

Anthropogenic Mercury Emission Inventory in China, 1999



David G. Streets, Ye Wu
Argonne National Laboratory
USA

Jiming Hao, Jingkun Jiang,
Hezhong Tian
Tsinghua University, China

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Project Sponsors

**National Key Basic Research and
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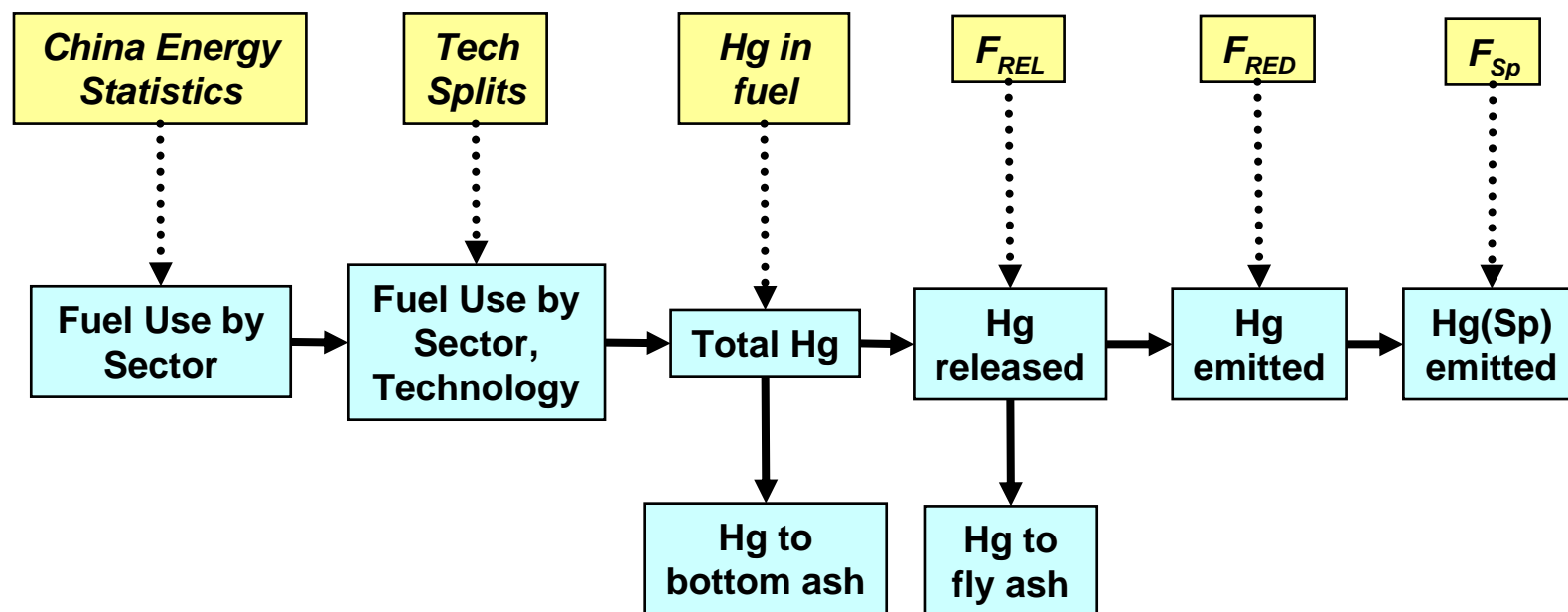
National Energy Technology Laboratory, USA

**Detailed analysis of this study is published in
Atmospheric Environment 39 (2005): 7789-7806.**

Objectives of Project

- **Develop a detailed inventory of Hg emissions in China, from coal and other sources, at provincial level**
- **Speciate the Hg emissions into Hg(p), Hg(2+), and Hg(0)**
- **Improve the data on Hg content of fuels, coal transportation, coal cleaning, performance of combustion technology, and efficiency of particulate removal devices**
- **Spatially allocate the emissions to a 30 min x 30 min grid for input to atmospheric chemistry/transport models such as U.S. EPA's CMAQ model**

Schematic of Hg Emissions Calculation Procedure



Spreadsheet is 107 x 32 (Fuel/Tech combinations x Provinces)

Sources of Data for Model Setup

China Energy Statistics

China Energy Statistical Yearbook;
China Coal Transportation Association

Tech Splits

Streets et al., *Atm. Env.*, 2001; Bond et al., *JGR*, 2003;
Tsinghua University, 2003-2004

Hg in coal

USGS, 2004; Zhejiang University, 2003; Huang and Yang, *Coal Geology of China*, 2002; Wang et al., *ES&T*, 2000; Zhang et al., *Advances in Environmental Science*, 1999; Ni et al., *Environmental Chemistry*, 1998

F_{REL}

Wang et al., *ES&T*, 2000; Wang et al., *China Environmental Science*, 1997; US EPA, EPA-600/R-02-083, 2002; Zhu et al., *Power Engineering*, 2002;

