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Assessment of the Mercury Content in Coal fed to Power Plants and study of Mercury Emissions from the Sector in India

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A report from
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of the UNEP Global Mercury Partnership

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The report can be found on UNEP Chemicals Branch website: http://www.unep.org/hazardoussubstances/Mercury/PrioritiesforAction/Coalcombustion/Reports/tabid/4492/language/en-US/Default.aspx

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Acronyms and Abbreviations

A	:	Ash
APCD	:	Air Pollution Control Device
ASTM	:	American Standard for Testing Materials
BCCL	:	Bharat Coking Coal Limited
CCL	:	Central Coalfields Limited
CEA	:	Central Electricity Authority
CESC	:	Calcutta Electric Supply Corporation
CIL	:	Coal India Limited
CIMFR	:	Central Institute of Mining and Fuel Research
CMPDI	:	Central Mine Planning & Design Institute
CSIR	:	Council of Scientific and Industrial Research
ECL	:	Eastern Coalfields Limited
ESP	:	Electrostatic Precipitator
FC	:	Fixed carbon
FGD	:	Flue Gas Desulphurization
GCV	:	Gross Calorific Value
g/t	:	gramme per tonne
GoI	:	Government of India
ISO	:	International Standard Organization
JSPL	:	Jindal Steel and Power Limited
kcal/kg	:	kilocalories per kilogramme
kWh	:	kilowatt hour
MCL	:	Mahanadi Coalfields Limited
mg/kg	:	milligramme per kilogramme
mg/m^3	:	milligramme per cubic metre
M	:	moisture
MoEF	:	Ministry of Environment and Forests
Mt	:	million tonne
mta	:	million tonne per annum
MW	:	megawatt
NCL	:	Northern Coalfields Limited
NTPC	:	National Thermal Power Corporation
ng	:	nanogramme
NO_X	:	Oxides of nitrogen
POG	:	Process Optimization Guidance
SCCL	:	Singerani Collieries Company Limited
SECL	:	South Eastern Coalfields Limited
SPM	:	suspended particulate matter
ppm	:	parts per million
SO_2	:	Sulphur dioxide
TPS	:	Thermal power station
$\mu g/Nm^3$	:	microgramme per normal cubic metre
UNEP	:	United Nations Environment Programme
US EPA	:	United States Environmental Protection Agency
VM	:	Volatile matter
WBPDCL	:	West Bengal Power Development Corporation Limited
WCL	:	Western Coalfields Limited

CONTENTS **page no.**

Executive Summary	**9**
1.0 Introduction	**10**
1.1 Project Objectives	10
1.2 Major Tasks of the study	11
1.3 Deliverables	12
2.0 Overview of Indian coal sector	13
2.1 Characteristics of Indian coals	13
2.2 Coal reserves of India	13
2.3 Pattern of coal consumption	16
2.4 Coal Washeries	17
3.0 Power Generation Sector in India	18
3.1 Installed generation capacity of electricity	18
3.2 Coal fired power plant in India	21
3.3 Air pollution control equipment in the power plants	23
4.0 Present study	23
4.1 Coal analysis	23
4.2 Mercury emissions measurement in power plants	25
4.3 Previous study at NTPC coal based power plants	27
4.4 Washery samples	28
4.5 Inter-calibration of analyses on selected coal samples	28
5.0 Mercury Emission factor and Emission Inventory	30
5.1 Partitioning of Mercury and Mercury Speciation	32
5.2 Future Mercury Emissions Estimate	32
6.0 Global Inventory of Mercury in coal and Mercury emissions	33
7.0 References	35

LIST OF FIGURES

Figure 1: Reserves of coal and lignite	15
Figure 2: Coal consumption profile of 2008-09	16
Figure 3: Primary energy sources in India	20
Figure 4: Installed electricity generation capacity in India	20
Figure 5: Coal consumption in the power sector	22
Figure 6: Share of indigenous, imported & washed coal in power sector	22
Figure 7: Mercury in Feed coals and emission from the thermal power stations	31

LIST OF MAPS

Map 1 : Location of the major coal reserves 15
Map 2 : Location of the Thermal Power Plants 19

LIST OF TABLES

Table 1 : Variability of coal quality of the major sources 14
Table 2 : Installed capacity of major non-coking coal washeries in India 17
Table 3 : Boiler unit sizes and installed power plant capacity 21
Table 4 : Unit size wise electricity generation 21
Table 5 : The methods adopted for collecting, preparing and analyzing samples 24
Table 6 : Quality parameters of the coals fed to Power Plants 25
Table 7 : Major and minor elements in coal 25
Table 8 : Mercury content of the feed coal to power plants 26
Table 9 : Mercury concentrations in flue gas samples and other combustion Products 27
Table 10 : Distribution of Mercury in Flue Gas and other Combustion Products at NTPC coal based power plants 27
Table 11 : Distribution of Mercury in the Washery products 28
Table 12 : Certified mercury concentrations of reference coal samples 29
Table 13 : Method adopted and instrument used by the laboratories 29
Table 14 : Inter laboratory variability of mercury concentrations 29
Table 15 : Projected estimates of Mercury Emissions from Power sector 32
Table 16 : Mercury contents in raw coals across the world 33
Table 17 : Mercury emission inventory of ten countries 34
Table 18 : Global mercury emission inventory 34

Executive Summary

Under the Small Scale Funding Agreement between United Nations Environmental Programme (UNEP), Ministry of Environment and Forests, Government of India (MoEF) and Central Institute of Mining and Fuel Research (CSIR-CIMFR), the project entitled "Characterization of the coal fired power sector in India, assessment of the mercury contents in coal fed to power plants and calculation of mercury emissions from the Sector" was undertaken. MoEF as the National Project Manager and Coordinator for the project had the overall responsibility for the implementation of the activities of the project. CSIR-CIMFR was the executing agency for implementation of the project.

Information was collected on coal consumed in power plants in India by coal source from 2003 to 2011. Information has been provided on existing commercial non-coking coal washeries in the country supplying coal to the power plants. Coal samples collected from power plants cover the major coal fields of India. The samples were characterized for proximate, ultimate analyses, mercury (Hg), arsenic (As), selenium (Se), chlorine (Cl), calcium (Ca), and sodium (Na) content. Coal samples from five major non-coking coal washeries were collected and analyzed for mercury.

This report presents Indian power sector information which includes locations of major coal based power plants, installed power plant capacity and electricity generation by coal combustion in 2010 and projections for 2020 and also the status of air pollution control at power plants. The report also presents an inventory of mercury emissions from the coal based power sector and mercury emission projections. The mercury content estimated from the results of the sixty six samples studied varied from 0.003-0.34 g/tonne with the mean value being 0.14 g/tonne. Salient findings of this report indicate that the mercury emissions from coal-fired power generation are estimated at 38.54 metric tonnes/annum for 2008 using the default ODF of 0.9. Future mercury emissions have been estimated based on the projected coal consumption without taking into consideration future mercury emission reduction measures. Assessment of the reduction potential of mercury content of coal through washing has been made after conducting studies at five non coking coal washeries. The reduction of mercury content in the clean product of the washeries varied between 13.1% to 39.8%.

Mercury concentration in flue gas was measured in three power plants. The three power plants are NTPC, Talcher (Odisha), Korba (west), Chhattisgarh, and Budge Budge, West Bengal. The average mercury concentration in the flue gas at the outlet of ESP of the three power stations was 14.84, 11.50 and 4.24 μg/Nm^3 respectively. Significant portion of mercury present in feed coal have been found to be associated with fly ash.

The results mentioned in the report are indicative in nature. It may be noted that sample size is small for emission study. Rigorous sampling of Indian coal is required to make it a representative study. Based on archive data and data collected through present study, the output distribution factor (ODF) varies between 0.27 to 0.81 as per estimates. The mean value of ODF for Mercury in Indian coal would be 0.58 in place of default value of 0.9 as per UNEP tool kit.

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1.0 Introduction

Emissions of mercury from thermal power stations are a subject of increasing concern because of its toxicity, volatility, persistence, long range transport in the atmosphere. Mercury has the tendency for bioaccumulation as methyl mercury and thus enters into the food chain. Once released into the environment, mercury contaminates soil, air, surface and ground water. Mercury is a neurotoxin and exhibits adverse health effects. Mercury is a global pollutant that is emitted, deposited, and reemitted on both a local and global scale in both terrestrial and marine environments.

The mercury emitted from coal-fired power plants originates from the mercury present in the coal. Typically, mercury is present in the coal in the tens of parts-per-billion range. Burning of enormous quantity of coal for power generation makes it the largest anthropogenic source of mercury emissions at global level.

India ranks third in world coal production after USA and China. The majority of the coal production, approximately 70%, is used for thermal power generation. Coal combustion is the major source of anthropogenic mercury emissions in India.

Ministry of Environment & Forests, UNEP and CSIR-CIMFR have entered into a Small Scale Funding Agreement (SSFA) to undertake a project titled "Characterization of the coal fired power sector in India, assessment of the mercury contents in coal fed to power plants and calculation of mercury emissions from the Sector". In accordance with UNEP Governing Council priorities identified in Decisions 24/3 and 25/5 and with the goal of the reduction of mercury emissions from coal partnership area under the UNEP Global Mercury Partnership, the project aims to present national information on coal types and coal usage, characterize coal-fired power sector in India and develop an emission inventory for the coal fired energy sector and present other relevant information to improve accuracy of future emission inventories for the sector.

1.1 Project Objectives

The project has the followings objective:

- (i) Assessment of Mercury content of coal fed to coal fired power plants;
- (ii) Direct measurement of the emissions of mercury from the flue gas of selected power plants based on the capacity, vintage, fuel types, emission control systems, including the partitioning and speciation of mercury in the combustion products;
- (iii) Estimation of the Mercury emission factors based on the information gained during this project and comparison with relevant published emission factors; and
- (iv) Calculation of mercury emissions from the coal fired power sector in India based on developed emissions factors.

