

**MERCURY EMISSIONS FROM HIGH-TEMPERATURE SOURCES
IN THE NY/NJ HUDSON-RARITAN BASIN**

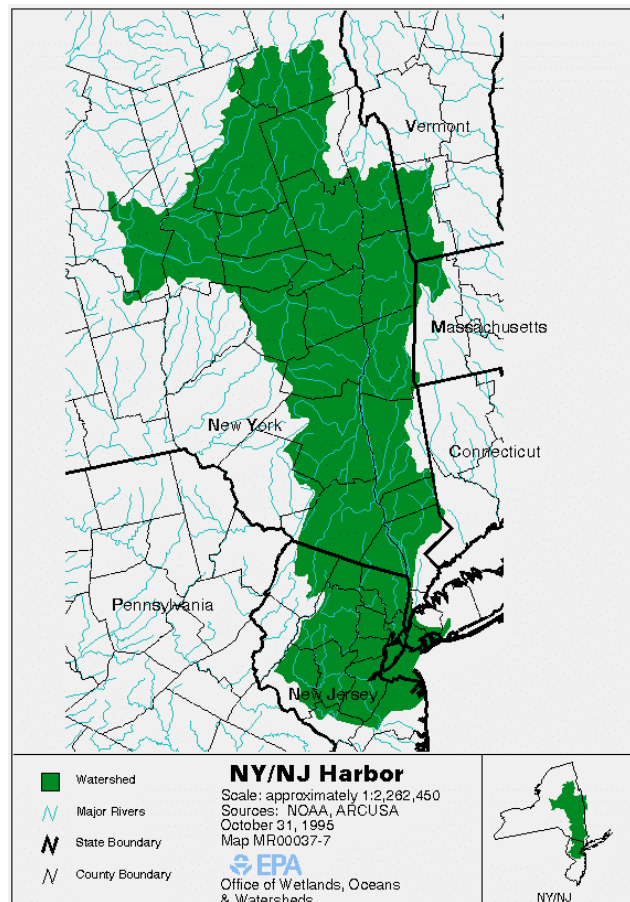
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ABSTRACT

This report presents some of the results of a study conducted for the New York Academy of Sciences on the sources of past and current emissions of mercury in the Hudson-Raritan basin (HRB), an area of 42,000 square kilometers with a population of fifteen million. Mercury emissions to the atmosphere are reported from all high temperature processes, such as utility, commercial and residential boilers, secondary iron and steel smelters, Waste-to-Energy (WTE) plants, and sewage sludge incinerators. At present, the primary sources of atmospheric emissions in HRB are utility and industrial boilers (873 kilograms of mercury/year), secondary iron and steel plants (595 kg), Waste-to-Energy plants (147 kg), and sewage sludge incinerators (90 kg). The total deposition of mercury from the atmosphere on the surface of HRB was estimated at about 1,100 kilograms per year. The study examined in detail the decrease in mercury emissions from WTE plants. A metric was developed that expresses emissions from WTE plants as kilograms of mercury per million tons of MSW combusted. It was shown that reported annual emissions of mercury from the U.S. WTE plants have decreased from a high of 81,800 kilograms in 1989 to an estimated 2,200 kilograms at the present time.



The Hudson-Raritan Basin (HRB)

1. INTRODUCTION

The results presented in this paper were obtained in the course of a study by the Earth Engineering Center (EEC) of Columbia University (Themelis 2001). The study was sponsored by the New York Academy of Sciences (NYAS) and was part of the project *Industrial Ecology for Pollution Prevention* of the Harbor Consortium of NYAS. The objectives of this project included quantifying the sources of past and present emissions of mercury in the Hudson-Raritan basin (HRB), an area of 42,000 square kilometers with a population of fifteen million; and recommending measures to be taken in order to decrease mercury contamination in the NY/NJ Harbor.