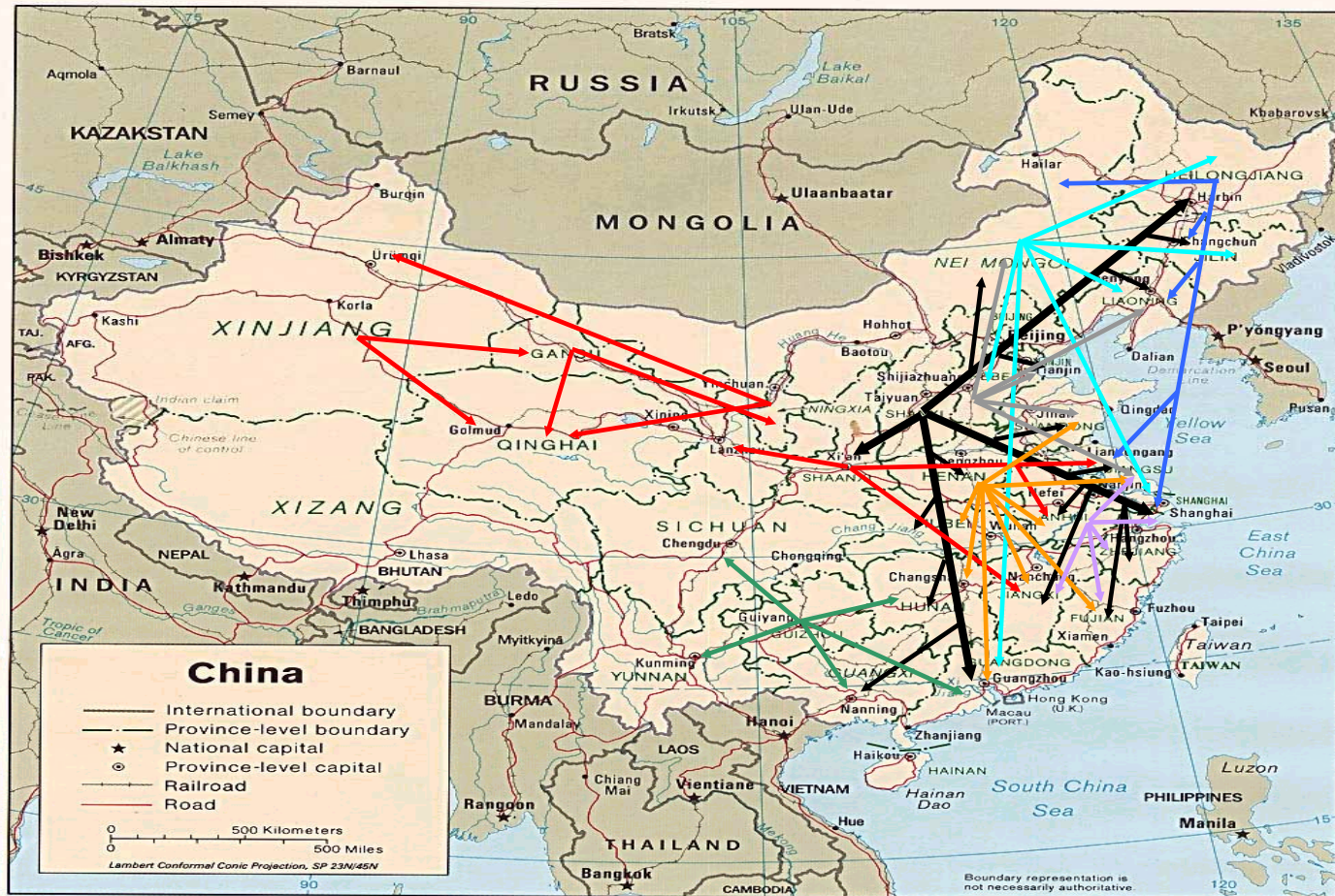
F_{RED}

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US EPA, EPA-600/R-01-109, 2002;
US EPA, EPA-452/R-97-004, 1997;
Wang et al., *ES&T*, 2000;
Zhu et al., *Power Engineering*, 2002

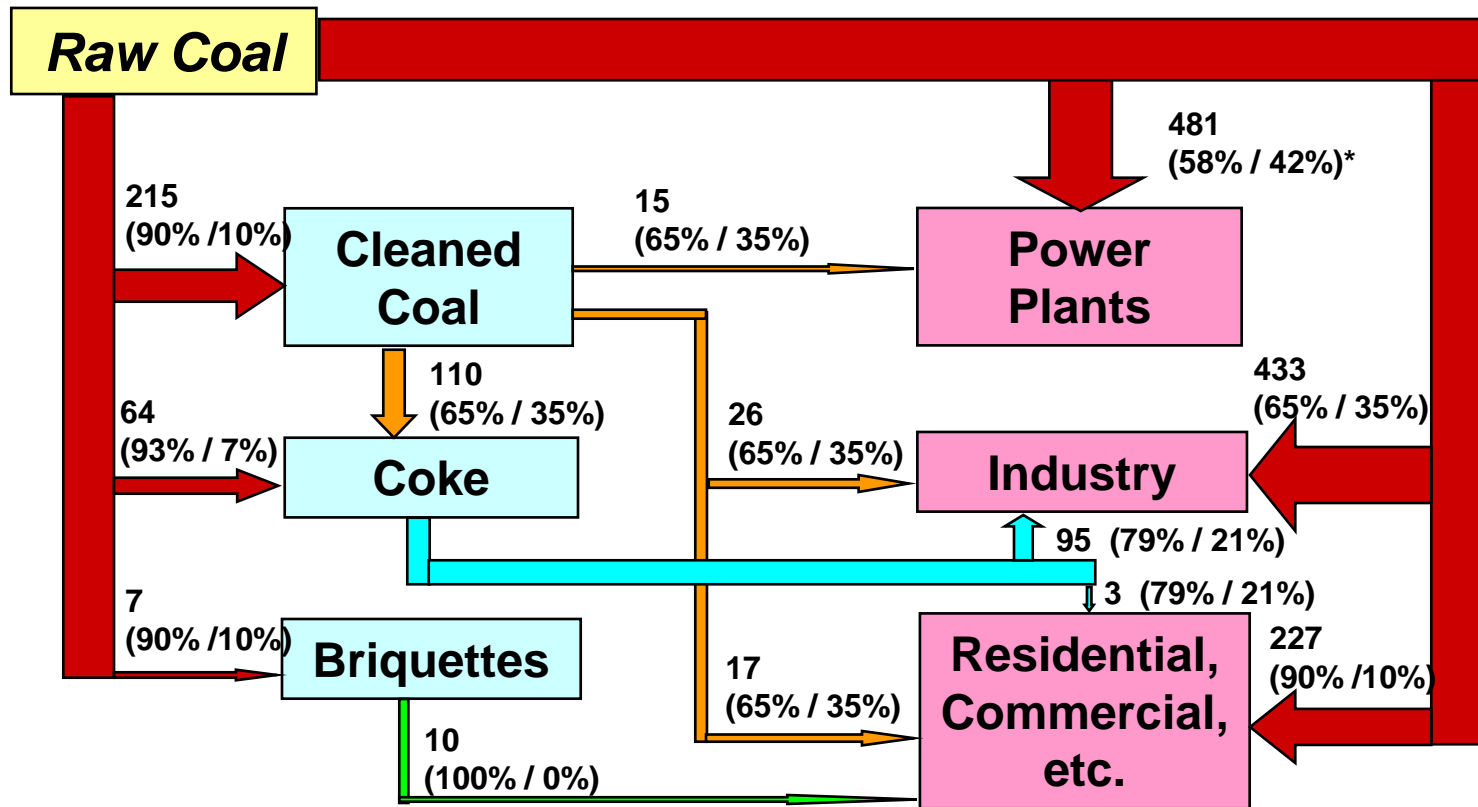
Inter-province Model of Coal Transportation Flows