1.2 Major tasks of the study:

Task 1.Coal information

(i) Collection of information on the amount of coal consumed (for electricity production) by coal source, available information on coal analysis (including Hg, As, Se, Cl, Br, Ca, and Na content);

(ii) Collection of available information (or estimation) on the coal consumption (projected coal use) for electricity generation for the target years 2020;

(iii) Collection and chemical analysis of samples of coal from power plants to broadly cover coals from the major coalfields of India. Parameters for analyses include proximate, ultimate and determination of mercury, arsenic, selenium, sodium, calcium and chlorine content following relevant national and international Standards;

(iv) Collection and analyses of washery samples (feed coals and products); and

(v) Inter-calibration of analyses to be carried out on selected coal samples.

Task 2. Power plant information:

(i) Collection of national and provincial information on installed power plant capacity and electricity generation by coal combustion in 2008, including the approximate of power plants;

(ii) Collection of national and provincial information on air pollution control configuration and its typical operational efficiency;

(iii) Collection of national and provincial information on any available results of measurements of mercury emissions from power plants; and

(iv) Mercury emission measurements at selected power plants: Direct measurements of emissions in three coal based power plants adopting international accredited methods (flue gas measurements Ontario Hydro Method-ASTM D6784-02). Measurements to be carried out on one boiler unit (500 MW/200MW series) in each power plant.

In summary, the work at these power plants includes:

- Measurement of mercury concentration in flue gas;
- Measurement of Suspended Particulate Matter (SPM) concentration in the flue gas; and
- Assessment of the partitioning of mercury in different combustion pathways and also mercury speciation (particulate, elemental and oxidized) in flue gas.

Task 3. Mercury emission inventories and future estimates

i) Develop mercury emission factors based on data sets from selected power plants;

ii) The emission inventories will be shared by a network of experts and stakeholders for comments; and

iii) Develop future mercury emission estimates (scenario for 2020).

Task 4. Information seminar

An information seminar, including a workshop on the "Process Optimization Guidance for Reducing Mercury Emissions from Coal Combustion in Power Plants (POG)" to be organized by CSIR-CIMFR to disseminate information to relevant stakeholders (policymakers, administrative staff in the power plant sector)

1.3 Deliverables

a) Mercury emission factors (g/tonnes) of the studied coals;
b) Mercury emissions (gaseous and particulates) from the coal-fired power plants in India and speciation of mercury species in the flue gas;
c) Mercury concentrations in other combustion products (Fly ash, Bottom ash) of the power plants; and
d) A technical report presenting results.

2.0 Overview of Indian coal sector

2.1 Characteristics of Indian coal

Coal, in general and Indian coal of Gondwana origin in particular, is heterogeneous in nature. The term Gondwana originally denoted a geological system comprising a great succession of mainly fresh water sediments in the stratigraphy of the Indian subcontinent. The characteristics of these coals influenced by the origin and mode of formation are dissimilar to that of the coals of Northern Hemisphere in some respects.

The physico-chemical characteristics of Indian Gondwana coals of Permian period (210-270 million years) are different from the carboniferous coals (deposited 50-100 million years earlier than Gondwana coals) mainly due to the environment of deposition and post depositional features. This difference is significantly reflected in the composition of the petrographic constituents such as vitrinite, exinite and inertinite present in the coals. As most of the coals were deposited under oxidising condition they are poor in vitrinite (between 20-45%) and rich in inertinite (sometimes as high as 70%) with low content of exinite. Because of their low vitrinite content, Gondwana coals are comparatively low in hydrogen and high in nitrogen. The substantial proportions of low reflecting micro-components of inertinite group (mainly semi-fusinite and fusinite) with their relatively greater porosity allow higher “in-situ” moisture retention and result in lesser heating values. Most of India's coal is characterised by high ash content, but the coals has other useful qualities such as low sulphur content (generally 0.5%), low iron content in ash, high fusion characteristics of ash and low chloride content.

The volatile matter of the Gondwana coals, compared to carboniferous coals of the same maturity, is relatively low due to low vitrinite content. Although most of the Gondwana coals reached the bituminous stage, the majority falls at the lower end of this class (mean reflectance about 0.6%) ideally suitable for combustion purpose. Another typical feature is the relatively high proportion of inter grown mineral matter besides inter banded stone layers. An indication of the variability of quality parameters of the major thermal coal resources of the country, based on available data at CSIR-CIMFR are given in Table 1.

2.2 Coal reserves

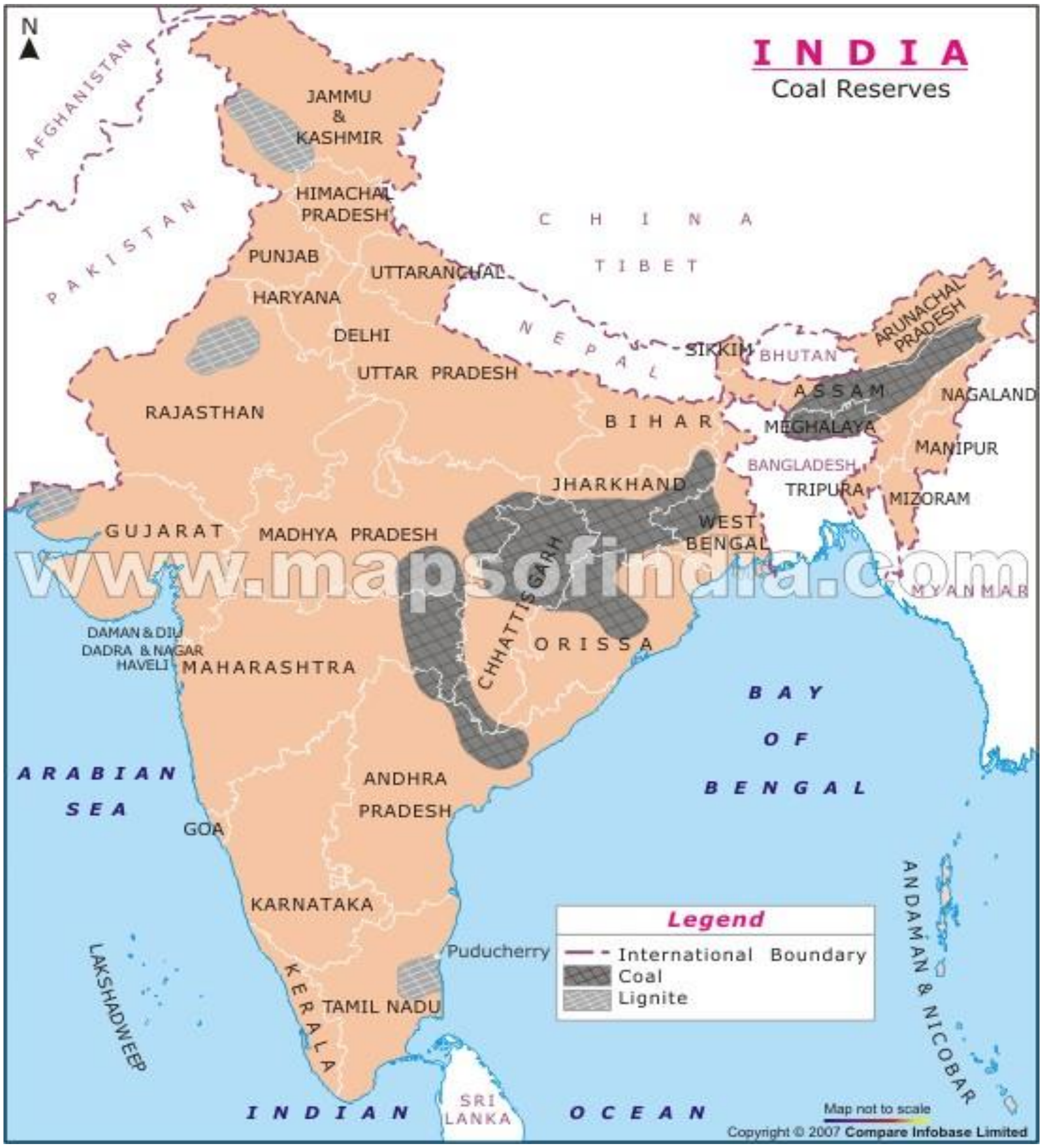
India having good reserve of coal and lignite stands eighth in the world in terms of estimated coal reserves and third in terms of volume of production. About 90% coals are of Permian Gondowana formation. South Africa, South America, Australia also has coal reserves formed in the same era. Coal deposits are mainly confined to eastern and south central parts of the country (see Map 1). The states of Jharkhand, Orissa, Chhattisgarh, West Bengal, Andhra Pradesh, Maharashtra and Madhya Pradesh account for more than 99% of the total coal reserves in the country. About 88% of the total coal production in the country is produced by Coal India Ltd. (CIL) which is the largest producer of coal in the country. CIL has seven coal producing subsidiary companies; viz. Central Coalfields (CCL), Eastern Coalfields (ECL), Bharat Coking Coal (BCCL), Northern Coalfields (NCL), Western Coalfields (WCL), Southern Eastern Coalfields (SECL), Mahanadi Coalfields (MCL) and the Central Mine Planning and Design Institute Limited (CMPDIL), which is entrusted with the job of providing total research and consultancy support to the industry. The only other major producer outside of CIL is the Singerani Collieries Company (SCCL) that is located in Andhra Pradesh. The locations of the major reserves of the Indian coals are shown in Map 1.