The EEC study was based on a detailed analysis of data of several documents and published technical reports, using industrial ecology methodology. The New Jersey and New York City Departments of Environmental Protection and the Port Authority of NY/NJ provided data on current emissions of mercury. This paper concentrates on the findings regarding atmospheric emissions and deposition of mercury in the Hudson-Raritan basin. Unless noted otherwise, mass is reported in metric tons (1t = 1000 kg).

The principal sources of mercury emissions in the past were: Mercury production, consumption and discarding of used products; coal combustion; waste incineration, and non-ferrous smelting. Most of the mercury produced intentionally by industry was used in the manufacture of chemicals (mainly chlorine in chlor-alkali plants) and products that are used by other companies or the public. All the mercury contained in products, with the exception of those recycled in a way that mercury is captured, eventually ends up in the form of gas, liquid or solid emissions. There is also unintentional generation of mercury by industry in the form of gas, liquid and solid emissions.

In the temperature range of 0 to 40°C, mercury is a liquid and its vapor pressure increases from 0.001 to 0.007 mm Hg. This is a much lower pressure than water (e.g., the water vapor pressure at 40°C is 5.67 mm Hg) but corresponds to a saturation concentration that is several orders of magnitude higher than the concentration of mercury in the global atmosphere. Therefore, exposed mercury, e.g. mercury droplets in landfilled solid wastes, will slowly evaporate.

Mercury emissions from combustion sources, such as coal-fired power plants, are principally in the form of mercury vapor or as mercury compounds attached to particulate emissions. Emissions can be divided into three categories: a) Naturally occurring, or pre-industrial, emissions from land and oceans, b) anthropogenic new emissions, and c) anthropogenic re-emissions of previously mobilized and deposited mercury (Table 1, Themelis 2001). Table 1 shows that there has been a large reduction in mercury emissions in the last decade of the 20th century.

Table 1. Hypothesis as to rates of global mercury emissions and deposition at assumed atmospheric residence time of 1 year (Themelis 2001)

	Year 1990, tons	Year 1994, tons
Pre-industrial emissions:	1900	1900
Anthropogenic re-emissions	1800	1800
Anthropogenic new emissions	2100	1000
<i>Anthropogenic total</i>	<i>3900</i>	<i>2800</i>
Total emissions to atmosphere	5800	4700
Atmospheric loading	5800	4700
Decrease in atmospheric loading (annual average for 1990 -1994)		270
Annual deposition (total emissions + +decrease in atmospheric load)	5800	4970

The rapid decrease in consumption since 1980 was due to legislation to eliminate mercury in batteries (54% of demand for mercury in 1984 down to 2% by 1992) and paints (16% in 1989 down to zero by 1992) and to market forces away from mercury use in other products (thermometers, thermostats, switches, etc.). In the period of 1993 to 1998, the remaining domestic mines closed and legislation was enacted mandating mercury recycling (Sznoppek and Goonan 2000).

