

## **Emissions from Waste-to-Energy: A Comparison with Coal-fired Power Plants**

Dionel O. Albina and Nickolas J. Themelis  
*Earth Engineering Center, Columbia University and  
Waste-to-Energy Research and Technology Council, New York City*

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### **Abstract**

Nationwide data of the emissions from waste-to-energy and coal-fired power plants are compared. The emissions of sulfur dioxide and hydrogen chloride, particulate matter, nitrogen oxides and trace elements, such as cadmium, lead and mercury are compared, both in terms of thermal energy input and electrical energy output. The results of the study have shown that emissions of sulfur dioxide, particulate matter and nitrogen oxides were lower from waste-to-energy (WTE) facilities than from coal-fired plants. Hydrogen chloride emissions are higher in WTE flue gases. Emissions of cadmium, lead and mercury from WTE and coal-fired plants are nearly the same.

### **1. Introduction**

The conversion of Municipal Solid Waste (MSW) in Waste-to-Energy facilities has been recognized globally as a means to conserve fossil fuels and improve environmental quality by lessening the amount of waste to be landfilled [1]. Worldwide, over 130 million tons of MSW are combusted annually in WTE facilities that produce electricity and steam for district heating. In the US alone, about 30 million tons of MSW are combusted in WTE plants to produce about 2.8 GW of electricity and some steam for district heating [2], which is approximately 0.3 % of total US electricity production. However, one of the major concerns in combustion of MSW in WTE plants is the emission to the atmosphere. The WTE emissions of concern are trace organic compounds, particularly polychlorinated dioxins and furans, volatile trace metals such as

mercury, lead and cadmium, total particulate matter, and acidic gases such as hydrogen chloride, hydrogen fluoride, sulfur dioxide and nitrogen oxides.

Of the one billion tons of coal produced annually in the United States, approximately 90 % is burned to generate electricity. In 2000, 52 % of the 3,800 billion kWh of the net power generated by the electric power industry was from coal-fired power plants [3]. Coal-fired generating units produce more sulfur dioxide and nitrogen oxides than oil or gas-fired units as coal generally contains more sulfur than other fossil fuels, in addition to being the principal fuel in the U.S.

This study compared the gaseous and particulate emissions of post-MACT (Maximum Achievable Control Technology) WTE facilities with those of the U.S. coal fired plants, on the basis of a) thermal energy input and b) electricity output.

## **2. Emission Standards**

The U.S. Congress passed the Clean Air Act (CAA) in 1963 to respond to the concerns about emissions of sulfur dioxide, nitrogen oxides and several other air pollutants. It was not until 1970, however, that the Environmental Protection Agency was empowered to set enforceable air quality standards. In 1971, the Agency established New Source Performance Standards (NSPS) that limited the emissions of SO<sub>2</sub> and NO<sub>x</sub> from coal-fired utility boilers. In 1977, Congress amended the CAA to require states to set limits on existing sources in regions not attaining goals established in the Act. In 1979, the Environmental Protection Agency established the Revised New Source Performance Standards (RNSPS) requiring new or modified boilers to further reduce SO<sub>2</sub> emissions by at least 90%. In 1990 the Clean Air Act was amended further requiring the fossil-fuel-fired generators of electricity to reduce 1980 levels by a 10-million-ton reduction in SO<sub>2</sub> emissions and a 2-million ton reduction in NO<sub>x</sub>. The reductions in SO<sub>2</sub> were to occur in two phases that began in 1995 and 2000, respectively.

As part of the 1990 Clean Air Act mandates, EPA promulgated in 1995 new air pollution control standards for large WTE facilities (municipal waste combustors). These standards required facilities to implement the Maximum Achievable Control Technology (MACT). The 1995 MACT standards apply to facilities with large units, i.e. that combust

more than 250 tons each day of trash. MACT standards for small units that combust less than 250 tons of trash per day were proposed in the summer of 1999. Table 1 shows the existing MACT rules for existing large units.