Table 1: Variability of coal quality of the major sources

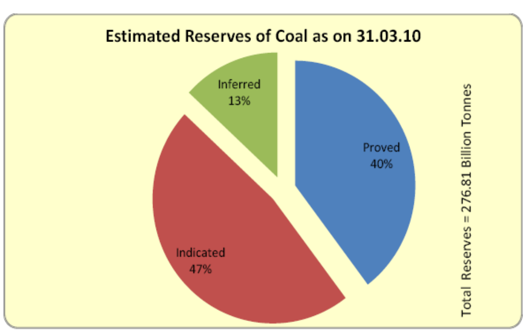
Coal Field		M	A	VM	FC	GCV	C	H	S	N	CaO	Na_2O	Pb	As	Hg
		Weight %				Kcal/kg	Weight %				Weight % in ash		mg/kg		
		Air Dried Basis													
Central Coalfields Limited	Min	0.8	23.5	15.7	26.0	3280	34.8	2.3	0.24	0.00	0.03	0.20	12.40	2.40	0.08
	Max	8.4	46.5	29.8	43.1	5635	57.7	3.7	0.60	1.60	4.21	0.78	42.20	9.20	0.36
	Average	4.6	35.4	25.2	35.3	4438	46.6	3.0	0.48	0.99	1.63	0.40	26.62	4.06	0.20
Mahanadi Coalfields Limited	Min	2.5	32.4	20.8	21.3	2585	28.9	2.3	0.18	0.56	0.11	0.17	22.50	0.90	0.12
	Max	8.3	52.8	28.7	37.5	4460	47.5	3.4	0.87	1.10	1.47	0.61	52.50	3.50	0.29
	Average	5.9	40.1	25.0	29.0	3779	40.3	2.9	0.46	0.82	0.82	0.29	38.50	2.45	0.20
Northern Coalfields Limited	Min	5.2	17.4	22.5	25.4	3541	38.8	2.8	0.00	0.57	0.11	0.13	17.90	0.60	0.08
	Max	10.0	42.4	30.0	45.4	5545	60.0	3.9	0.51	1.12	1.99	1.80	38.70	9.70	0.49
	Average	7.1	31.5	27.0	34.5	4437	47.1	3.3	0.37	0.87	0.83	0.71	28.49	3.64	0.21
Singareni Colliery company Limited	Min	4.5	17.1	20.8	27.6	3311	35.6	2.0	0.30	0.80	0.49	0.27	22.40	2.30	0.08
	Max	8.9	46.5	29.5	50.2	5681	60.5	3.3	2.20	1.20	7.01	0.44	41.40	6.60	0.22
	Average	6.6	33.5	25.0	34.9	4444	46.5	2.7	1.00	1.02	2.86	0.33	32.08	4.47	0.14
Western Coalfields Limited	Min	1.5	18.9	13.7	16.9	2104	23.0	1.2	0.30	0.50	0.29	0.20	10.10	1.80	0.05
	Max	9.1	60.8	29.7	43.3	5379	55.1	3.5	2.20	1.20	3.29	0.70	48.80	8.90	0.40
	Average	6.6	34.5	24.3	34.7	4323	45.1	2.6	0.98	0.96	1.53	0.33	30.67	5.35	0.21
South Eastern Coalfields Limited	Min	2.2	15.0	20.8	27.8	3555	36.6	2.2	0.70	0.20	0.14	0.13	12.20	2.30	0.06
	Max	9.1	43.2	27.8	52.8	6345	63.1	3.7	1.30	1.40	6.46	2.76	36.30	10.50	0.31
	Average	6.2	25.4	24.4	44.0	5318	54.4	3.0	1.09	0.70	1.32	1.11	20.27	5.28	0.14

(M=Moisture; A=Ash; VM=Volatile Matter; FC=Fixed Carbon; C=Carbon; H=Hydrogen; N=Nitrogen; S=Sulphur; GCV=Gross Calorific Value)

The total estimated reserve of coal in India as on 31.03.2010 was around 277 billion tonnes and that of lignite was 40 billion tonnes (Figure 1), of which 80% was in the southern State of Tamil Nadu. Other states with lignite deposits are Gujarat, Jammu and Kashmir, Rajasthan, Kerala, and the union territory of Pondicherry.



Map 1: Locations of the Major Coal Reserves (not to scale)



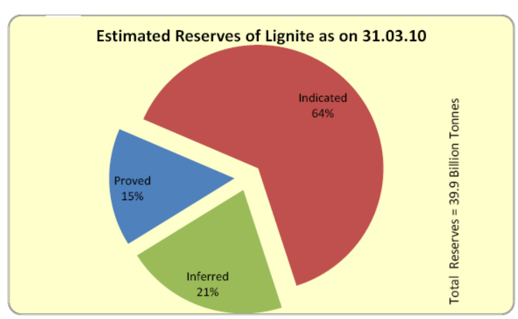


Figure 1- Reserves of coal and lignite

2.3 Pattern of Coal Consumption

Coal is the dominant energy source in India, accounting for more than half of the country's requirements. 70% of India's coal production is used for power generation, with the remainder being used by heavy industry and public use. Domestic supplies satisfy most of India's coal demand. The estimated total consumption of raw coal by industry, including power sector, has increased from 71.2 million tonnes during 1970-71 to 586.07 million tonnes during 2009-10. Consumption of lignite increased from 3.39 million tonnes in 1970-71 to 34.42 million tonnes in 2009-10. Consumption of Lignite is highest in electricity generation sector, accounting for about 80% of the total lignite consumption.

Industry-wise estimates of consumption of coal shows that from the year 1975-76 electricity generation is the biggest consumer of coal, followed by steel industries. Estimated coal consumption for electricity generation increased from 23 million tonnes during 1975-76 to 417.56 million tonnes during 2011-12. Similarly, the estimated consumption of coal by steel sector and washery increased from 19 million tonnes to 41 million tonnes, a two times increase, during the same period. The coal consumption profile for the year 2008-09 is shown in Figure 2.

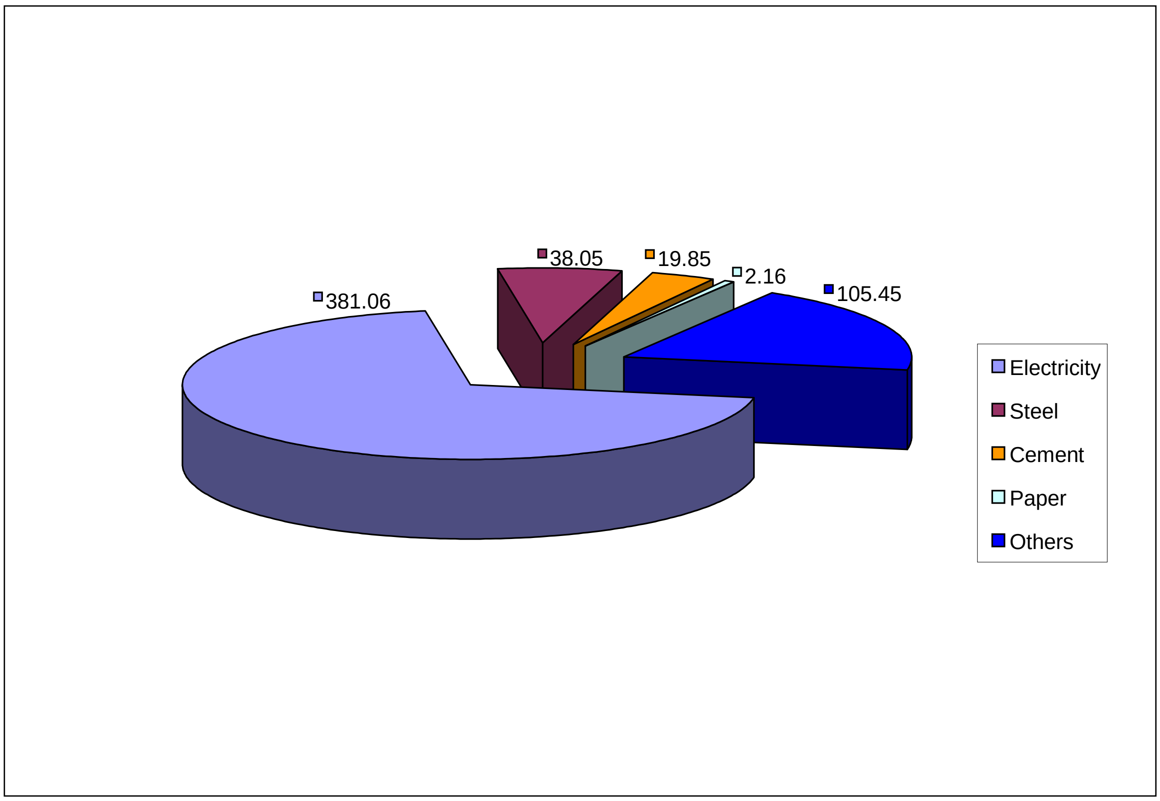


Figure 2: Coal Consumption profile (million tonnes) of 2008-09

2.4 Coal washeries

Coal washing is an important component in the total 'coal- energy' chain. Raw coals coming from mines are washed to produce a clean product of the desired quality for different end users. Washing of coking coals to meet the needs of the steel sector has a long history in this subcontinent but thermal coal washing for the power sector is yet to mature to the desired level. A coal washery does not normally form part of coal mine in India. As on 31st March, 2010, a total of 52 washeries, both public sector unit (PSU) and private, were operating in the country. The total installed washing capacity was 126 million tonnes per year, for both coking (29.69 million tonnes per annum) and non-coking coal (96.32 million tonnes per annum). The capacity and the locations of some of the major non coking washeries are given in Table 2.