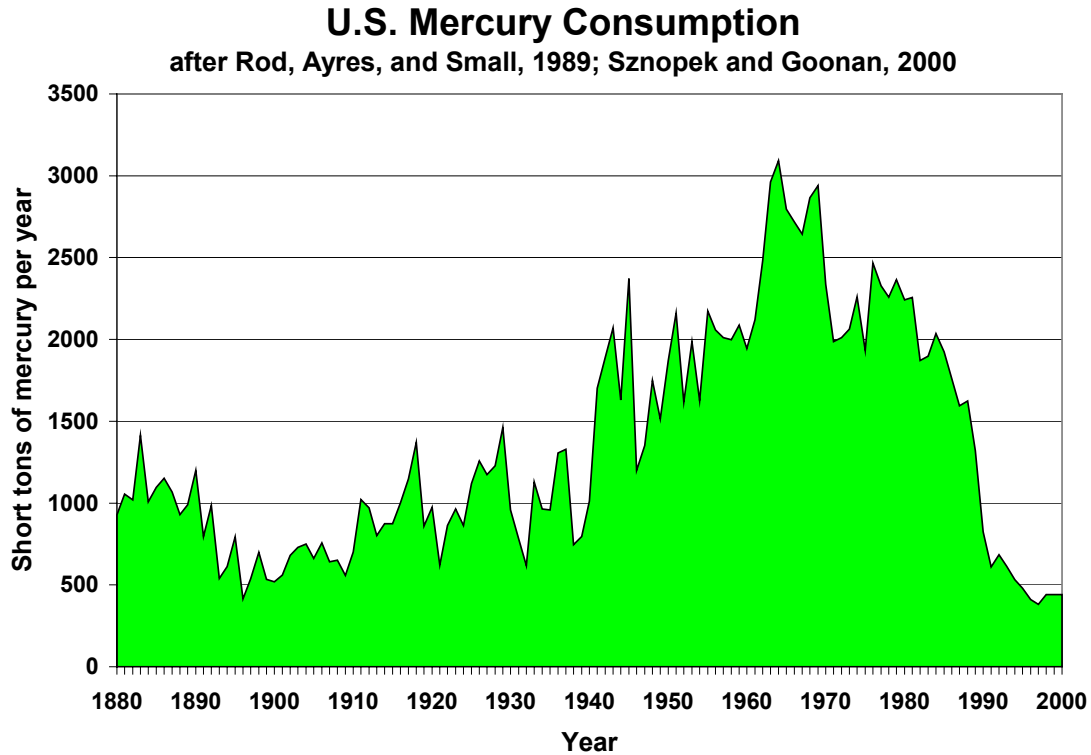


Figure 1. Consumption of mercury in the U.S. economy, 1880-2000 (1 metric ton = 1.1 short tons)

2. CURRENT EMISSIONS OF MERCURY FROM HIGH-TEMPERATURE SOURCES

This section examines the emissions of mercury in HRB from high-temperature operations such as utility boilers, Waste-to-Energy plants, iron and steel smelters, and waste incinerators.

2.1 Mercury emissions from fossil fuel combustion

Most coals contain 0.1-0.3 parts per million of Hg (EPA 1997); the average concentration of mercury in global coal has been estimated at 0.15 ppm (Hopke, 1985; Rod et al 1989). The residues from oil refining contain about the same amount of mercury. Fossil fuels are used in utility boilers to produce electricity, in industrial and commercial boilers to produce electricity or steam, and in residential boilers to produce heat. The reported 1998 emissions of mercury from all U.S. coal-fired utilities amounted to 42.7 tons (EWG 2000). This number is about 10% lower than the 1995 emissions of 47.2 tons reported in the EPA Report to Congress (1997) that catalogued mercury emissions for all types of boilers. In the same report, New Jersey and New Jersey were shown to have total boiler emissions of 644 and 3,101 kilograms of mercury, respectively (Table 2). The 1998 data on utility emissions in Table 2 were obtained from the EPA compilation of mercury emissions from all U.S. utility boilers (EPA 2001). These data show that

mercury emissions from New York and New Jersey boilers decreased by 60% between 1994 and 1998, mainly by changing from coal to fuel oil at some power plants.

Table 2. Mercury emissions from utility, industrial and residential boilers (kg/y; Themelis 2001)

	New Jersey		New York		Basis/assumptions for 1998 numbers
	1994 (EPA)	1998	1994 (EPA)	1998	
Utility: Coal	173	NA	1208	NA	EPA 2001
Gas	0	NA	0	NA	
Oil	5	NA	57	NA	
<i>Total</i>	<i>178</i>	<i>186</i>	<i>1265</i>	<i>487</i>	
Industrial-commercial	230	78	1310	500	NJ: Total reported – utility and in same proportion as in 1994. NY: Assumed 62% reduction since 1994 (same as reported for NJ industrial.+ residential)
Residential	236	81	526	200	
Total NJ, NY fossil fuel	644	345	3101	1187	NJ from NJ DEP, 2001 NY by addition of all boilers.
Total HRB emissions from fossil fuel combustion [Population of HRB=57% of NY+NJ populations]:					
<ul style="list-style-type: none"> • 1994: (644 + 3101) x (0.57) = 2135 kg • 1998: (345+1187) x (0.57) = 873 kg 					

