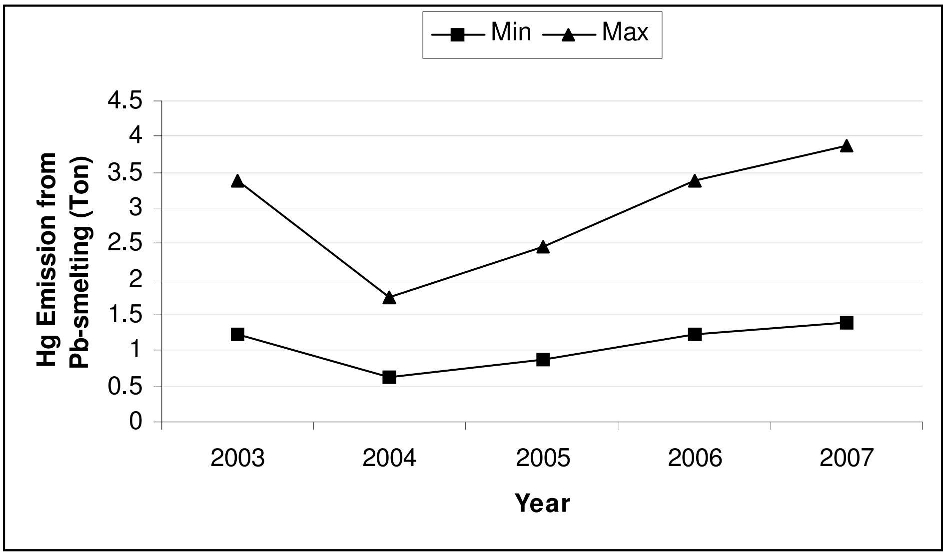

Fig. 2: Estimated emission of Hg from Pb-smelting between year 2003 to 2007 in India

The estimated Hg-emission from Cu-smelting industries showed a steady growth from year 2003 to 2006 and decline in the following year. Estimated decline in Hg-emission in the year 2007 was because of decline in the production figure for the same year. The difference between max and min estimated Hg-emission in the respective years were ~3-fold only because of the emission factor applied.

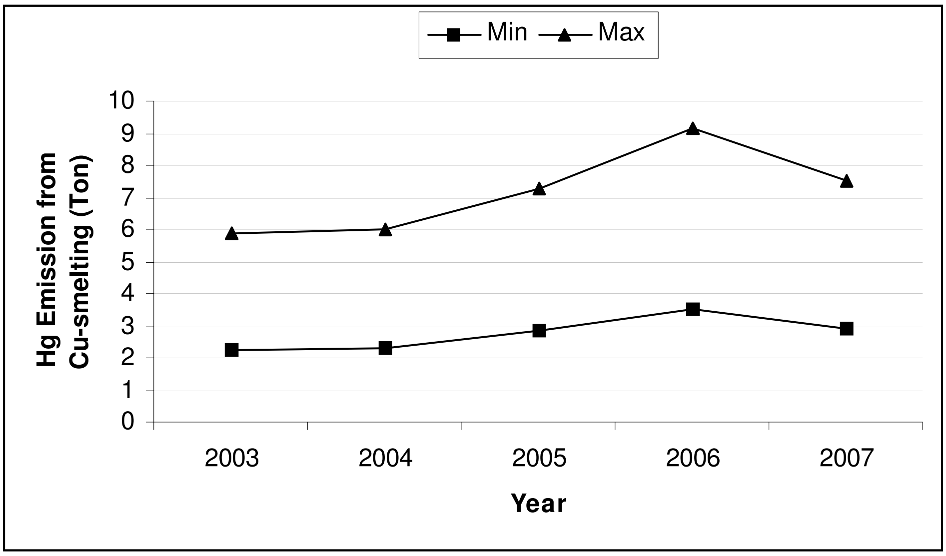

Fig. 3: Estimated emission of Hg from Cu-smelting between year 2003 to 2007 in India

4.2. Estimated Max and Min Hg- emission from the non-ferrous smelters

Maximum and minimum range of the estimated Hg-emission from the non-ferrous (Zn, Pb and Cu) smelters was calculated by adding the respective contribution from these. The minimum estimated Hg-emission had increased from 5.5 to 7.6 Ton whereas maximum one were 15.5 Ton to 21.7 Ton respectively from 2003 to 2007 from non-ferrous smelters. The uncertainty in the current emission estimates are huge but estimating the minimum possible and maximum possible range certainly gave us privilege to feel about the emission range rather than working only with the mean average figure. For example for the year 2007, emission range is between 7.6 to 21.7 Ton which is a better indicator for the policy-makers to think about the policy options to reduce Hg emission (Fig 4). And also for the academicians to make a better estimate by taking into account various uncertainty parameters currently not considers under this study. The relative contribution of Zn, Pb and Cu smelting industries in shows that Zn smelting and Cu have share more than 80% and rest by Pb industries (Figure 5, 6).