Transportation Matrix of Raw Coal by Province (All Sectors, 10³ tons), 1999

	Anhui	Beijing	Fujian	Gansu	Guangdong	Guangxi	Guizhou	Hainan	Hebei	Heilongjiang	Henan	Hong Kong	Hubei	Hunan	Jiangsu	Jiangxi	Jilin	Liaoning	Macao	Nei Mongol	Ningxia	Qinghai	Shaanxi	Shandong	Shanghai	Shanxi	Sichuan	Tianjin	Xinjiang	Xizang	Yunnan	Zhejiang	
Anhui	35925	391	0	0	0	0	0	0	0	0	6000	0	177	0	1058	452	0	0	0	0	0	0	1190	1490	0	7678	0	0	0	0	0	370	
Beijing	0	8113	0	0	0	0	0	0	400	0	0	0	0	0	0	0	0	0	0	2805	0	0	0	0	0	10328	0	0	0	0	0	0	
Fujian	500	0	14744	0	0	0	0	0	0	0	1000	0	0	0	0	300	0	0	0	0	0	0	0	0	0	2944	0	0	0	0	0	340	
Gansu	0	0	0	17691	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1533	0	1205	0	0	0	0	0	2066	0	0	0	
Guangdong	1000	0	0	0	15557	157	2422	0	0	1000	3138	0	0	2000	0	0	0	0	0	3991	0	0	0	0	0	22810	0	0	0	0	0	0	
Guangxi	0	0	0	0	0	10180	3814	0	0	0	1596	0	0	600	0	0	0	0	0	0	0	0	0	0	0	3511	0	0	0	0	554	0	
Guizhou	0	0	0	0	0	0	52027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hainan	0	0	0	0	0	0	50	379	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	78	0	1130	0	0	0	0	0	0	
Hebei	0	2200	0	0	0	0	0	0	82577	0	0	0	0	0	0	0	0	0	0	2828	0	0	0	0	0	29277	0	2044	0	0	0	0	
Heilongjiang	0	0	0	0	0	0	0	0	0	56098	0	0	0	0	0	0	400	0	0	7544	0	0	0	0	0	0	0	0	0	0	0	0	0
Henan	0	0	0	0	0	0	0	0	0	0	79206	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	9523	0	0	0	0	0	0	
Hong Kong	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hubei	1023	0	0	0	0	0	0	0	0	0	15481	0	19158	1286	0	0	0	0	0	0	0	0	3119	1000	0	11016	2145	0	0	0	0	0	
Hunan	0	0	0	0	0	0	538	0	0	0	2200	0	200	28455	0	200	0	0	0	0	0	0	300	0	0	2125	50	0	0	0	0	0	
Jiangsu	10000	0	0	0	0	0	0	0	2127	0	4258	0	0	0	32450	0	0	0	0	0	0	0	5000	1297	598	31142	0	0	0	0	0	0	
Jiangxi	400	0	0	0	0	0	100	0	0	0	1028	0	0	0	0	19626	0	0	0	0	0	0	300	200	0	750	0	0	0	0	0	200	
Jilin	0	0	0	0	0	0	0	0	0	7570	0	0	0	0	0	0	22988	66	0	9081	0	0	0	0	0	0	0	0	0	0	0	0	0
Liaoning	0	500	0	0	0	0	0	0	0	4753	0	0	0	0	0	0	699	52147	0	7443	0	0	0	0	0	9364	0	0	0	0	0	0	0
Macao	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nei Mongol	0	0	0	0	0	0	0	0	1000	1000	0	0	0	0	0	0	0	0	0	44939	0	0	0	0	0	6756	0	0	0	0	0	0	0
Ningxia	0	0	0	279	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13726	0	0	0	0	0	0	0	0	0	0	0	0
Qinghai	0	0	0	1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3806	0	0	0	0	0	0	571	0	0	0	
Shaanxi	0	0	0	214	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	644	0	29265	0	0	1956	0	0	0	0	0	0	
Shandong	707	200	0	0	0	0	0	0	0	0	736	0	0	0	1500	0	0	0	0	0	0	0	800	87969	0	15974	0	0	0	0	0	0	
Shanghai	3147	0	0	0	0	0	0	0	0	0	2800	0	0	0	2077	0	0	0	0	1563	0	0	0	1400	5068	14337	0	0	0	0	0	387	
Shanxi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	157029	0	0	0	0	0	0	
Sichuan	0	0	0	0	0	0	2126	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72220	0	0	0	63	0	
Tianjin	0	2549	0	0	0	0	0	0	389	0	0	0	0	0	0	0	0	0	0	1500	0	0	0	0	0	12428	0	3666	0	0	0	0	
Xinjiang	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25662	0	0	0	0	
Xizang	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Yunnan	0	0	0	0	0	0	1797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	225	0	0	0	26539	0	
Zhejiang	4459	0	2625	0	0	0	0	0	0	0	2000	0	0	0	1875	400	0	0	0	1000	0	0	800	1100	450	22243	0	0	0	0	0	9936	

Coal Transportation Flows by Usage, 1999



* 481 (58% / 42%): million tons of coal consumed (percent in-province supply / percent inter-province supply)