2.2 Mercury emissions from secondary iron and steel production

For some reason, mercury emissions from iron and steel smelters were not included in the 1997 EPA report (EPA 1997). Many of the U.S. cars in operation are equipped with one or more lights, anti-lock braking systems, or “active ride control” switches, that contain from 1-3 grams of mercury each. When cars are compacted or shredded and the scrap metal is smelted much of the contained mercury is emitted to the atmosphere. Table 3 shows estimates of mercury emissions from iron and steel plants in New Jersey and New York. It shows that an estimated 595 kilograms of mercury are emitted annually and that there is considerable variation in the emissions of mercury per ton of iron or steel production. This may be due to the mix of the feed scrap or to differences in gas control technology. Generally, it would be expected that plants equipped with dry scrubbers and bag filters would have higher mercury collection efficiency than wet scrubbers.

It should be stressed that the figure of 595 kg of mercury per year (Table 3) is based on the assumption that the “spot” samples of mercury concentration, some of which were measured three to four years ago, apply over the permitted period of operation of each plant (hours per year). Therefore, since mercury in switches is slowly being phased out in recent years, it is possible that current emissions from iron and steel plants are lower than shown in Table 3.

2.3 Mercury emissions from Waste-to-Energy (WTE) plants

Walsh (2000) reported that at some point there were in New York City as many as 17,000 apartment/house and 32 municipal incinerators burning municipal solid wastes (MSW) (Walsh et al 2000). Between 1908 and 1990, an estimated 100 million metric tons of MSW were incinerated in incinerators that were provided with little or no emission controls. Collectively, they emitted one million tons, i.e. 1% of the MSW weight, of soot particles to the atmosphere (Walsh et al 2000). Many people confuse the polluting incinerators of the past with the modern Waste-to-Energy plants. For example, the Waste-to-Energy plant of SEMASS at Rochester, MA that has replaced many landfills in southern Massachusetts processes one million short tons of MSW per year in three combustion chambers and has a particulate emission rate of 0.003%, that is 300 times lower than the emissions of the NYC incinerators of the past (Themelis and Kim 2002).

Mercury emissions from WTE plants are due to mercury contained in the MSW that vaporizes during combustion. Mercury-containing products include electric switches, lamps, paint residues, and thermometers (EPA 1997). The mercury content of MSW can be reduced by better collecting/sorting methods, for example by recycling fluorescent tubes. By the late nineties, nearly all U.S. WTE plants were equipped with electrostatic precipitators or fabric filters, activated carbon injection, and other gas control devices. For example, the mercury emissions from the SEMASS, MA plant, amount to only 34 kilograms of mercury per year and the measured concentration of mercury in the collected flue dust (69,000 tons per year) is 18 parts per million, i.e. 1350 kg/year (Themelis and Kim 2002). Therefore, 97% of the input mercury in the MSW (estimated to be about 1.5 ppm in the feed MSW to the SEMASS plant) is captured in the form of flue dust.

Table 3. Mercury emissions from iron and steel production in NJ¹ and NY² smelters 2001)

Facility	Gas control system	Plant capacity, Short tons/year ¹	Estimated mercury emissions, lb/year ¹	Estimated mercury emissions, kg/year	Mercury emissions, gram/ short ton of metal production
Atlantic States IP	Venturi scrubber	234,000	108	48.8	0.21
Hoeganaes Corp	Baghouse	119,028	21	9.5	0.08
Co-Steel Sayreville	Baghouse	800,000	466	210.6	0.26
Co-Steel Raritan	Baghouse	1,160,320	224	101.2	0.09
Griffin Pipe Products	Venturi scrubber	182,000	20	9.0	0.05
U.S. Pipe and Foundry	Baghouse	262,964	96	43.4	0.17
NJ subtotal		2,758,312	935	423	0.15
Auburn Steel Co.		NA	252	114	
A.T. Specialty Steel		NA	71	32	
Allegheny Technology		NA	29	13	
Crucible Materials		NA	29	13	
NY subtotal		NA	381	172	
NY and NJ total			1316	595	