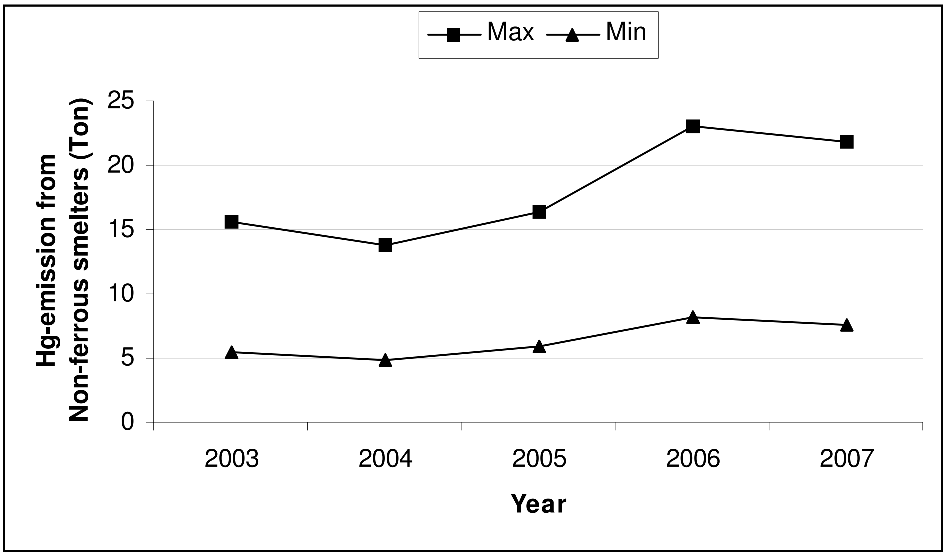

Fig. 4: Estimated maximum and minimum emission of Hg from Non-ferrous smelters between year 2003 to 2007 in India

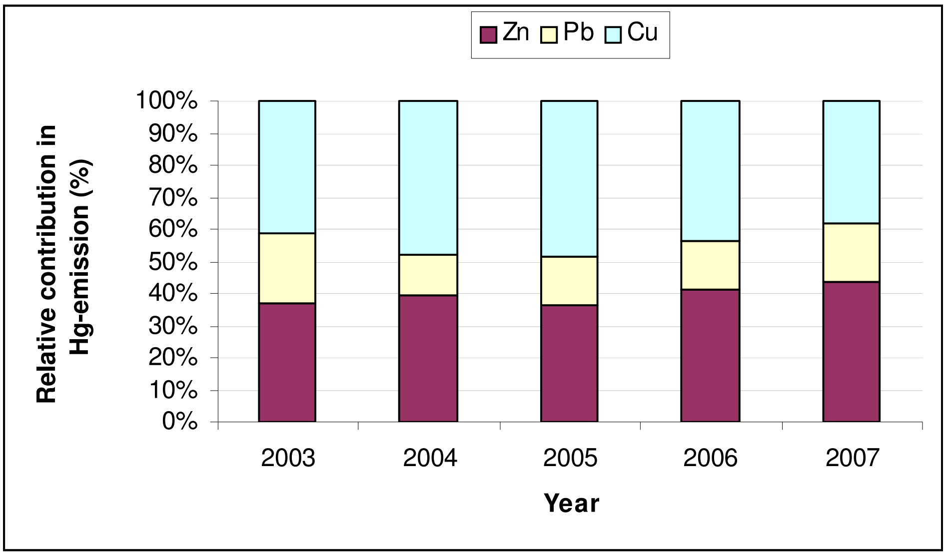

Fig. 5: Relative contribution of non-ferrous (Zn, Pb and Cu) smelters in the minimum Hg-emission estimated from year 2003 to 2007