*Table 1. MACT rules for existing large Municipal Waste Combustion units*

<b>Emissions</b>	<b>Limits</b>	
<b>Dioxin/Furans</b>		
Large-ESP Equip Units	60 ng/dscm	
All others	30 ng/dscm	
<b>Metals</b>		
Cadmium	0.04 mg/dscm	
Lead	0.44 mg/dscm	
Mercury	0.080 mg/dscm or 85% removal	
<b>Acid Gases</b>		
Sulfur Dioxide	29 ppm or 75 % removal	
Hydrogen Chloride	29 ppm or 95 % removal	
<b>Nitrogen Oxides</b>		
	Option A	Option B
Mass Burn/Water Wall	205 ppm	180 ppm
RDF	250 ppm	220 ppm
Mass Burn/Rotary	250 ppm	220 ppm
Fluidized bed	180 ppm	160 ppm
<b>Particulates</b>		
	27 mg	
<b>Fugitives</b>		
	Visible less than 5% of time	

Source: [http://www.wte.org/m\\_act.html](http://www.wte.org/m_act.html)

### 3. Emission Estimates Methodology

Emission estimates from coal-fired plants and WTE facilities are presented on the basis of thermal energy input (lb/million BTU) and electrical energy output (g/kWh). Except for trace elements (i.e. cadmium, lead and mercury) where emission factors from different combustion control technologies were available, all emissions presented are nationwide estimates. Data for total emissions [4], total energy input [5], and electrical energy output [6] were used as the basis for calculating nationwide estimate of emissions for coal-fired power plants.

In estimating the emissions from WTE facilities, estimates were made on the yearly average operating time of the units, nationwide estimate of the total waste combusted, average heating value of the waste and total electrical energy output. In the calculation of

emission factor, a 310 days/year operating time, heating value of 10,500 BTU/kg feed and an electrical output of 2,600 MW were used. All data are estimates obtained from approximately 170 WTE units larger or equal to 250 tons/day feed input.

#### 4. Emissions

##### **4.1 Acid Emissions: Sulfur Oxides, Hydrochloric and Hydrofluoric Acids**

The acid gases  $\text{SO}_2$ ,  $\text{SO}_3$ , HCl and HF are all removed by the same kind of control equipment, i.e. dry or wet scrubbers. The design of scrubbers for WTE systems is largely based on experience obtained from coal-fired power plants. Mass transfers and chemical reaction rates are similar in coal-fired combustion and MSW combustion. However; MSW combustion has significantly lower levels of sulfur oxides, higher levels of HCl and lower levels of fly ash compared with that of coal combustion. Since HCl and HF are easier to scrub than  $\text{SO}_2$ , a system designed to scrub  $\text{SO}_2$  will have no problem with these gases with respect to removal efficiency. Wet limestone scrubbers are the most commonly used control devices for large coal-fired plants. A more recent development is the dry scrubbing system, which may use either dry sorbent or an aqueous sorbent solution (spray dry absorber, SDA) that is sprayed in the flue gas. Dry systems are generally less expensive to install than wet scrubbers but have higher operating costs because larger amounts of sorbents are required [7].

##### **4.1.1 Sulfur Oxides Emissions**

Gaseous sulfur oxides from coal combustion are primarily sulfur dioxide ( $\text{SO}_2$ ), plus a much smaller quantity of sulfur trioxide ( $\text{SO}_3$ ) and gaseous sulfates. These compounds form as the organic and pyritic sulfur in coal are oxidized during the combustion process. On the average, about 95% of the sulfur present in bituminous coal is emitted as gaseous  $\text{SO}_x$  whereas somewhat less of sulfur is volatilized when sub-bituminous coal is fired [8].

Emissions of sulfur dioxide from coal-fired plants were reduced from 13.8 million tons in 1990 to 9.6 million tons in 2000, which represented 65% of the total U.S. sulfur emissions. With regard to WTE sulfur dioxide emissions, they were reduced by 87% from a pre-MACT emission estimate of 31 thousand tons to a post-MACT estimate of 4 thousand tons, which represented only 0.03 % of the total U.S. sulfur dioxide emissions

in the year 2000. The MACT regulation limits the emission concentration of sulfur dioxide at the source to 29 parts per million dry volume (ppmdv) at 7 % O<sub>2</sub>. Table 2 shows the emissions of sulfur dioxide from coal-fired plants and post-MACT WTE facilities in terms of thermal energy input and electrical energy output. It shows that emissions of sulfur dioxide from WTE plants amounts to about 0.03 lb/million BTU (0.01 g/MJ) while that of coal-fired plants is several times higher, at approximately 1.0 lb/million BTU (0.45 g/MJ).