¹ NJ plant data from NJ DEP 2001; ²NY data from New York Facility Data Source: "Toxic in Vehicles: Mercury", January, 2001

With respect to HRB, New Jersey regulations mandated that by the end of 1995 all municipal waste combustors (MWCs) be retrofitted with activated carbon injection (ACI). Table 4 (NJ DEP 2001) shows that the mercury emissions of the NJ WTE plants decreased by a factor of ten in the years between 1993 and 1999. This has been attributed to two principal factors:

- The decreased usage of mercury in consumer products and therefore in the MSW stream. As mentioned earlier, U.S. consumption of mercury has decreased from about 2000 short tons in the eighties to the present level of about 400 short tons per year.
- Improved gas controls, such as activated carbon injection.

Table 4. Decrease in mercury emissions from New Jersey Waste-to-Energy plants, 1991-1999 (NJ DEP, 2001)

Facility	WTE capacity, short tons/day	1991,'92,'93	1996	1997	1998	1999
		Pounds of mercury per year				
Camden	1,050	1,084	431	350	144	113
Essex	2,275	1,771	216	323	115	162
Gloucester	575	149	32	51	25	15
Union	1,440	844	84	42	24	32
Warren	400	562	4	4	3	4

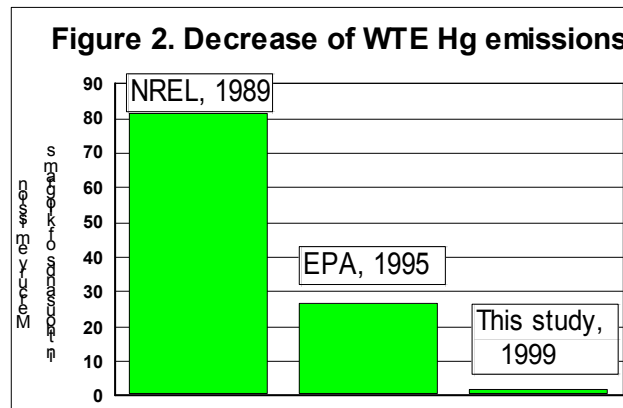
Total	5,740	4,410	767	770	311	326
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(all units left as reported by NJ DEP 2001; 1 ton = 1.1 short tons; 1kg = 2.2 pounds)

Table 5 lists the 1999 mercury emissions of the New Jersey and New York plants with the SEMASS Waste-to-Energy plant. The last column of Table 5 brings all the data into a common metric: kilograms of mercury emitted per million metric tons of MSW combusted. Obviously, the lowest figure in this column is the most environmentally desirable. It should be stressed that the data shown in Table 5 reflect both better gas control systems and also the ability of some communities to divert mercury-containing objects from the MSW stream. For example, an aggressive campaign in Warren County, NJ, reduced the amount of mercury in the MSW stream from 3 parts per million to less than 1 ppm (NJ DEP 2001).

The total MSW combusted annually in New York and New Jersey WTE plants is about 4.2 million tons (Table 5). Using the HRB/(NY+NJ) population ratio of 0.57, as was done for fossil fuels (Table 2), the corresponding MSW combustion for HRB is estimated at $4.2 \times 0.57 = 2.4$ million short tons. This number is close to the estimate by Fitzgerald and O'Connor (2001) of 2.37 million short tons. It corresponds to 68 kilograms of mercury per million metric tons of MSW processed and is higher than the emission ratings (in kilograms per million tons) of some of the WTE plants shown in Table 5.