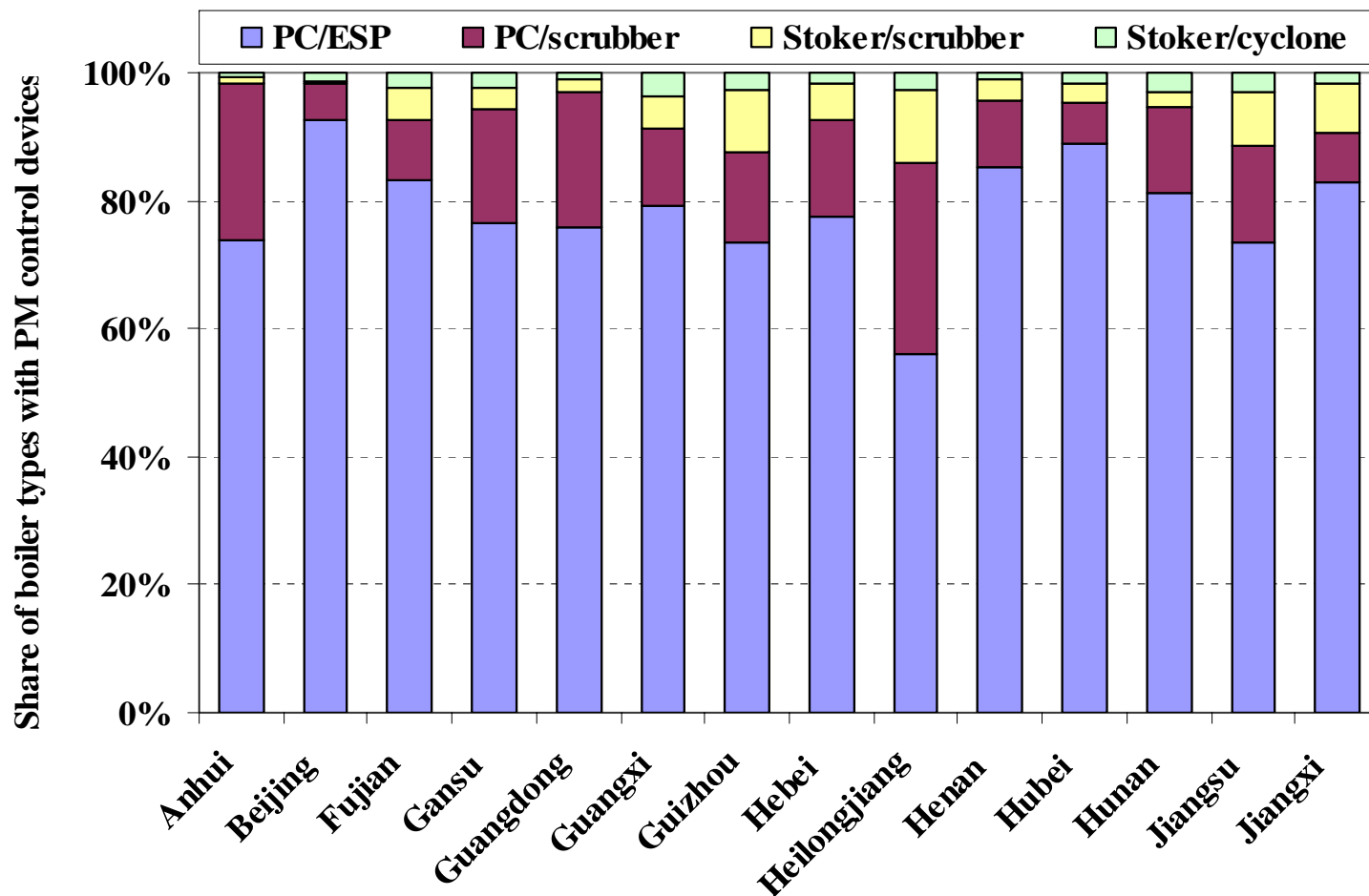
Hg Content of Raw Coal as Mined, g/Mg

Province	This Study	USGS, 2004	Wang, 2000	Huang, 2002	ITPE, 2003	Zhang, 1999	Ni, 1998
Anhui	0.26	0.19	0.22	0.26	0.37		
Beijing	0.44	0.54	0.34				
Fujian	0.08	0.07			0.08		
Gansu	0.05	0.05					
Guangdong	0.15	0.05			0.25		
Guangxi	0.30	0.33			0.28		
Guizhou	0.52	0.20		0.52	0.14	0.55	0.50
Hebei	0.14	0.14	0.13	0.80			
Heilongjiang	0.09	0.06	0.12	0.14			
Henan	0.25	0.21	0.30	0.17	0.32		
Hubei	0.16	0.16					
Hunan	0.10	0.14		0.07			
Jiangsu	0.16	0.34		0.09	0.04		
Jiangxi	0.22	0.27	0.16				
Jilin	0.20	0.07	0.33				
Liaoning	0.17	0.18	0.20	0.13			
Nei Mongol	0.22	0.15	0.28	0.02	0.63		
Ningxia	0.20	0.20					
Qinghai	0.04	0.04					
Shaanxi	0.11	0.13	0.16	0.08	0.07		
Shandong	0.18	0.13	0.17	0.21	0.22		
Shanxi	0.16	0.15	0.22	0.20	0.07	0.16	
Sichuan	0.14	0.11	0.18				
Xinjiang	0.02	0.02	0.03				
Yunnan	0.29	0.14		0.34		0.38	
Zhejiang	0.35				0.35		
China	0.19						

Examples of Average Hg Content of Raw Coal as Mined and as Burned, g/Mg

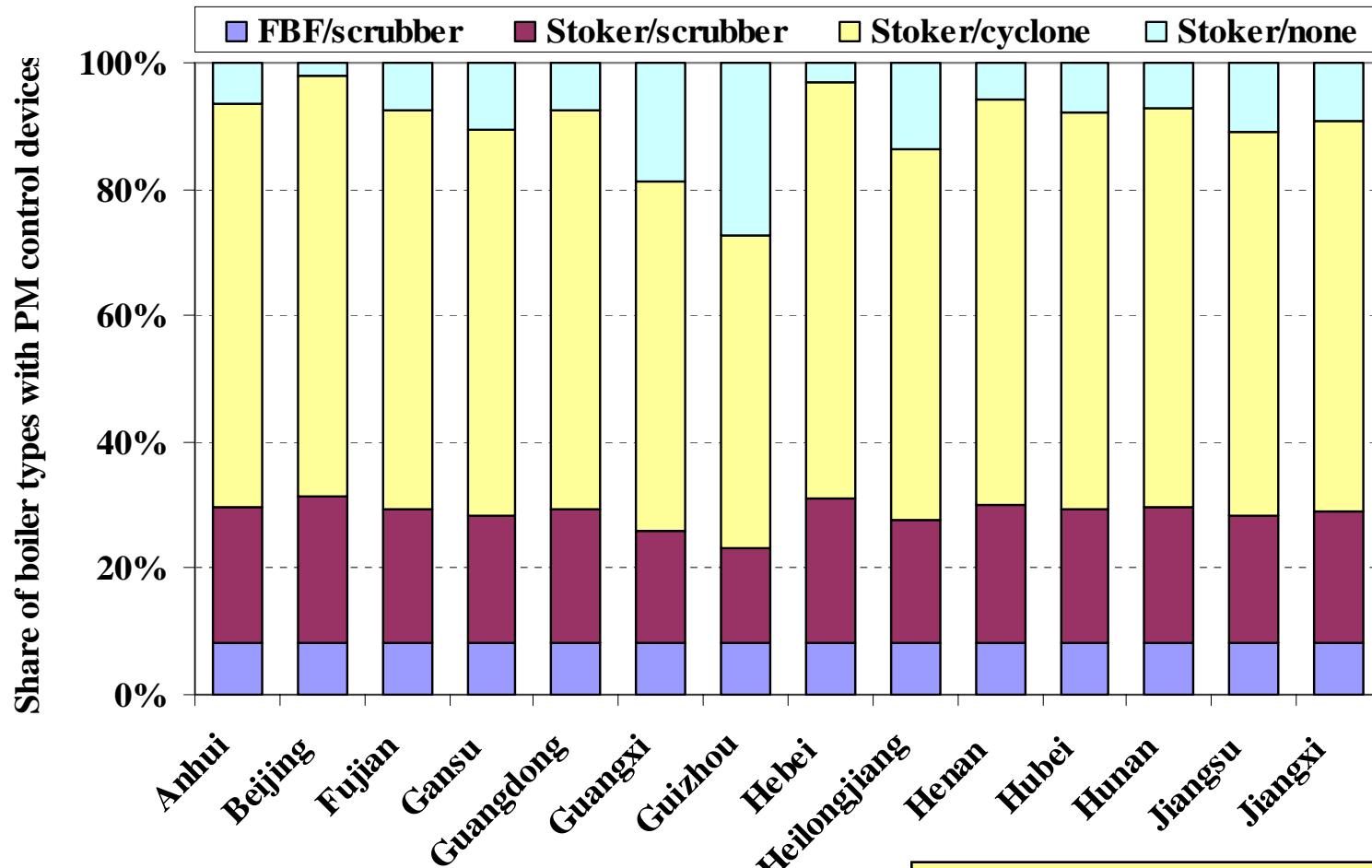
Provinces	Coal as mined	Coal as burned, 1999			
		Power Plants	Coking	Industry	Others
Anhui	0.26	0.23	---	0.24	0.24
Beijing	0.44	0.24	0.16	0.26	0.31
Fujian	0.08	0.11	0.08	0.12	0.08
Gansu	0.05	0.07	0.05	0.06	0.05
Guangdong	0.15	0.18	---	0.19	0.16
Guangxi	0.30	0.28	---	0.32	0.28
Guizhou	0.52	0.52	0.52	0.52	0.52
Hainan	0.15	0.16	---	0.21	0.15
Hebei	0.14	0.15	0.15	0.16	0.15
Heilongjiang	0.09	0.14	0.09	0.09	0.09
Henan	0.25	0.23	0.23	0.24	0.25
Hongkong	---	0.18	---	---	---
Hubei	0.16	0.18	---	0.19	0.17
Hunan	0.10	0.13	0.10	0.13	0.10
Jiangsu	0.16	0.16	0.16	0.19	0.18
Jiangxi	0.22	0.22	---	0.22	0.22
Jilin	0.20	0.20	---	0.16	0.18