*Table 2. Sulfur dioxide emission in coal-fired and WTE plants*

Year	Total Emissions (in 1000 tons)		% of Total SO <sub>2</sub> Emissions		Emission Factor <sup>d</sup>			
	Coal- fired <sup>a</sup>	WTE	Coal- fired	WTE	lb/10 <sup>6</sup> Btu (g/MJ)		g/kWh	
					Coal-fired	WTE	Coal-fired	WTE
1990	13,836	30.7 <sup>b</sup>	65.95	0.15	1.87 (0.81)	nd	8.7	nd
1995	10,548	nd	62.32	na	1.33 (0.57)	nd	6.2	nd
1998	11,335	nd	65.81	na	1.3 (0.56)	nd	6.1	nd
2000	9,625	4.076 <sup>c</sup>	64.88	0.03	1.05 (0.45)	0.031 (0.013)	4.9	0.21

Source: <sup>a</sup>EPA, (2003), Average Annual Emissions, All Criteria Pollutants (Table A-8)

<sup>b</sup>EPA, Docket A-90-45, Item VIII-B-7 (pre-MACT Emissions)

<sup>c</sup>EPA, Docket A-90-45, Item VIII-B3 (post-MACT Emissions)

<sup>d</sup>Data for energy input and energy output were taken from Energy Information Administration/Annual Energy Review 2001 (Table 2.1f and Table 8.2a) respectively

#### ***4.1.2 Hydrogen Chloride and Hydrogen Fluoride Emissions***

Emissions of hydrogen chloride from WTE facilities reduced approximately 95% from 46,900 tons in 1990 to 2,670 tons in the year 2000. Large existing WTE facilities were required by EPA to reduce 95% of the input HCl emissions or maintain an exit gas concentration below 29 ppmdv at 7% O<sub>2</sub>. Table 3 shows a comparison of emission factor for coal fired plants and WTE facilities; because of the nature of the fuel, WTE facilities emits more HCl per unit of energy input and per electrical energy output as compared to that of coal-fired plants.

Table 3. Hydrogen chloride and Hydrogen fluoride emissions

	Emissions	Emission Factors			
		lb/10 <sup>6</sup> BTU	g/10 <sup>9</sup> J	lb/MWh	g/kWh
Coal-fired plants	Hydrogen Chloride <sup>a</sup>	0.04	17	nd	nd
	Hydrogen Fluoride <sup>a</sup>	0.005	2.2	nd	nd
WTE Plants	Hydrogen Chloride <sup>b</sup>	0.20	87	3	1.3

Source: <sup>a</sup>EPA, AP-42, Fifth Edition, Vol.1, September 1998, Table 1.11-15

<sup>b</sup>EPA, Docket A-90-45, Item VIII-B-3 (post-MACT Emissions);nd-no data

#### 4.2 Nitrogen Oxides Emission

Nitrogen oxide (NO<sub>x</sub>) is formed in MSW combustion facilities in two separate pathways: thermal fixation of molecular nitrogen present in the combustion air (thermal NO<sub>x</sub>) and the conversion of nitrogen present in the fuel (fuel NO<sub>x</sub>). While thermal fixation is extremely sensitive to temperatures above 1800 K, formation of fuel NO<sub>x</sub> is insensitive to temperature and depends primarily on the availability of oxygen. Conditions that promote good mixing of fuel and air tend to increase the conversion of nitrogen in the fuel to NO<sub>x</sub> and raise emission levels [7].

Nitrogen oxide emissions from coal combustion are primarily nitric oxide (NO) and a small quantity of nitrogen dioxide (NO<sub>2</sub>) by volume. Nitrous oxide (N<sub>2</sub>O) is also emitted at a few parts per million. As in the case of MSW combustion, NO<sub>x</sub> is formed from thermal fixation of atmospheric nitrogen in the combustion flame and also from oxidation of nitrogen in the coal. Bituminous and sub-bituminous coal usually contain from 0.5 to 2% nitrogen by weight; therefore, fuel nitrogen can account for up to 80 percent of the total nitrogen oxides from coal combustion.

Emissions of nitrogen oxides from coal-fired plants were reduced from 5.1 million tons in 1990 to 4.1 million tons in the year 2000; this represented a reduction from 22% to 19.5% of the total U.S. nitrogen oxide emissions. During the same period, emissions of large WTE facilities were reduced 17% from a pre-MACT emission estimate of 56.4 thousand tons to 46 thousand tons in the year 2000; this emission represents only 0.03 % of the total U.S. nitrogen oxide emissions. MACT regulation limits emission of nitrogen oxides

at the source below a concentration from 160-250 ppmdv at 7% O<sub>2</sub> (depending on the type of burning technology; i.e. mass burn, refuse-derived fuel or fluidized bed).

Table 4 shows a comparison of the emission factors of coal-fired and large WTE facilities complying MACT standards. It can be seen that emissions from coal-fired plants ranged from 0.69 lb/million BTU (0.3 g/MJ) in 1990 to 0.45 lb/million BTU in the year 2000. Emission from post-MACT WTE facilities is lower at 0.35 lb/million BTU (0.15 g/MJ). However, NO<sub>x</sub> emission is slightly higher in terms of electric energy produced: 2.41 g/kWh compared to 2.1 g/kWh in coal-fired plants; this is attributed to the fact that coal-fired plants have a higher thermal efficiency (30-33%) as compared to that of WTE facilities (17-20%).