To appreciate the reduction in mercury emissions caused by MSW combustion in the last decade of the 20th century, it should be noted that a study by the National Renewable Energy Laboratory (NREL 1993) reported that the 1989 emissions of all U.S. incinerator plants amounted to 81,800 kilograms of mercury. A few years later, the EPA Report to the Congress (EPA 1997) showed that the 1995 emissions from all U.S. Waste-to-Energy plants amounted to 26,900 kg of mercury. Finally, if one applies the metric of 68 kilogram/million metric tons of MSW for HRB to the 33 million metric tons currently combusted in WTE plants (Berenyi, 1998), the corresponding mercury emissions from all U.S. WTE plants would amount to 2,244 kilograms, i.e. ten times lower than the EPA 1995 estimate and forty times lower than the NREL 1989 estimate (Figure 2).



2.4 Mercury emissions from sewage sludge incinerators

New Jersey and several other states incinerate the sludge generated in the process of treating sewage in Waste Water Treatment Plants. NJDEP (November 2001) provided a detailed tabulation of the estimated mercury emissions from the New Jersey sewage sludge incinerators (SSI). Table 6 shows that the sum of the estimated mercury emissions amounts to 90 kilograms (200 lb.). These numbers are based on stack measurements and estimates of amounts of sludge incinerated. NJ DEP (2001) estimated that, due to uncertainties in quantities of sludge incinerated, this estimate may be off by $\pm 25\%$. The New York City sludge is dewatered, pelletized and used as soil conditioner (NYC DEP, 2001).

Table 5. 1999 Mercury emissions from Waste-to-Energy plants

Facility	Gas control system (all use carbon injection)	MSW combusted, Short tons per year	Annual micrograms of mercury per dry standard cubic meter	Mercury emission kg/y	Kg of mercury per million metric tons Of MSW
Camden, NJ	ESP	451,000	25.1	51.3	125
Essex, NJ	ESP	985,000	31.8	73.5	82
Gloucester, NJ	Fabric filters	210,000	38.0	6.8	36
Union, NJ	Fabric filters	562,000	2.2	14.5	28
Warren, NJ	Fabric filters	160,000	2.4	1.8	12
New Jersey total		2,368,000		148	69
Onondaga, NY*	Fabric filters	330,000	8.1	15.3	51
Hempstead, NY	Fabric filters	700,000	NA	43.9*	69*
Niagara Falls, NY	Fabric filters	800,000	NA	50.2*	69*
New York total		1,830,000		109.4	66
NY/NJ total		4,198,000		277.3	68
HRB: 0.57(NY/NJ tot.)		2,392,860		146.7	68
SEMASS, MA	Fabric filters	1,000,000	5.1	33.0	36

* Hempstead and Niagara Falls emissions assumed to be at NJ average of 69kg/million tons

Table 6. 2000 emissions from New Jersey sewage sludge incinerators (NJ DEP May 2001)

Sewage sludge incinerator	Mercury emissions (kg/y)
Atlantic CUA	4.7
Bayshore Regional SA	7
Camden CUA	9
Gloucester CUA #2	1.8
Northwest Bergen UA	9
ParsippanyTroy Hill UA	7.5
Twin Bridges SA	14.7
Stony Brook RSA	20.2
Township of Wayne SA	3.8
Somerset Raritan Valley SA	12.6
Total	90.3

2.5 Mercury emissions from medical waste incinerators (MWI)

The EPA Report to Congress (EPA 1997) reported that in 1995 there were about 2400 Medical Waste Incinerators (MWI) in the U.S., ranging in capacity from 1 to 54 tons per day. Sixty-one of these were in New Jersey and eighteen in New York. The 1995 mercury emission rates from all U.S. MWI were estimated at 14,600 kg of mercury. For the HRB population (5.6% of U.S), the corresponding emissions in 1995, would be 818 kg. However, a very recent and detailed communication from NJ DEP (Table 7, NJ DEP 2001) shows that the total NJ emissions from MWIs in 2000 were only 0.9 kg/year. On the basis of this estimate, the MWI mercury emissions are negligible.