Examples of Shares of Boiler Types with PM Control Devices for Coal-fired Power Plants by Province, 1999



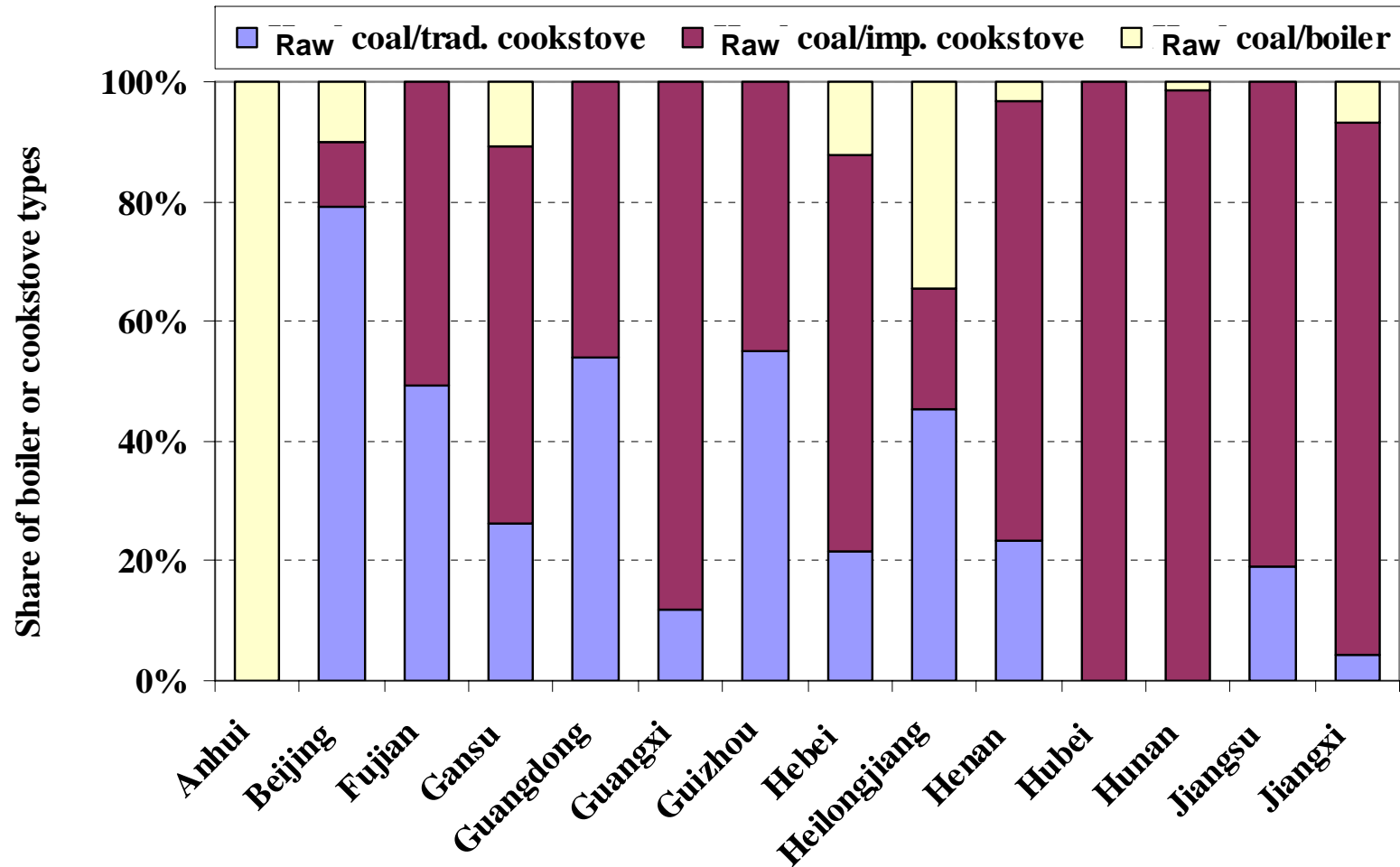
PC: pulverized coal; ESP: electrostatic precipitators

Examples of Shares of Boiler Types with PM Control Devices for Industrial Coal Use by Province, 1999



FBF: fluidized-bed furnace

Examples of Shares of Boiler or Cookstove Types for Residential Raw Coal Use by Province, 1999



Hg Remaining in Bottom Ash

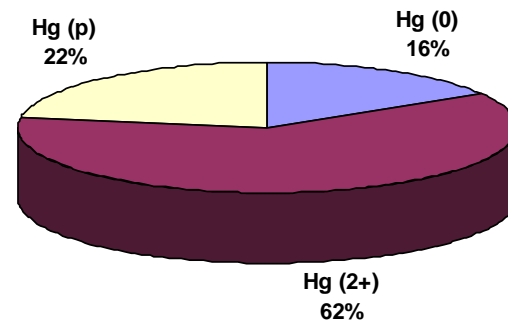
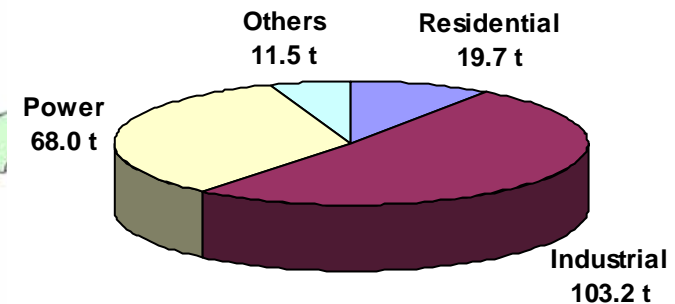
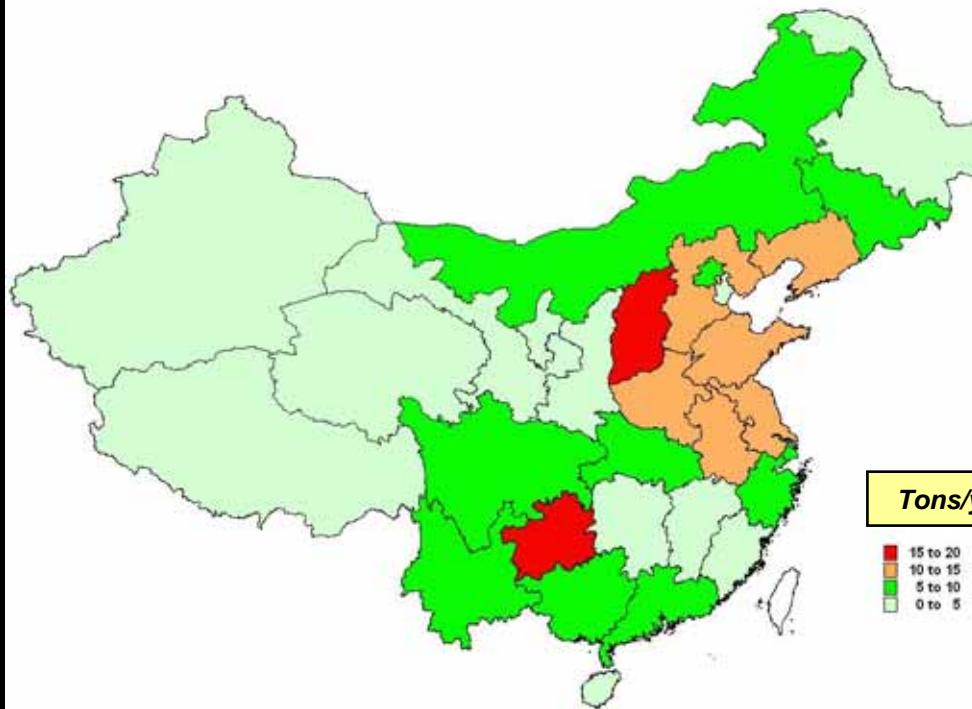
Sectors	Boiler types	Ratio, %
Residential Use	Traditional cookstove	17.0
	Improved cookstove	17.0
	Stoker	17.0
Industrial Use	FBF/PC	8.0
	Stoker	17.0
Power Plant	PC	1.0
	Stoker	2.0
Farming, Construction, and etc.	Stoker	17.0