*Table 4. Nitrogen Oxides emission in coal-fired and WTE plants*

Year	Total Emissions (in 1000 tons)		% of Total US Emissions		Emission Factor <sup>d</sup>			
	Coal-fired <sup>a</sup>	WTE	Coal-fired	WTE	lb/10 <sup>6</sup> Btu (g/MJ)		g/kWh	
					Coal-fired	WTE	Coal-fired	WTE
1990	5,129	56.4 <sup>b</sup>	22.1	0.24	0.69 (0.30)	nd	3.2	Nd
1995	5,072	nd	22.36	nd	0.64 (0.28)	nd	3.0	Nd
1998	4,942	nd	22.33	nd	0.57 (0.24)	nd	2.6	Nd
2000	4,124	46.5 <sup>c</sup>	19.55	0.22	0.45 (0.19)	0.35 (0.15)	2.1	2.4

Source: <sup>a</sup>EPA, (2003), Average Annual Emissions, All Criteria Pollutants (Table A-4)

<sup>b</sup>EPA, Docket A-90-45, Item VIII-B-7 (pre-MACT Emissions)

<sup>c</sup>EPA, Docket A-90-45, Item VIII-B3 (post-MACT Emissions)

<sup>d</sup>Data for energy input and energy output were taken from Energy Information

Administration/Annual Energy Review 2001 (Table 2.1f and Table 8.2a) respectively, nd: no data

### 4.3 Particulate Matter Emissions

Particulate matter (PM) composition and emission levels are a complex function of boiler firing configuration, boiler operation, pollution control equipment and coal properties [8]. In pulverized coal systems, combustion is almost complete; thus, the emitted PM is primarily composed of inorganic ash residue. Electrostatic precipitators (ESPs) and fabric filters are used to control particulate emissions from coal-fired power plants. Overall particulate removal efficiencies are often well over 99% and since most trace elements are associated with particulates, most trace elements are collected along with the

particulates. New WTE plants and the majority of existing large WTE plants use a combination of fabric filters and dry scrubbers.

Approximately 2.5% of U.S. particulate matter (PM<sub>10</sub>) emissions were emitted from coal-fired power plants in the year 2000. PM emission reached 240,000 tons in the year 1990 and has increased to approximately 570,000 tons in the year 2000. PM emissions from WTE facilities reached 7 thousand tons in 1990 and were reduced to 0.7 thousand tons in the year 2000. MACT regulation limits PM concentration at the source at 27 milligram per dry standard cubic meter (mg/dscm) at 7% O<sub>2</sub> for compliance. Table 5 compares the emissions from coal-fired and WTE facilities after MACT retrofit. PM emissions from coal-fired plants are in the range of 33 lb/billion BTU (14 g/GJ) to 62 lb/billion BTU (27 g/GJ) while that of post-MACT WTE facilities is significantly lower at 5 lb/billion BTU (2.3 g/GJ).

*Table 5. Particulate matter emissions from coal-fired and WTE plants*

Year	Total Emissions (in 1000 tons)		% of Total Emissions		Emission Factor <sup>d</sup>			
	Coal- fired <sup>a</sup>	WTE	Coal- fired	WTE	lb/10 <sup>9</sup> Btu (g/GJ)		g/kWh	
					Coal-fired	WTE	Coal-fired	WTE
1990	241	6.93 <sup>b</sup>	0.95	0.03	33 (14)	nd	0.15	nd
1995	222	nd	0.95	nd	28 (12)	nd	0.13	nd
1998	179	nd	0.86	nd	21 (8)	nd	0.10	nd
2000	566	0.707 <sup>c</sup>	2.52	0.003	62 (27)	5(2.3)	0.29	0.037

Source: <sup>a</sup>EPA, (2003), Average Annual Emissions, All Criteria Pollutants (Table A-6: PM<sub>10</sub>)

<sup>b</sup>EPA, Docket A-90-45, Item VIII-B-7 (pre-MACT Emissions)

<sup>c</sup>EPA, Docket A-90-45, Item VIII-B3 (post-MACT Emissions)

<sup>d</sup>Data for energy input and energy output were taken from Energy Information Administration/Annual Energy Review 2001 (Table 2.1f and Table 8.2a) respectively