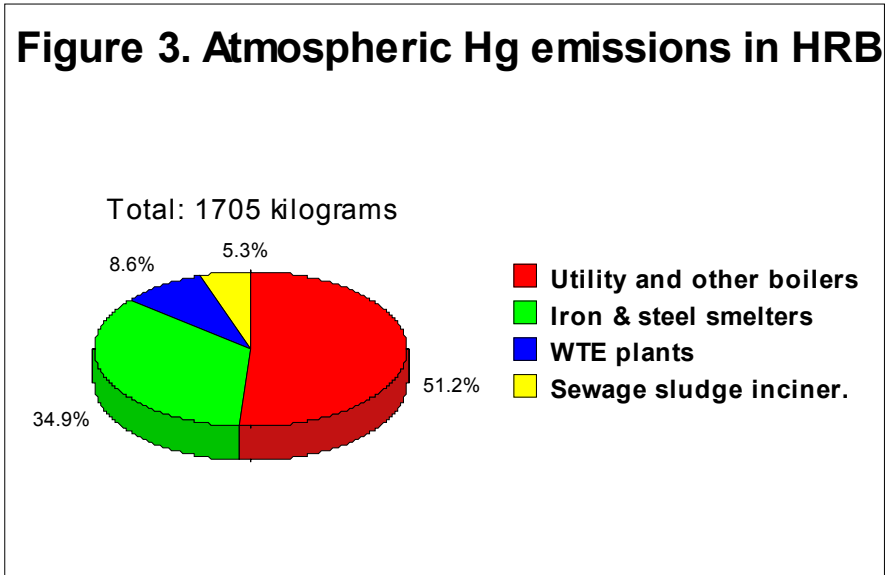
Table 7. Mercury emissions from New Jersey medical waste incinerators (NJ DEP 2001)

Medical waste incinerator	Mercury emissions (kg/y)
Elizabeth General Medical Center	0.003
Helene Fuld Medical Center	0.09
Monmouth Medical Center	0.11
Morristown Memorial Hospital	0.20
Passaic Valley Hospital	0.02
Rahway Hospital	0.03
Shore Memorial Hospital	0.01
St. Joseph's Hospital and Medical Center	0.45
Total	0.91

2.6 Summary of emissions from high-temperature sources in HRB

The above findings on current combustion and smelting sources of mercury emissions in HRB for 1999-2000 are summarized below and in Figure 3.

- Utility, industrial, and residential boilers: 873 kilograms/y
 - Emissions from iron and steel smelting: 595
 - Emissions from Waste-to-Energy plants: 147
 - Emissions from sewage sludge incinerators: 90
- Total: 1,705 kilograms/year



3. DEPOSITION OF ATMOSPHERIC MERCURY IN HRB

Mercury exists in the atmosphere principally in the form of metal vapor. However, most of the deposition on land and water is in the form of “wet” deposition, as oxide, chloride or other compounds. The annual rate of wet precipitation of mercury has been measured at various locations in North America (Table 8). It has been found to range from 10 to 35 grams/km². In

northern New York, it was measured at 10 grams/km² which corresponds to a deposition of 420 kilograms per year for the HRB area of 42,000 km².

EPA (1997) assumed that about 60% of the mercury emitted from combustion sources is in elemental form and contributes to the global mercury load in the atmosphere; 40% is in reactive form and tends to deposit locally. On this basis, the mercury emitted from HRB that is deposited in the same area amounts to 1705*0.4=682 kg/y. This “short-range” deposition is in addition to the 420 kilograms of long-range deposition estimated for the HRB area. Therefore, the total atmospheric deposition of mercury in HRB is estimated about 1,100 kilograms per year. On a surface area basis, the total deposition on HRB corresponds to nearly 27 g/km² per year, which is in line with the measured deposition in other populated areas of the U.S. (Table 8).