The ratios shown here are Hg remaining in bottom ash

Hg Removal Efficiencies by PM Control Device, Power Sector

Case	Fuel/Combustor Type	PM Control	Removal Efficiency (%)				
			Provinces of China				
			Anhui	Beijing	Fujian	Gansu	Guangdong
31	Hard coal/PC	filter or ESP	30.6	30.6	30.6	30.6	30.6
33	Hard coal/PC	scrubber	6.5	6.5	6.5	6.5	6.5
34	Hard coal/PC	cyclone	0.1	0.1	0.1	0.1	0.1
32	Hard coal/stoker	filter or ESP	30.6	30.6	30.6	30.6	30.6
35	Hard coal/stoker	scrubber	6.5	6.5	6.5	6.5	6.5
36	Hard coal/stoker	cyclone	0.1	0.1	0.1	0.1	0.1
85	Hard coal/cyclone	scrubber	6.5	6.5	6.5	6.5	6.5
86	Hard coal/cyclone	cyclone	0.1	0.1	0.1	0.1	0.1
37	Cleaned coal/PC	filter or ESP	30.6	30.6	30.6	30.6	30.6
39	Cleaned coal/PC	scrubber	6.5	6.5	6.5	6.5	6.5
40	Cleaned coal/PC	cyclone	0.1	0.1	0.1	0.1	0.1
38	Cleaned coal/stoker	filter or ESP	30.6	30.6	30.6	30.6	30.6
41	Cleaned coal/stoker	scrubber	6.5	6.5	6.5	6.5	6.5
42	Cleaned coal/stoker	cyclone	0.1	0.1	0.1	0.1	0.1

Total Hg Emissions by Province, 1999 (Coal Combustion Sources)



Total Hg emissions from coal combustion: 202.4 tons

The 3 highest emitting provinces:

1) Guizhou (19.2 t); 2) Shanxi (15.3 t); and 3) Henan (14.0 t)

Other Source Types

❖ Other combustion sources

- Fuel oil (gasoline, diesel, kerosene, and residual oil)
- Biofuels
- Grassland/Savanna/Forest fires
- Agricultural residue/Household waste burning
- Coal mines spontaneous burning

❖ Non-combustion sources (feedstock emissions only)

- Mercury mining
- Battery/Fluorescent lamp production
- Cement production
- Iron and steel production
- Caustic soda production
- Nonferrous metals smelting (zinc, copper, gold, and lead)

Total Hg Emission Factors of Other Sources

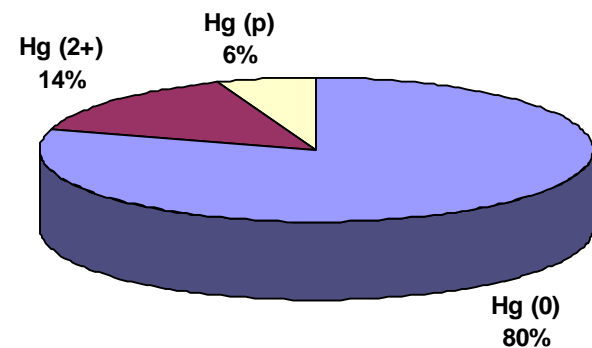
	Source category	Unit	Emission factor	Pacyna et al, 2002
1.	Fuel oil for stationary sources (e.g., power plants, industrial use, etc.)	g/t oil	0.014	0.06
2.	Gasoline , diesel and kerosene	g/t oil	0.058	
3.	Biofuels	g/t biofuels	0.020	
4.	Grassland/savanna burning	g/t grass burning	0.080	
5.	Forest burning	g/t forest burning	0.113	
6.	Waste and residue burning			
	--agricultural residue	g/t residue	0.037	
	--house hold waste	g/t waste	2.80	1.0/5.0
7.	Coal mines spontaneous burning	g/t coal	0.02-0.43 (0.16)	
8.	Cement production	g/t cement	0.04	0.1
9.	Iron and steel production	g/t steel	0.04	0.04
10.	Caustic soda production	g/t caustic soda	20.4	
11.	Non-ferrous metal smelting			
	--Zinc (Zn)	g/t Zn	13.8-156.4 (86.6)	20.0
	--Copper (Cu)	g/t Cu	9.6	10.0
	--Lead (Pb)	g/t Pb	43.6	3.0
	--Gold (Au): large scale production	t/t Au	0.79	
	--Gold (Au): artisanal production	t/t Au	15.0	
12.	Mercury mining	kg/t Hg	45.0	
13.	Battery & fluorescent lamp production	kg/t Hg	50.0	

Emissions from Other Source Types for 1999

	1999
Fuel oil combustion	6.1
Biofuel combustion	8.3
Grassland/Savanna/Forest fires	7.0
Ag residue/Household waste burning	5.9
Coal mines spontaneous burning	3.0
Mercury mining	8.8
Battery/Lamp production	24.3
Iron and steel production	4.9
Caustic soda production	0.2
Cement production	22.7
Zinc smelting	147.6
Copper smelting	10.1
Lead smelting	40.1
<u>Gold smelting</u>	<u>44.6</u>