Table 2: Installed capacity of major non coking coal washeries in India (as of 31st March, 2010)

SI.NO	Washery & Operator	Location	Capacity (million tonnes)
(A)	Coal India Ltd.(CIL)		
1	Dugda-I,CIL	Jharkhand	2.50
2	Madhuban,CIL	Jharkhand	2.50
3	Piparwar, CIL	Jharkhand	2.50
4	Gidi,CIL	Jharkhand	6.50
5	Kargali,CIL	Jharkhand	2.72
6	Bina, CIL	Uttar Pradesh	4.50
		(A.)CIL Total	21.22
(B)	Private		
1	Dipka, Aryan Coal beneficiation Pvt. Ltd.	Chhattisgarh	12.00
2	Gevra, Aryan Coal beneficiation Pvt. Ltd.	Chhattisgarh	5.00
3	Panderpauni, Aryan Coal beneficiation Pvt. Ltd.	Maharastra	3.00
4	Chakabuwa, Aryan Energy Pvt. Ltd.	Chhattisgarh	4.00
5	Talcher, Aryan Energy Pvt. Ltd.	Orissa	2.00
6	Wani, Kartikay Coal Washeries Pvt. Ltd.	Maharastra	2.50
7	Ramagundam, Gupta Coalfield & Washeries Ltd.	Andhra Pradesh	2.40
8	Sasti, Gupta Coalfield & Washeries Ltd.	Maharastra	2.40
9	Tamnar, Jindal Steel & Power Ltd.	Chhattisgarh	6.00
10	Ghugus, Bhatia International Ltd.	Maharastra	4.00
11	Wani, Bhatia International Ltd	Maharastra	3.00
12	Ib Valley, Global Coal Mining (P) Ltd.	Orissa	3.25
13	Bilaspur, Gupta Coalfield & Washeries Ltd	Chhattisgarh	3.50
14	Gondegaon, Gupta Coalfield & Washeries Ltd	Maharastra	2.40
15	Majri, Gupta Coalfield & Washeries Ltd	Maharastra	2.40
16	Talcher, Global Coal Mining (P) Ltd.	Orissa	2.50
17	Punwat, Punwat, Indo Unique Flame Ltd.	Maharastra	2.40
		Private others	15.35
		(B) Private Total	75.10
	Total non-coking (for power sector) (A+B)		**96.32**

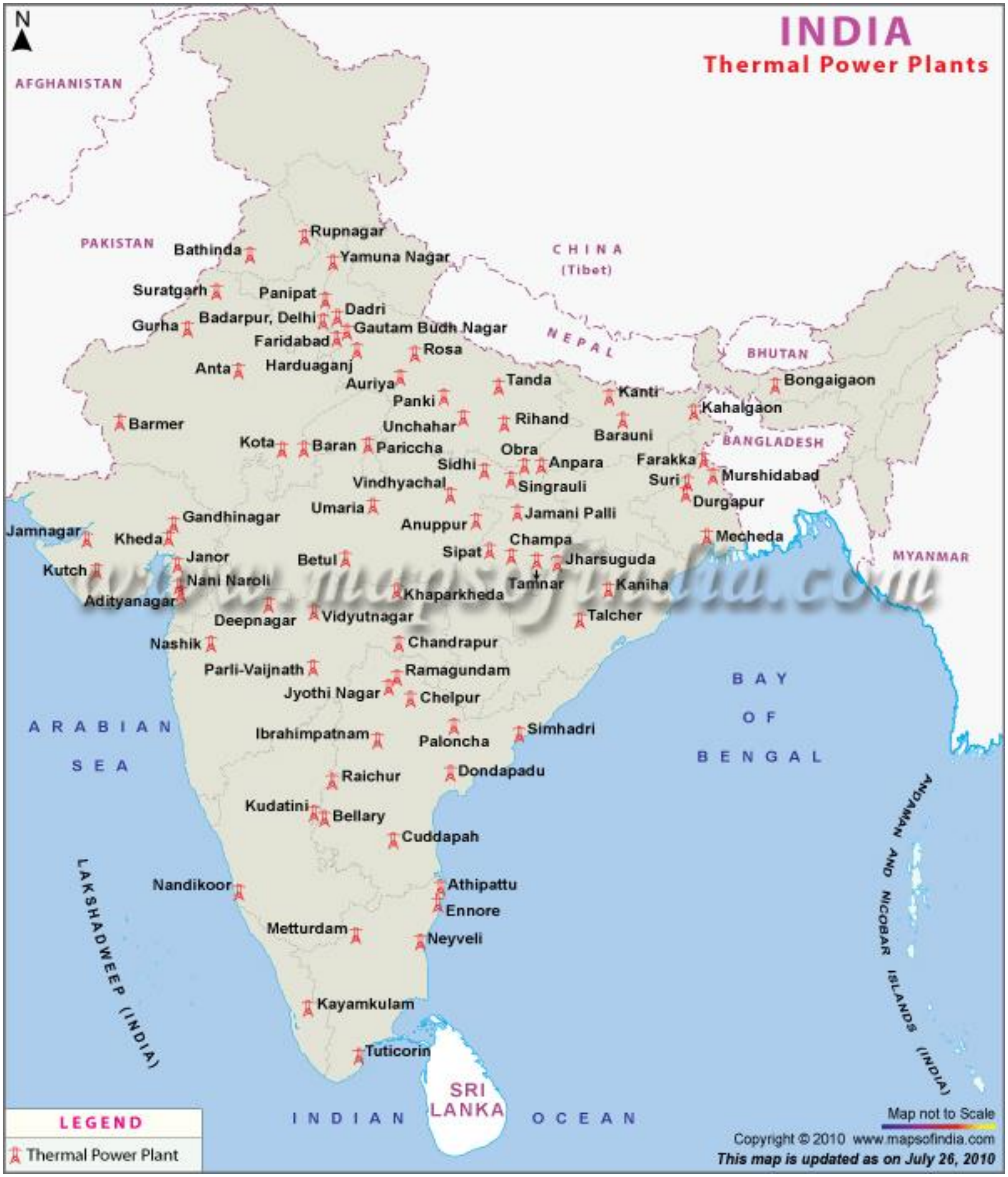
3.0 Power Generation Sector in India

3.1 Installed generating capacity of electricity

The total installed capacity for electricity generation in the country has increased from 16271 MW as on 31.03.1971 to 199877 MW as on 31.03.2012. By the end of March 2012, thermal power plants accounted for 65.8% of the total installed capacity in the country, with an installed capacity of 131603 MW. This is followed by hydro power plants with an installed capacity of 38990 MW, accounting for 19.5% of the total installed Capacity. The share of nuclear energy is only 2.4% (4780 MW).

The geographical distribution of installed generating capacity of electricity as of 31st March, 2012 indicates that Western Region (both central and state sector) accounted for the highest share (32.21%) followed by Southern Region (26.38%), Northern Region (26.97%), Eastern Region (13.15%) and North Eastern Region (1.2%). There are more than 90 thermal power plants across the length and breadth of the country using coal as the main fuel resource. The share of generation capacity by the state sector, central sector and private sector are 43 %, 30% and 27% respectively.

The locations of the major coal based power stations in the country are given in the Map 2.



Map 2: Locations of the Thermal Power Plants (not to scale)

The trends in energy production in the country by primary sources and the installed electricity generation capacity are shown in Figures 3 and 4 respectively.

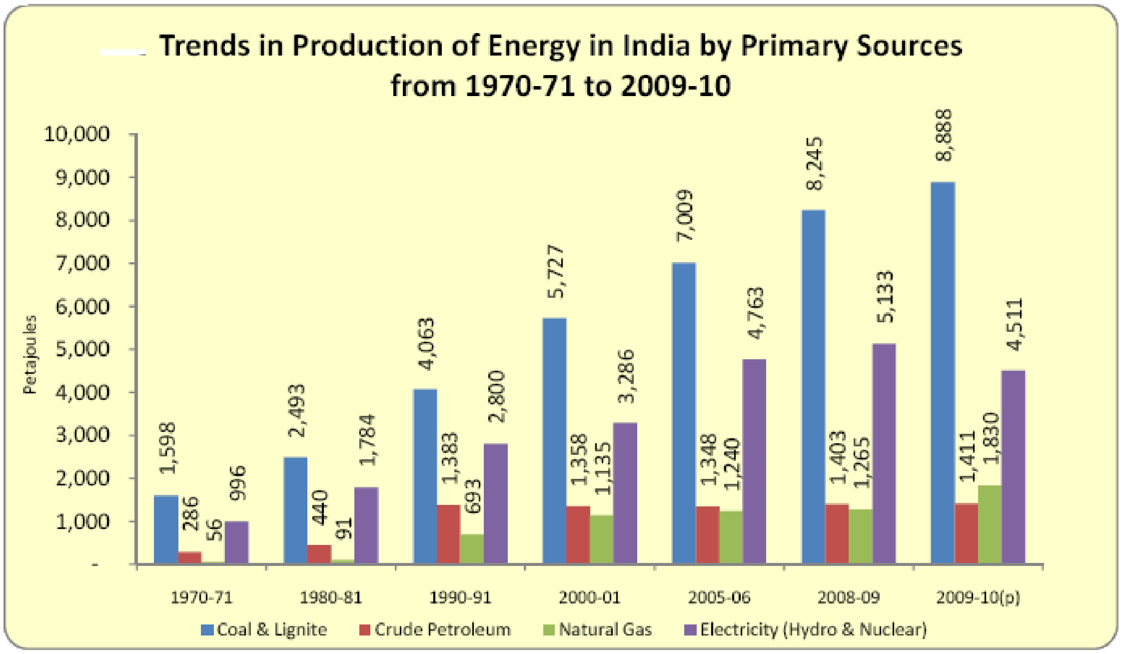


Figure 3: Primary energy sources in India (source-Energy statistics-2011)