Table 8. Measured rates of wet deposition of mercury in grams per square kilometer (data from Bergan et al. 1999; Weinstein et al. 2000)

Location	Observation (Range)	Reference
Scandinavia		
Northern Norway	(3-5)	Iverfeldt (1991)
Northern Sweden	10	Iverfeldt (1991)
SW Sweden 1985-1989	27	Iverfeldt (1991)
SW Sweden 1990-1992	10	Iverfeldt et al. (1995)
USA		
Northern NY State 1993	10	Burke et al. (1995)
Little Rock Lake, WI	8.7	Fitzgerald et al. 1991
Wisconsin	9 (5 – 13)	Benoit et al (1994)
NE Minnesota 1988-1989	15 (6 – 20)	Glass et al. (1991)
Upper Midwest	7.4	Glass and Sorensen 1999
Florida 1992-1993	(15 – 23)	Guentzel et al. (1995)
Lake Michigan	8.3	Hoyer et al. 1995
Chesapeake Bay	21.0	Mason et al. 1994
Baltimore, MD	35.0	Mason et al. 1994
Lake Champlain, NY	7.9	Rea and Keller 1996
Japan		
Kobe	40	Lindberg et al. (1992)
Oceans		
Tropical Pacific	3	Fitzgerald et al. (1983)
NW Atlantic	11	Fitzgerald (1989)
NE Pacific	10	Fitzgerald (1989)
Enewetak (11N, 165E)	4.2	Fitzgerald (1989)
Samoa (13S, 170W)	7.0	Fitzgerald (1989)
Tasman Sea (35S, 170E)	3.8	Fitzgerald (1989)

4. CONCLUSIONS

At present, the primary sources of atmospheric emissions in HRB are utility and industrial boilers (873 kilograms of mercury/year), secondary iron and steel plants (595 kg), Waste-to-Energy plants (147kg), and sewage sludge incinerators (90 kg). An estimated 40% of the HRB stack emissions of mercury (i.e., 679 kilograms per year) are deposited within the HRB (short-range deposition) and 60% are added to the global atmospheric load of mercury. The annual deposition of mercury from the global atmosphere in this region (10 grams per square kilometer) amounts to an additional 420 kg of mercury. Thus, the estimated overall atmospheric deposition of mercury from the atmosphere on the surface of HRB is about 1,100 kilograms per year. The NYAS study from which this paper is drawn (Themelis et al, 2002), concluded that much of the deposited mercury eventually ends in the sediments settling in the dredged areas of New York/New Jersey Harbor. The same report states that the decrease in mercury emissions in recent years is reflected in the fact that the concentration of mercury in “new (surficial) sediments deposited in the Harbor has decreased from over 10 ppm (parts per million) in the eighties to 0.7

ppm in recent years. The latter value is approaching the pre-industrial level of mercury in sediments (0.1-0.2 ppm). However, according to some marine biologists, is still high enough to present an ecological threat to some organisms. It is therefore necessary to curtail mercury emissions further (Themelis et al, 2002).

The iron and steel plant emissions can be reduced by providing incentives to firms and individuals who collect used and abandoned cars, for the value of their spare parts and metal content, to remove and recycle mercury switches. Mercury switches can be removed only before the automobile body is compacted or shredded. This will be a much less costly route than requesting several iron and steel smelting plants to incorporate activated carbon injection in their gas control systems.

In the last decade of the 20th century, there has been an enormous reduction in mercury emissions from the HRB Waste-to-Energy plants. This was due to the diminished use of mercury in the economy and also the implementation of activated carbon injection (ACI) in the gas control systems of WTE facilities. Apparently, ACI is effective both with bag filters and the older electrostatic precipitator systems.

In the full report of the Earth Engineering Center to the New York Academy of Sciences, the following measures were recommended for further reduction of mercury emissions to the environment:

- a) Removal of mercury switches from discarded automobiles prior to compacting or shredding.
- b) Strengthening current programs for collection and recycling of fluorescent lamps.
- c) Implementing Activated Carbon Injection (ACI) in coal-fired power plants.
- d) Diverting mercury-containing products from landfills and WTE plants.
- e) Requiring that all combustion process plants dispose their flue dusts in dedicated landfills that do not include organic materials (monofills), or in beneficial uses that do not allow chronic formation of methyl mercury.

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