Total

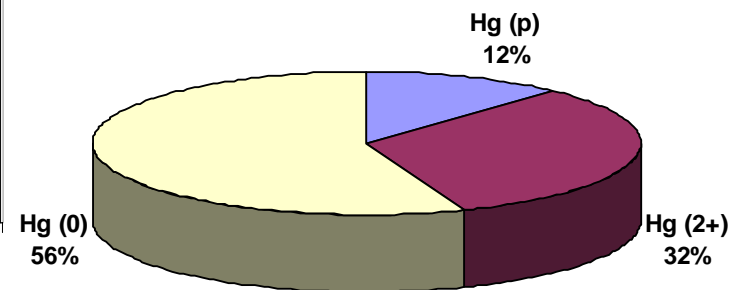
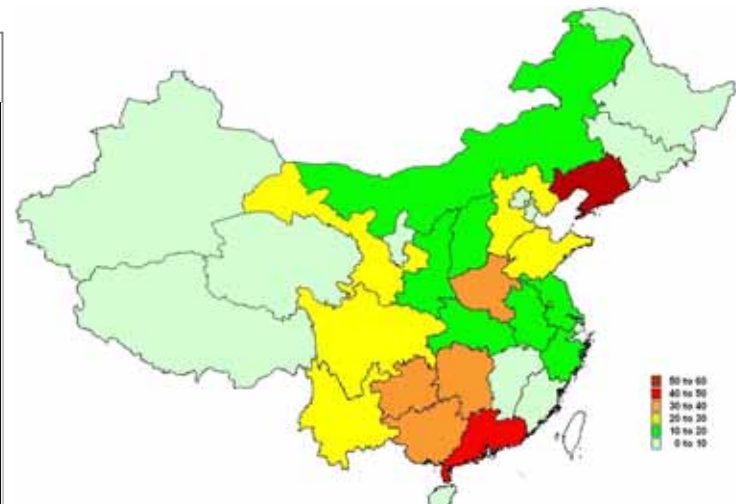
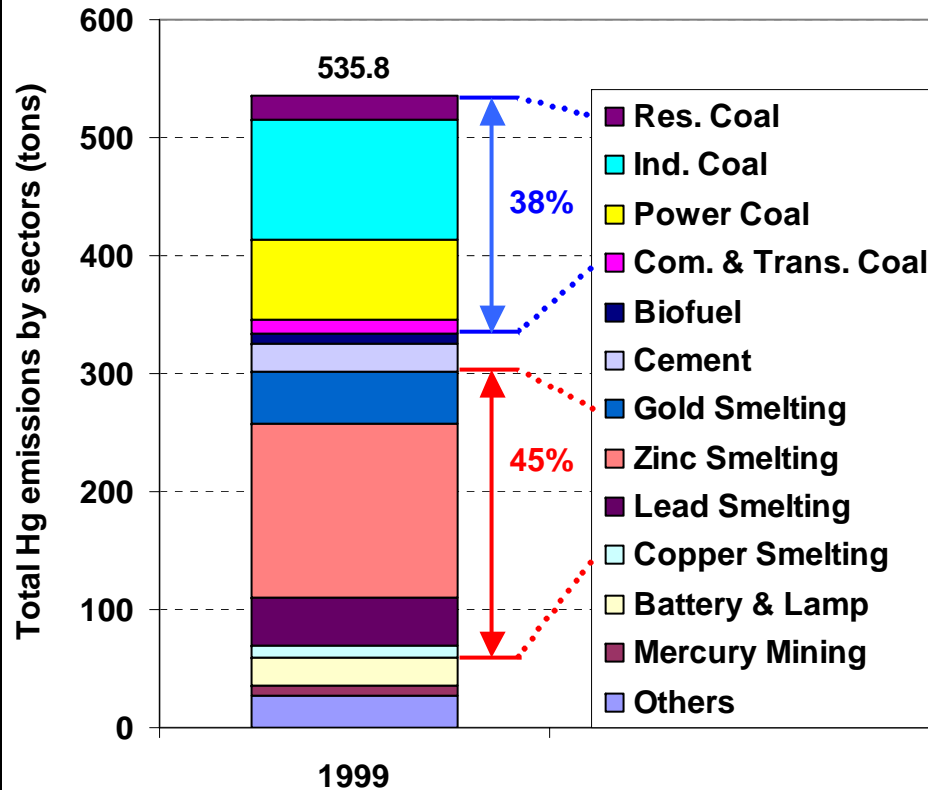
333.5 tons



The 3 highest emitting provinces:

1) Liaoning (43.8 t); 2) Guangdong (36.8 t); and 3) Hunan (28.7 t)

Total Hg Emissions by Sector, by Province, and by Species

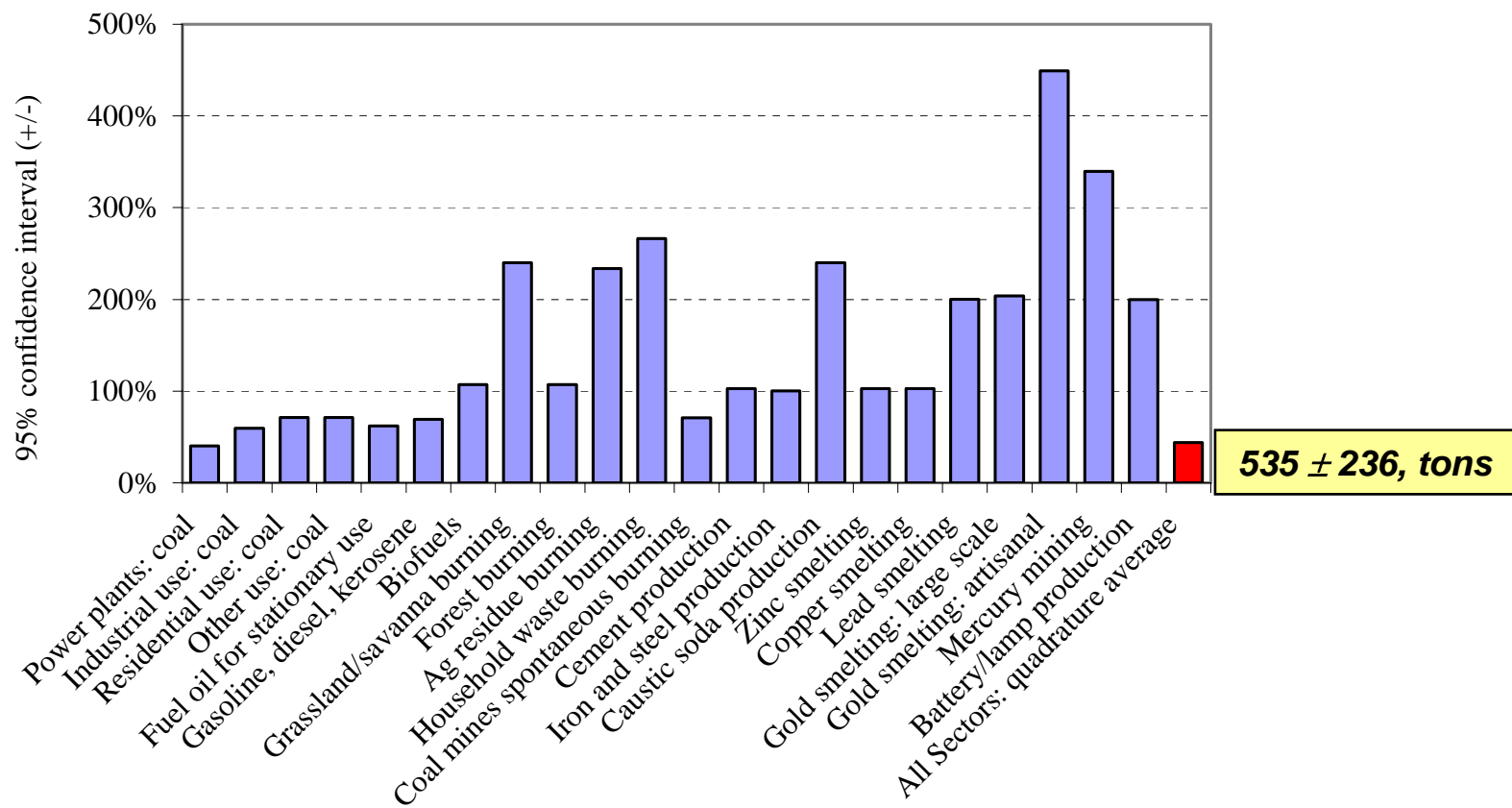


Total Hg emissions (all sources together): 535.8 tons

The 3 highest emitting provinces:

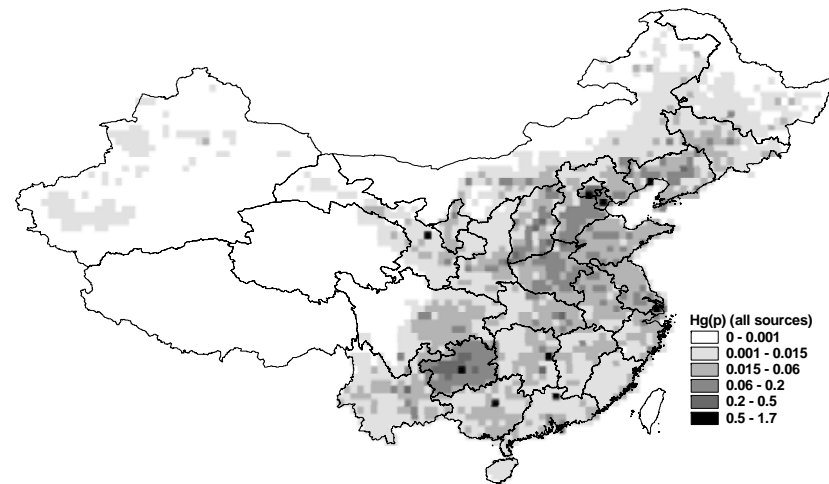
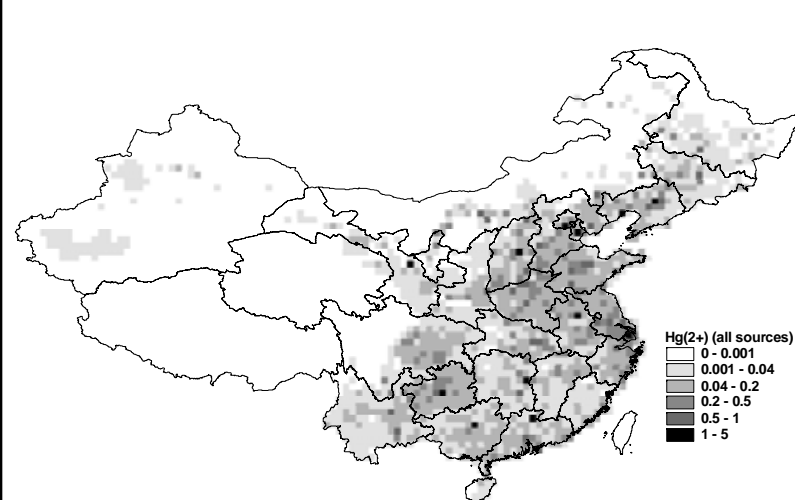
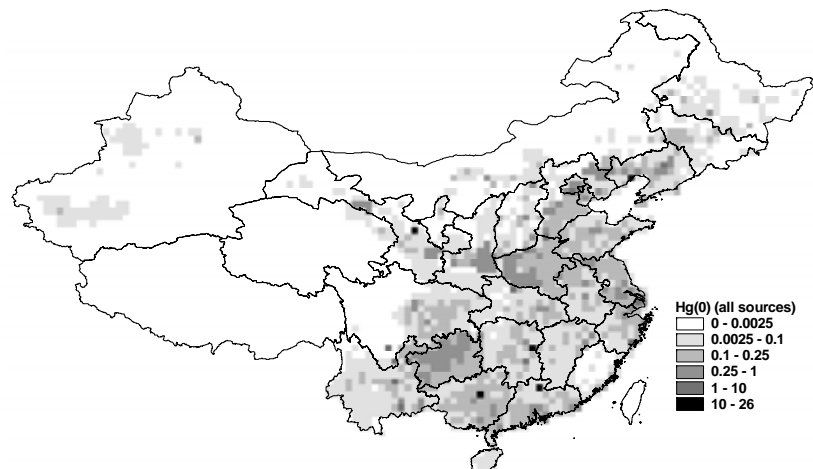
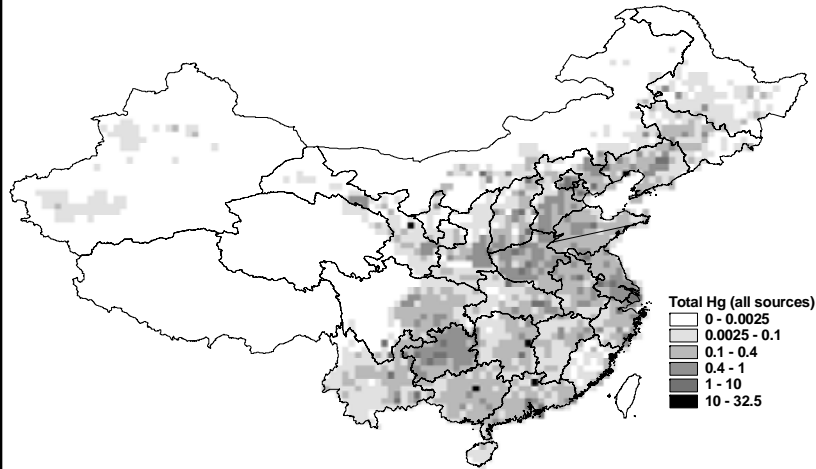
1) Liaoning (54.1 t); 2) Guangdong (44.2 t); and 3) Guizhou (39.0 t)

Uncertainty in Hg Emission Estimates by Sector



Hg emission estimates for non-coal-combustion sources are subject to much higher uncertainties.

Gridded Total Hg Emissions, All Sources Together (30 min × 30 min resolution, unit: t yr⁻¹ per grid cell)



Areas for Improvement and Further Cooperation

- Energy use and coal transportation ✓
- Improvements to our characterization of source mix by sector, especially industry ✓
- Hg retained in ash, by combustor type ✓, but need test data for **small cookstove and small boilers**
- Hg content of raw coal, cleaned coal, and briquettes by province ✓, but need to resolve differences for raw coal
- Effect of coal cleaning on Chinese coals (% Hg removed) ✓, but need **more test data from Chinese sources**
- Hg releases from small, unconventional sources (stokers, stoves, etc.) ✓, but need **more test data from Chinese sources**
- Measurement of Hg collection efficiencies in China ✓, but need **more test data from Chinese sources**
- Smelting process ✓, but need **more test data from Chinese sources**
- Speciation of Hg from sources in China context
- Types of coal preparation/cleaning typically performed