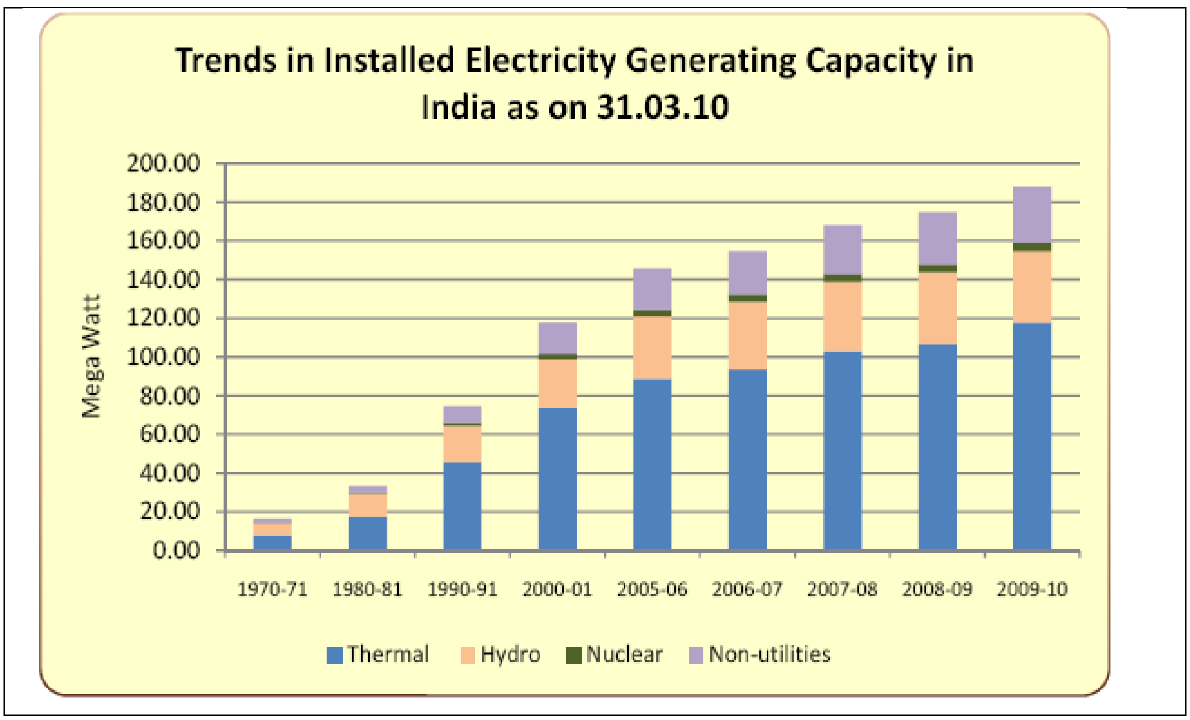


Figure 4: Installed electricity generation capacity in India
(Source-Energy statistics-2011)

3.2 Coal fired power plant in India

At present, coal based power plants accounts for about 55% of the total installed capacity in the country. Existing coal-fired power plants in India are mostly based on pulverized coal fired system with subcritical steam conditions, having unit sizes ranging typically from 30 MW to 500 MW. However, few units of 600 MW are also in operation. About nine units (660/800 MW) based on supercritical technology have been commissioned by March 2012. The total installed capacity of different boiler unit sizes and their gross generation from 2007-08 to 2010-11 is given in Table 3 and Table 4. The source (imported or Indian) wise coal consumption by the power sector is given in Figure 5. The distribution of untreated, washed and imported coals fed to the coal fired plants in the year 2010 is given in Figure 6.

Table 3: Boiler unit sizes and installed power plant capacity

Capacity of boiler units (MW)	Installed power plant capacity			
	2007-08	2008-09	2009-10	2010-11
500	18500	20000	20990	22480
300-330	-	1500	2430	5220
250	4250	5500	7750	9000
210	28980	29610	29820	29820
195-200	4795	4795	4990	4990
100-150	9160	8860	9695	9645
25-99	4884.50	4649.50	4462	4402

Table 4: Unit size wise electricity generation

Capacity of boiler units (MW)	Gross generation (million kWh)			
	2007-08	2008-09	2009-10	2010-11
500	133668.14	144265	154453.09	161637.17
300-330	-	6834.55	13513.47	28622.33
250	29079.03	36228.31	5424.93	62687.35
210	210342.55	210112.15	209483.37	200464.66
195-200	34836.80	33895.43	34559.69	33903.7
100-150	44315.55	42036.67	45818.21	44973.28
25-99	23309.64	24656.55	22795.14	21407.68

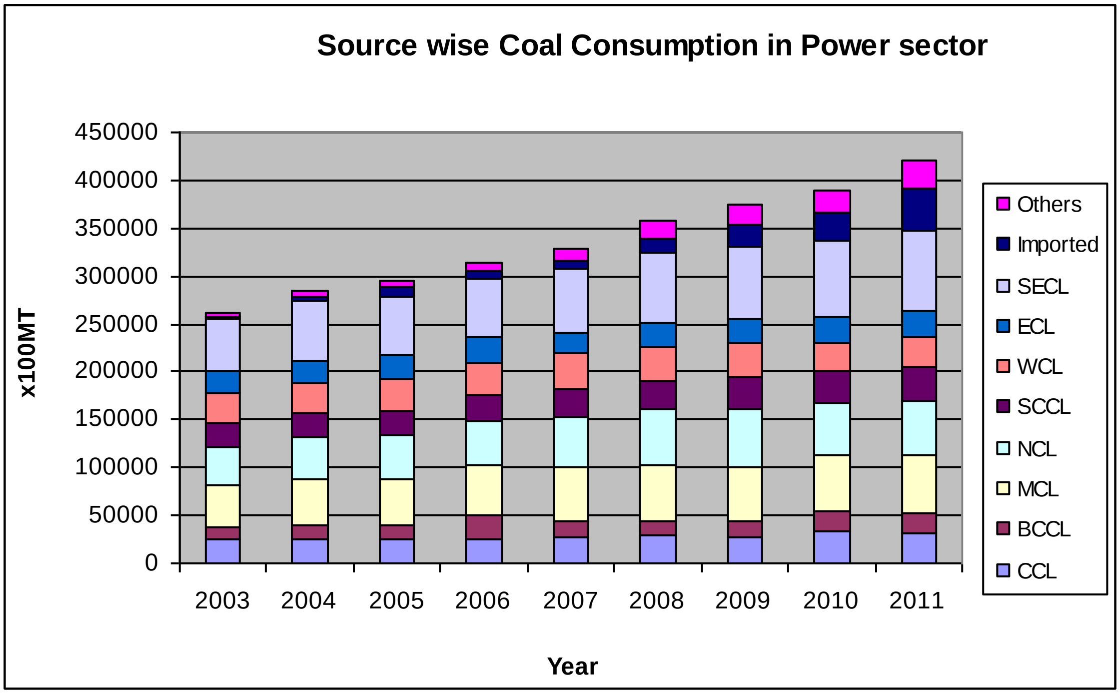


Figure 5: Coal consumption in the power sector (source wise)

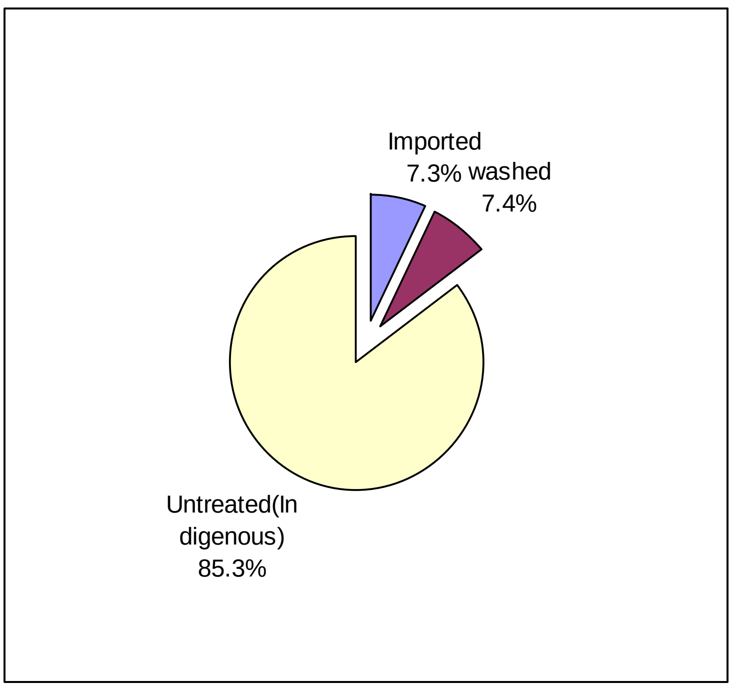


Figure 6: Share of Indigenous, imported & washed coal (2010) in the power sector

3.3 Air pollution control equipment in the power plants

Due to high ash level and low calorific values of Indian coals, the dust load of the flue gases are generally very high. The electrical resistivity of typical Indian fly ashes lies in the range 10^9 to 10^{12} ohm. m. The high ash resistivity and dust load need higher efficiency of particulate capture devices. Almost all the coal/ lignite based power plants in India are equipped with electrostatic precipitators with typical operational efficiencies of particulate capture of more than 99.0 per cent.

The following power plants have installed additional air pollution control devices (APCDs) :

- Koradi TPS of Maharastra have installed fabric filters along with electrostatic precipitator;
- Trombay Power Plant and Dhanu Power Plants have installed wet flue gas desulphurization; and
- A few pulverized coal fired power plants have employed ammonia conditioning and SO_3 dosing to enhance efficiency of ESP.