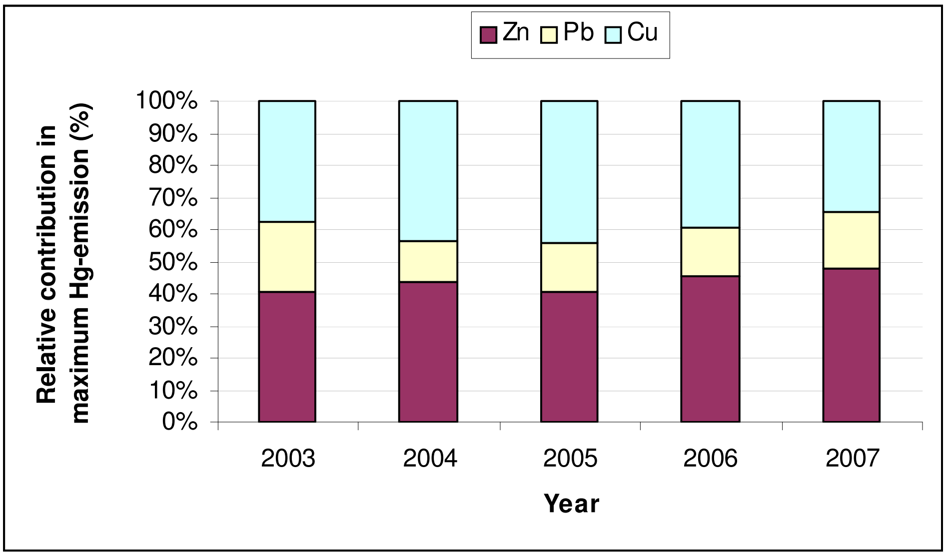

Fig. 6: Relative contribution of non-ferrous (Zn, Pb and Cu) smelters in the maximum Hg-emission estimated from year 2003 to 2007

4.3 Species- specific Emission profiles of Hg from non-ferrous smelters in India

Based upon the estimated range (maximum and minimum) of Hg-emission from non-ferrous smelters (Fig. 4) emission factor for the speciation into elemental (Hg^0), mercuric (Hg^{2+}) and particulate-form (Hg^p) was applied (sub-section 3.4). About 6 Ton to 17 Ton of

Hg^0 forms were generated in the year 2007 whereas Hg^{2+} were 1.1 to 3.2 Ton and rest (3.8 to 10 Ton) in Hg^p.

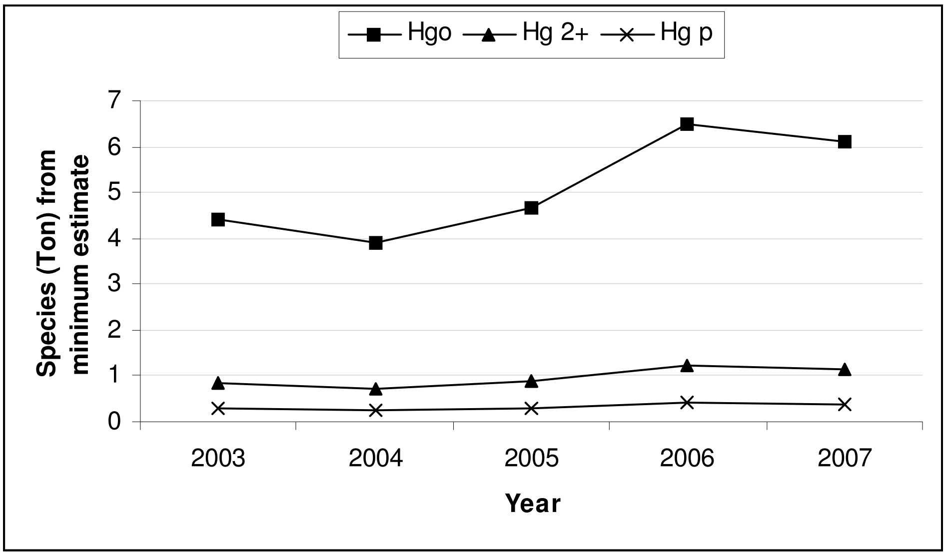

Fig. 7: Estimated species of Hg from non-ferrous smelters

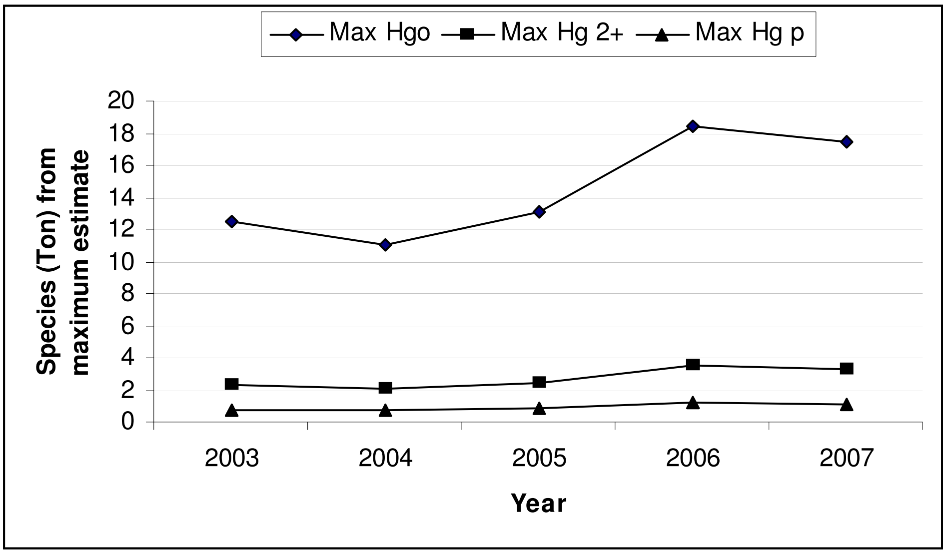

Fig. 8: Estimated species of Hg from non-ferrous smelters

5. Limitations and further scope of the study

The current report provides the emission profile of Hg from non-ferrous smelting industries in India but there are certain limitations of this and hence results must be interpreted with care. For example: Emission factor, There was scarcity of the Indian emission factor data for non-ferrous smelting industries as per our best knowledge. Emission factor used under the present study based upon the available literature mostly from China. Factors like mercury content in the respective ore type of these non-ferrous metals, technologies used to control emissions affects the emission factor. So as per the availability of emission factors for India there is scope for better emission inventory for India.

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http://www.hzlindia.com/operations.aspx?ID=3#

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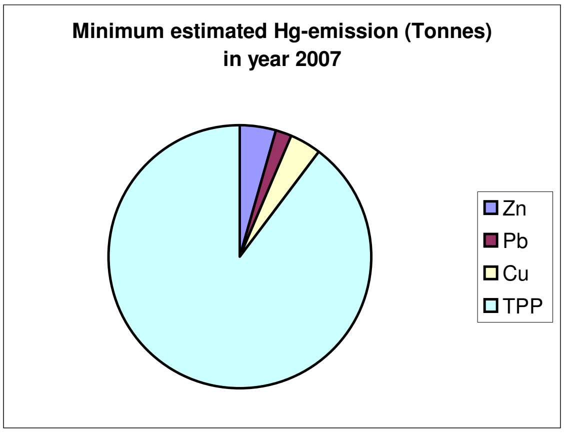
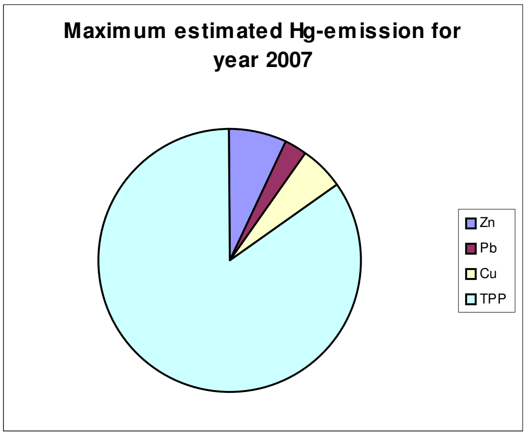
Over all results

In this report we have estimated the emission range from TPPs and non-ferrous smelters. Since there was a variation of almost double in case of emission factor used so with the estimated Hg-emission inventorized. For example for the year 2007, the Hg-released from TPPs and non-ferrous smelters was 73.6 Tonnes if lower side of emission factor taken and was almost double if highest probable emission factor taken into account for the same year 2007.





So certainly there are areas like better availability of data can improve the present report.