4.0 Present Study

In tune with the project objectives, the present study was focused on three broad tasks:

i) Quality assessments and estimation of mercury concentrations of the coals being fed to coal power plants;
ii) Assessing the reduction potential of mercury through coal washing in the existing commercial coal washeries; and
iii) Mercury emissions measurement at three pulverized coal fired power plants.

4.1 Coal analysis

Twenty three power plants have been selected by Central Electricity Authority (CEA) taking into account the locations and feed coal sources. Most of the power plants in the country receive coals from multiple mine sources that are located at different coalfields of the country.

The methodology adopted in collection of coal samples, solid residues, flue gases and suspended particulate matter; sample preparation/ dissolution; testing and analytical techniques are according to the relevant National and International Standards the details of which are given in Table 5.

Table 5. The methods adopted for collecting, preparing and analyzing samples

Activity	Sample	Procedures
Collection of samples	Coal	Indian Standard IS : 436 (Part l/Set 1) – *1964:* Methods for sampling of coal and coke sampling of coal: Manual Sampling
		Indian standard IS 436(Part I/Sec 2)-1976 Methods for sampling of coal and coke: Part I Sampling of coal Section 2: Mechanical Sampling
		ISO 13909-2001Hard coal and coke- Mechanical sampling-Part 1: General Information
Sample preparation	Coal	ASTM D2013 - Standard Practice of Preparing Coal Samples for Analysis
Chemical analysis	Coal	Indian standard IS 1350 Part I to Part V for proximate analysis, gross calorific value, total sulphur, carbon & hydrogen, nitrogen and chlorine content in coal.
Chemical analysis	Coal ash	Indian standard IS 1355:1984 Methods of determination of chemical composition of ash of coal and coke Indian standard IS 1727:1967 Methods of tests for pozzolanic materials
Mercury analysis	Coal	ASTM D3684-1978: Standard Test Method for Total Mercury in Coal by the Oxygen Bomb Combustion/Atomic Absorption Method Combustion Residues by Acid Extraction or Wet Oxidation/Cold Vapor Atomic Adsorption
		ISO 15237: Solid mineral fuels-Determination of total mercury content of coal
Mercury analysis	Coal and solid residue	EPA Method 7473 - Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry
		ASTM D6414 - Standard Test Method for Total Mercury in Coal and Coal Combustion Residues by Acid Extraction or Wet Oxidation/Cold Vapor Atomic Adsorption
Analyses of arsenic and selenium	Coal	ISO 11723, Solid Mineral Fuels- Determination of arsenic and selenium in coal- Hydride generation method
Flue gas sampling(gaseous and particulate) and analysis	Flue gas & SPM	ASTM D6784-2002 Standard test method for elemental, oxidized, particle bound and total mercury in flue gas generated from coal fired stationary sources (Ontario Hydro Method)

A total of sixty six coal samples (sub-bituminous and bituminous) from twenty three power plants spread across the country were collected and characterized in terms of the proximate, ultimate, heat value, heavy metal and chlorine contents and major oxides. The coal samples were collected from the outlet of coal bunkers before they are fed to the mill. Out of these sixty six coal samples analyzed, only two were washed coal, used, at Dadri and Unchahar power plants. The estimated average values of the quality parameters for the coal samples are shown in Tables 6 and 7. The mercury and chlorine contents of the feed coals of the respective power plants are given in Table 8.

Table 6 : Quality parameters of the coals fed to Power Plants

Coal Source	**CCL**	**BCCL**	**MCL**	**NCL**	**WCL**	**ECL**	**SECL**	**SCCL**
Weight %	Air dried basis							
Moisture	7.8	1.0	8.2	9.4	7.5	5.3	6.1	5.2
Ash	33.0	41.4	40.9	37.4	37.8	29.6	28.0	31.4
VM	23.0	15.9	23.8	23.3	23.4	25.8	26.1	26.4
FC	36.2	41.7	27.1	29.9	31.3	39.2	39.8	37.0
C	42.3	43.0	35.6	40.3	42.1	46.9	50.2	46.2
H	2.7	2.6	2.5	2.6	2.9	3.0	3.1	2.9
N	0.9	1.0	0.9	0.8	0.9	1.2	1.1	0.9
S	0.5	0.4	0.5	0.3	0.7	0.5	0.5	1.0
GCV(kcal/kg)	4111	4875	3570	3835	4562	4450	5008	5110

Table 7: Major and Minor Elements

Coal Source(Air dried basis)	**CCL**	**BCCL**	**MCL**	**NCL**	**WCL**	**ECL**	**SECL**	**SCCL**
Na g/tonne	1005.4	355.4	427.2	17.8	271.3	560.4	280.7	430.3
Ca (Weight % in dry ash)	0.38	0.42	1.05	0.92	0.55	0.58	0.46	0.87
Cl g/tonne	356.9	93.4	167.8	266.0	70.3	100.2	92.7	79.5
Hg g/tonne	0.22	0.08	0.20	0.06	0.12	0.08	0.10	0.12
As g/tonne	0.86	1.45	0.95	1,15	1.92	1.30	1.44	1.58
Se g/tonne	3.22	1.52	2.14	5.76	1.32	1.20	1.22	0.48

Table 8: Mercury content of the feed coals to power plants

Sr. No	Power Plant	coal source	No of samples	Mercury	Chloride
				Air dried basis	
				(g/tonne)	(g/tonne)
1	Ropar	PANAM, Captive	1	0.207	106
2	Lehra Mohabbat	PANAM, Captive	1	0.148	42
3	Yamuna Nagar	CCL	1	0.243	254
4	Unchahar NTPC	CCL	1	0.192	80
5	Bhatinda,GNDTP	CCL	1	0.215	97
6	Kahalgaon NTPC	BCCL,ECL	3	0.014-0.055	64-146
7	Farakka NTPC	BCCL,ECL	7	0.053-0.154	33-255
8	BkTPP, WBPDCL	ECL,BCCL,MCL	10	0.015-0.192	35-143
9	Feroz Gandhi TPP	BCCL	1	0.117	74
10	Budge Budge,CESC	ECL,MCL,BCCL	4	0.05-0.183	55-135
11	SgTPP,WBPDCL	ECL,MCL,BCCL	4	0.02-0.214	55-190
12	Raichur	SCCL; MCL;WCL	3	0.141-0.185	
13	Ennore TPS	MCL	2	0.307-0.342	140-155
14	Khaperkheda TPS	WCL,SECL,MCL	5	0.051-0.167	30-285
15	Talcher STPS NTPC	MCL	4	0.205-0.303	212-266
16	Singrauli, NTPC	NCL	2	0.055-.065	213-319
17	Ramagundam NTPC	SCCL,SECL	2	0.097-0.144	53-106
18	Satpura, MPPGCL	WCL,SECL,MCL	1	0.123	80
19	Kolaghat, WBPDCL	ECL	1	0.105	145
20	Korba(W), CSEB	SECL	1	0.176	85
21	Talcher TPS	MCL	3	0.173-0.229	106-155
22	Kota,STPS, Rajasthan	SECL	4	0.003-0.215	53-124
23	Dadri, NTPC	CCL(Washed & Raw)	4	0.223-0.257	66-1489

4.2 Mercury emissions measurement in power plants

Direct emissions measurement was carried out in one boiler unit at three pulverized coal fired power plants. The unit generation capacities of the boiler units are 210 MW, 250 MW and 500 MW. The power plants are:

1. Talcher STPP, National Thermal Power Corporation, (Public sector);
2. Korba (West), Chhattisgarh Electricity Board (Chhattisgarh State owned);
3. Budge Budge, Calcutta Electric Supply Corporation (private sector).

All the three power plants are equipped with electrostatic precipitator (ESP) for particulate capture. The measured average flue gas temperature at the outlet of the ESP's are 150^{O}C (Talcher STTP), 130 ^{O}C (Korba) and 127 ^{O}C (Budge Budge). Representative samples of crushed coal (20 mm top size), pulverized coal (<212µm), fly ash and bottom ash, mill rejects were collected from one boiler unit of each of the three power stations. The composite fly ash samples were collected from the silos of the respective power plants. The samples were dried, crushed and reduced by standard coning and quartering method, pulverized to less than 212 µm, bottled and stored for analyses. Field measurements on emissions and speciation of Mercury had been conducted in one boiler units of three power stations .Flue gas (upstream of ESP) was iso-kinetically pulled through a quartz fibre filter and a series of chilled impinges. The filter retains particulate present in the gas stream and vapour phase components of the flue gas are absorbed in impinger liquids. The collection of flue gas samples and that of suspended particulate matter (SPM) were performed simultaneously. The duration of sample collection ranged between 2-3 hours. The results shown in Table 9 are the average values of three runs in each boiler units.

In Budge Budge power plant, the sampling of flue gas was done at 91 metre elevation in the stack. In the other two power plants the gas sampling was done in the ducts at the outlet of ESP.

Table 9: Mercury concentrations in flue gas samples and combustion products

	Unit Capacity	**LOI of Fly ash (Weight %)**	**Solid Products Mercury concentrations(dry basis)**				**Flue Gas**	**Speciation**		**Fr. of Hg emitted (average)**
Power Plants			Fly ash	Bottom ash	Mill rejects	SPM	µg/NM^3	Hg^{2+}	Hg^0	
			g/t	g/t	g/t	g/t		%	%	
Talcher STPP, NTPC	500MW	0.64	0.097	0.006	-	0.066	14.84	30.8	60.8	0.81
Korba (W) CEB	210 MW	0.85	0.158	0.011	1.373	0.057	11.50	11.3	88.1	0.61
Budge Budge CESC	250 MW	2.05	0.242	0.017	0.143	0.105	4.24	41.60	58.1	0.27

(LOI= Loss on Ignition)

4.3 Previous study at NTPC coal based power plants

A similar study was carried by this Institute earlier in seventeen boiler units at three super thermal power plants of NTPC having unit sizes 200, 210 and 500 MW with a total generation capacity of 5260 MW. The results are presented in Table 10.

Table 10: Distribution of Mercury in Flue Gas and Other Combustion Products at NTPC coal based power plants

	Unit Capacity	**Feed coal mercury**	**Distribution of Mercury in combustion products (%)**				**Speciation**		**Fr. of Hg emitted (average)**
Power Plants			Fly ash	Bottom ash	SPM	Flue Gas	Hg^{2+}	Hg^0	
		g/t	%	%	%	%	%	%	
Singrauli STPP	200MW/ 500MW	0.140	26.29	Not detected	0.69	73.71	30.08	68.98	0.73
Vindhyachal STPP	6X210 MW/ 2X500 MW	0.138	38.63	1.13	0.39	60.24	30.09	69.26	0.60
Rihand STPP	2X500 MW	0.17	48.50	0.70	2.51	48.4	38.20	56.61	0.48

4.4 Washery samples

The feed and the products of five coal washeries were sampled and analysed for their Mercury content. The washeries located in three different states of Jharkhand, UttarPradesh and Chattisgarh are of diferent capacity and use different washing schemes. The equipment are mainly Jig, ROM Jig, and Heavy Medium washers. In most of the cases the reduction of mercury was observed through cleaning as evident from the results given in Table 11.

Study conducted in the five non-coking coal commercial washeries clearly indicates that significant reductions of mercury concentrations are achieved as a co benefit.The highest mercury reduction of 39.8% is achieved in Bina washery and the lowest reduction in mercury level of 13.1% is observed in case of JSPL washery. It is evident from Table 11 that there is no direct relation between the reductions in ash contents and the reductions in mercury concentrations in the product. The results indicats that reductions in mercury contents are highly coal specific. It depends not only on the nature of association and distribution of mercury in coal matrix, but also on the washing process adopted.

Table 11: Distribution of Mercury in the Washery products

Coal Washery	Samples	M	A	Hg(mg/kg)
		Weight % (air dried basis)		Air dried basis
Piparwar CCL	Feed coal	4.8	40.2	0.215
	Clean coal	4.6	33.5	0.185
	Rejects	4.2	55.1	0.198
Kargali CCL	Feed coal	0.9	45.6	0.132
	Clean coal	1.1	33.8	0.099
	Rejects	0.6	67.3	0.105
Gidi CCL	Feed coal	2.0	47.2	0.125
	Clean coal	4.5	32.6	0.102
	Rejects	2.0	65.0	0.104
JSPL Private	Feed coal	5.8	48.4	0.222
	Clean coal	7.3	31.9	0.193
	Middlings	2.8	66.2	0.240
	Rejects	1.6	79.0	0.526
Bina NCL	Feed coal	3.6	42.9	0.093
	Clean coal	4.3	36.6	0.056
	Rejects	1.5	76.1	0.096

(Clean coal, rejects,middlings- the three products of a washery.)

4.5 Inter-calibration of analyses on selected coal samples

For validation of estimated Mercury concentrations in coal samples, eight numbers of coal samples (six from power plants & two from coal washeries) along with two standard reference coal samples with certified Mercury contents (Table 12) were subjected to inter-laboratory testing. Coal samples were analyzed for Mercury contents at CSIR-NIO (CSIR-National Institute of Oceanography), Vishakhapatnam, India (Table 13).

Table 12 Certified mercury concentrations of reference coal samples

Certified reference coal sample	Certified mercury content(dry basis), µg/kg
BCR-182(European Commission)	40.0 ±7.0
NIST(USA) SRM-2693	37.3 ± 7.7

Table 13: Method adopted and instrument used by the laboratories

Laboratory	Method	Instrument
CSIR-CIMFR	US EPA Method 7473	Tri-cell DMA-80 (Milestone, Italy)
CSIR-NIO	US EPA Method 7473	Tri-cell DMA-80(Milestone, Italy)

Table 14 shows the replicate values for the mercury contents of the coal samples as obtained by CSIR-CIMFR and CSIR-NIO.

Table 14: Inter laboratory variability of mercury concentrations

Sample No	Mercury content estimated by CSIR-NIO (dry basis) µg/kg				Mercury content estimated by CSIR-CIMFR(dry basis) µg/kg			
	Rep-1	Rep-2	Rep-3	Average	Rep-1	Rep-2	Rep-3	Average
BCR-182	36.7	43.4	40.4	40.2	40.6	43.8	42.8	42.2
SRM-2693	34.1	34.1	32.8	33.7	40.2	37.3	38.4	38.6
16	62.1	62.5	61.3	61.9	66.3	64.1	64.6	65.0
18	96.0	93.3	99.7	96.3	97.9	96.7	97.3	97.3
30	122.0	129.5	128.5	126.7	126.6	142.8	131.4	133.6
57	178.1	169.4	178.4	175.3	183.2	177.5	192.8	184.5
59	104.8	111.8	110.1	108.9	111.1	115.3	112.9	113.1
67	71.8	72.7	62.8	69.1	61.5	60.6	58.2	60.1
W/8	94.9	96.5	91.0	94.1	99.8	103.2	102.4	101.8
W/9	108.1	107.7	108.1	108.0	122.6	113.8	108.3	114.9

The results indicate that the mercury concentrations of coal samples as determined by triplicate measurements by the two laboratories are comparable and the precision obtained for the standard reference coal samples lies within the acceptable uncertainty limits.

5.0 Mercury emission factor and Emission Inventory

The coal samples studied under this project activity show wide variability in terms of ash per cent, gross calorific value (GCV) and the mercury content. The minimum and maximum value of the mercury content is 0.003 g/tonne and 0.34 g/tonne. The average value of mercury content of 66 feed coal samples to TPS coming from eight coalfields is 0.14 g/tonne. The average value of 0.14 g/tonne has been considered as the input factor of the coals being used by the power sector and has been used to estimate the mercury emission inventory in this study.

The average mercury input factors (concentration, g/tonne) of the different coalfields are shown in Table 7 and the source wise coal consumption data are shown in Figure 5.

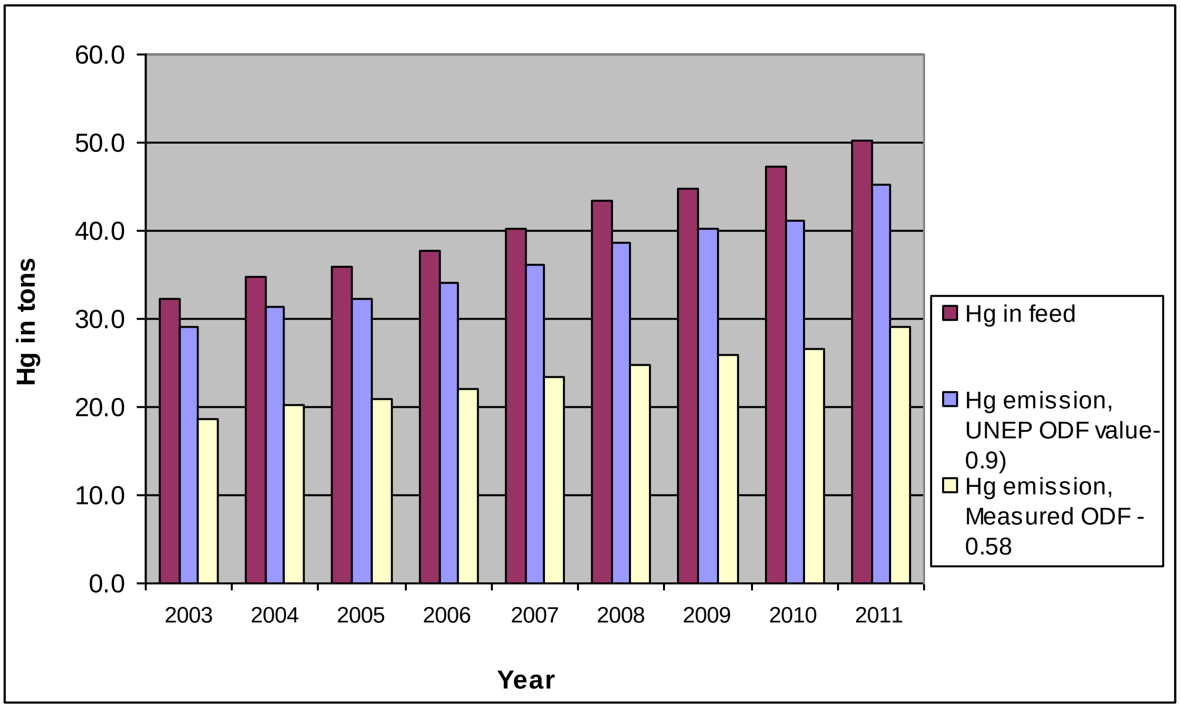
To estimate the mercury emissions from the power sector, the methodology provided in UNEP Tool Kit has been used. In the UNEP Tool Kit methodology, for coal combustion, the default output distribution factor for mercury to air is considered as 0.9 for those power plants which have an ESP for particulate capture.
The mercury release from the power sector has been estimated using the following equations.

Emissions factor = Input factor * output distribution factor to air

Estimated Mercury Release (tonne/year) = Activity rate * Emissions factor

Activity rate = Amount of coal fed to power plants in a year (tonne/year)
Input factor = Mercury Input Factor of coal (Hg concentration in coal, g/tonne)
Output Distribution factor to air = 0.9 (As per UNEP Tool kit for plants having General ESP). The results for the period 2003 to 2011 are depicted in Figure 7.

Figure 7: Trend of Mercury in feed coals and emission from the thermal Power stations



As mercury content in coals are subject to significant variation, there is a high degree of uncertainty in this estimate since the bulk of the emissions are estimated using emission factors obtained with limited number of coal samples. It needs to be mentioned that use of the default value of the output distribution factor of 0.9 is likely to give a higher estimate of the emissions. Implicit in the default value 0.9 is the assumption that the volatile mercury are entirely carried in the flue gas and depending on the efficiency of the existing air pollution control system a fraction of the mercury is retained and 90 % is released in the air. This default value considers only 10% retention of mercury in the solid combustion products. Previous study in 17 boiler units and the present measurements carried out in three boiler units in the country using high ash coals show that a significant portion of the Mercury is retained in the fly ash. Such observations have also been reported in literature. Hence the default factor needs to be modified in the Indian context.

From the Mercury emissions study carried out in three power plants (Table 9) and earlier study in three other plants (Table 10) the fraction of feed coal mercury emitted to air were found to be 0.81, 0.61 and 0.27, 0.73, 0.60, and 0.48. The measurements were carried in boiler units of different generation capacity and the very limited Mercury emissions data do not provide an objective basis for arriving at an average output distribution factor. However, the emissions results clearly indicate that the output distribution factor (ODF) can be much lower than the UNEP default factor of 0.9. Considering the data of the present study as shown in Table 9 and the archive data as depicted in Table 10, a tentative value of the mean Output Distribution Factor(ODF) of 0.58 has been arrived at for the coal based power plants in the country. This estimated figure, however, requires further refinement based on detailed study on large number of power plants considering the capacity, vintage and Air Pollution Control Device. The projected estimates based on the UNEP default value of 0.9 and the estimated mean value of 0.58 is shown in Figure 7. It is apparent that use of the lower value of ODF can significantly lower down the projected estimates of mercury emissions from the Indian power sector.

5.1 Partitioning of Mercury and Mercury Speciation

The results of the emissions measurement carried out in three power plants are shown in Table 9. Considering the quantity of fly ash generated from the high ash Indian coals and the mercury content in the fly ash, a significant proportion of feed coal mercury is retained in the fly ash. The Mercury concentrations in the bottom ash samples are not significant. This is also noted that there is considerable enrichment of Mercury in mill rejects. This reflects the probable association of coal Mercury with the hard minerals present in coal like pyrite, siderite etc.

Results from Table 9 reveal that a major portion of the emitted Mercury is in elemental form. This may be attributed to low chloride concentrations of the feed coals leading to lower conversions of mercury vapors to the oxidized form. It is also observed that the fraction of Mercury emitted in relation to input Mercury increases with the increase in the dust load at the outlet of ESP. It is also observed that the Mercury content of fly ash is a function of its loss on ignition. Loss on ignition is a measure of unburned carbon content of fly ash.

5.2 Future Mercury Emission Estimate

Based on the projected coal consumption in power sector in the year 2016 and 2021, the Mercury emissions from this sector has been estimated using the developed Mercury emission factor of coal as 0.14 g/tonne. The projected Hg emissions are estimated considering 0.9 as the distribution factor to air. The figures are shown in Table 15.

Table 15. Projected estimates of mercury emissions from power sector

Year	**2016**	**2021**
Projected Coal Consumption(tonne)	730,000,000	1,180,000,000
Projected Hg Emissions(tonne) using UNEP ODF of 0.9 (default value)	91.99	148.7
Projected Hg Emissions(tonne) using ODF of 0.58 (estimated value)	59.28	95.82

With efficiency improvements, use of increased washed coal , efficiency improvements of existing APCDs, installation of high efficiency air pollution control equipment the mercury emission in 2016 and 2021 will be lower than these estimated values.

6.0 Global Inventory of Mercury in coal and mercury emissions

The average mercury concentrations of coals of the major coal producing countries like USA, China, South Africa, Russia, Brazil and Australia are in the range of 0.11 to 0.31 g/tonne. In this study, the average mercury content of Indian coals for the power sector has been found to be 0.14 g/tonne. The mercury concentration in coals of different countries is given in Table 16.

Table 16: Mercury contents in raw coals across the world

Country	Coal Type	Av. Mercury Content g/tonne	Range (g/tonne)	Reference
India	Bituminous/Sub bituminous	0.14	0.003-0.34	This study
China	Bituminous/Sub-bituminous/ Anthracite/ Lignite	0.17	0.01-2.25	UNEP, 2011
USA	Lignite	0.15	0.03-1.0	US EPA 1997
	Bituminous	0.21	<0.01-3.3	
	Anthracite	0.23	0.16-3.0	
South Africa	Bituminous	0.31	0.01-1.0	UNEP, 2011
Russia	Bituminous	0.11	0.02-0.84	Fincleman, 2003
UK	Bituminous		0.2-0.7	Pirrone et al, 2001
	Sub bituminous	0.10	0.01-1.0	US EPA 1997
Poland	Bituminous		0.01-1.0	UNEP, 2011
Germany	Bituminous		0.7-1.4	Pirrone et al, 2001
	Lignite	0.11	0.02-0.19	UNEP, 2011
Australia	Bituminous	0.215	0.03-0.4	UNEP, 2011
South America	Bituminous	0.08	0.01-0.95	US EPA, 2002
Brazil	Bituminous	0.19	0.04-0.67	UNEP, 2011
Indonesia	Lignite	0.11	0.02-0.19	Fincleman, 2003
	Sub bituminous	0.03	0.01-0.05	US EPA, 2002
Vietnam	Anthracite	0.28	0.02-1.4	Fincleman, 2004

Tables 16 and 17 present the reported mercury emissions from different sources.

Table 17: Mercury emission inventory of ten select countries

No.	Country	Total(tpa)	Category		
			Stationary combustion	Industry production	Other sources
1	China	604.7	474.1	130.6	n.d
2	South Africa	256.7	82.6	174.1	n.d
3	India	149.9	133.0	16.9	n.d.
4	Japan	143.5	49.6	61.3	32.6
5	Australia	123.5	109.6	13.8	0.1
6	USA	109.2	60.4	23.6	25.2
7	Russia	72.6	26.5	24.4	21.7
8	Kazakhstan	43.9	36.9	7.0	n.d
9	Korea (DR)	46.0	38.5	7.5	n.d
10	Saudi Arabia	40.7	39.0	1.7	n.d.
Total		1590.7	1050.2	460.9	79.6

n.d. = no data available   tpa=tonnes per anum

The largest Hg emitter countries in 2000, (ref: Pacyna, E. G.; Pacyna, J. M.; Steenhuisen, F.; Wilson, S., Global anthropogenic mercury emission inventory for 2000. Atmospheric Environment 2006, 22 (40), 4048-4063)

Table 18: Global mercury emission inventory

Global emissions of total mercury from major anthropogenic sources ($Mg\,yr^{-1}$).

	SC[a]	NFMP	PISP	CP	CSP	MP	GP	WD	O	T	Ref. year	Ref.[b]
S. Africa	32.6	0.3	1.3	3.8	0.0	0.0	0.3	0.6	1.3	40.2	2004	(1)
China	268.0	203.3	8.9	35.0	0.0	27.5	44.7	14.1	7.6	609.1	2003	(2)
India	124.6	15.5	4.6	4.7	6.2	0.0	0.5	77.4	7.5	240.9	2004	(3)
Australia	2.2	11.6	0.8	0.9	.0	0.0	0.3	0.2	0.6	16.6	2005	(4)
Europe	76.6	18.7	0.0	18.8	6.3	0.0	0.0	10.1	14.7	145.2	2005	(5)
Russia	46.0	5.2	2.6	3.9	2.8	0.0	4.3	3.5	1.5	69.8	2005	(5)
N. America	65.2	34.7	12.8	15.1	10.3	0.0	0.0	13.0	1.7	152.8	2005	(6)
S. America	8.0	13.6	1.8	6.4	2.2	0.0	16.2	0.0	1.5	49.7	2005	(5)
Total	623.2	302.9	32.8	88.6	27.8	27.5	66.3	118.9	36.4	1324.3		
Rest of the world	186.8	7.1	10.4	147.1	135.1	22.5	333.7	68.5	28.2	939.4	2006	(7)
Total	810.0	310.0	43.2	235.7	162.9	50.0	400.4	187.4	64.6	2319.7[c]		

[a] SC, Stationary combustion; NFMP, Non-ferrous metal production; PISP, Pig iron and steel production; CP, Cement production; CSP, Caustic soda production; MP, Mercury production; GP, Gold production; WD, Waste disposal; CB, Coal-bed fires; VCM, Vinyl chloride monomer production; O, Other; T, Total

[b] References: (1) Leaner et al. (2009); (2) Feng et al. (2009); Streets et al. (2009a); (3) Mukherjee et al. (2009); (4) Nelson (2007); (5) AMAP/UNEP (2008); (6) USEPA (2005); Environment Canada (2008); CEC (2001); (7) Feng et al. (2009); Streets et al. (2009b)

[c] This sum considers also CB and VCM estimates, which account for 32.0 $Mg\,yr^{-1}$ and 24 $Mg\,yr^{-1}$, respectively. Totals for countries do not include these values.

(Ref: Global Mercury emissions to the atmosphere from anthropogenic and natural sources N. Pirrone, S. Cinnirella, X. Feng, et al. Atmos. Chem. Phys. Discuss., 10, 4719–4752, 2010)

In the two references, Mercury emissions from stationary combustion in India has been shown to lie between 124.6 -133.0 tonne per year. This figure is much above the estimate made in this study where the total Mercury emissions from thermal power plants from the year 2003-2010 varies between 29.07-41.22 tonne/year using ODF value of 0.9. Based on the estimated ODF value of 0.58, the emission is found to vary between 18.73-26.56 tonne/year

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