#### 4.4 Trace Metals

Trace metals are emitted both during coal and MSW combustion. The quantity of any given metal emitted in general depends on: the physical and chemical properties of the metal itself; the concentration of the metal in the fuel, the type of the particulate control device used, and its collection efficiency as function of particle size. In addition, emission of trace metals from the combustion of fuel depends not only on the element

concentrations in the fuel itself, but even more strongly on the chemical and physical phenomena associated with the combustion process. Some metals become concentrated in certain particle streams from combustor (e.g., bottom ash, collector ash, and flue gas particulate) while others do not. Various models have been developed to describe this partitioning behavior [9]. The phenomena involved in partitioning are important because they determine how and where trace elements are emitted and impact the type of emission control device that may be required. The same principles that apply to the partitioning of trace metals in coal combustion may also apply to the combustion of MSW.

#### ***4.4.1 Cadmium Emissions***

Cadmium oxide is the predominant form of cadmium in the atmosphere. However, the toxicology of cadmium does not appear to be dependent on the chemical forms. Because a typical residence time of particulate cadmium is between 1 and 10 days, long-range transport (up to thousand km) can occur. Emission control measures for both coal-fired and MSW combustion include better combustor design and operating practice that are directed at nitrogen oxides and particulate matter and add-on air pollution devices that are designed for acid gas and PM control. Emissions of cadmium from WTE facilities reached 4.75 tons in the year 1990 and were reduced to 0.33 tons in the year 2000.

Table 6 shows measured cadmium emission factors for coal-fired plants, for different coals and pollution control technologies. Table 7 shows the nationwide emissions of cadmium from WTE facilities after implementation of the MACT standards. As shown, cadmium emissions from coal are in the range of <4.3 to 18 lb/trillion BTU and from post-MACT WTE facilities, 2.5 lb/trillion BTU.

Table 6. Typical cadmium emission factors for coal combustion

Coal-type	Control Status <sup>a</sup>	Measured Emission Factors
		lb/10 <sup>12</sup> BTU (g/10 <sup>12</sup> J)
Bituminous	ESP	18 (7.7)
Bituminous	ESP/wet scrubber	<18 (<7.7)
Bituminous	ESP-2 stage	<18 (<7.7)
Sub-bituminous	ESP	10 (4.4)
Sub-bituminous	ESP/wet scrubber	<4.3 (<1.8)
Sub-bituminous	ESP-2 stage	<4.3 (<1.8)
Anthracite	ESP	4.3 (1.8)
Anthracite	ESP/wet scrubber	<4.3 (<1.8)
Anthracite	ESP-2 stage	<4.3 (<1.8)
Lignite	ESP	19 (<8.4)
Lignite	ESP/wet scrubber	<19 (<8.4)
Lignite	ESP-2 stage	<19 (<8.4)

Source: EPA, Locating and Estimating Air Emissions from Sources of Cadmium and Cadmium Compounds, (EPA-454/R-93-040, September, 1993), Table 6-8

Note: <sup>a</sup>ESP: electrostatic precipitator

Table 7. Estimated nationwide emission factor of cadmium from WTE facilities

	Emissions (tons)	Emission Factors			
		lb/10 <sup>12</sup> BTU	g/10 <sup>12</sup> J	lb/TeraWh	g/GWh
WTE Plants	0.333 <sup>a</sup>	2.5	1.1	38	17

Source: <sup>a</sup>EPA, Docket A-90-45, Item VIII-B-3 (post-MACT Emission)

#### 4.4.2 Lead Emissions

Emissions of lead from coal-fired power plants reached 42 tons in 1990 and increased to 49 tons in 1998, which represented about 1% and 1.4% of the total U.S. emissions, respectively [10]. Emissions of lead from large WTE plants were 52 tons in 1990 and were reduced to 4.7 tons in 2000.

Lead emission factor for controlled coal-fired utility boilers is about 14 lb/trillion BTU [11], while that of WTE facilities is estimated at 36.1 lb/trillion BTU. Table 8 presents the nationwide estimate of emission factors, using actual emissions of WTE facilities complying with MACT standards.

Table 8. Estimated nationwide emission factor of lead from WTE facilities

Year 2000	Emissions (tons)	Emission Factors			
		lb/10 <sup>12</sup> BTU	g/10 <sup>12</sup> J	lb/TeraWh	g/GWh
WTE Plants	4.76 <sup>a</sup>	36.1	10		250

Source: <sup>a</sup>EPA, Docket A-90-45, Item VIII-B-3 (post-MACT Emission)

#### 4.4.3 Mercury Emissions

Mercury is emitted in several chemical forms or oxidation states, including elemental and oxidized mercury, which impact not only in its removal but also on its transport and subsequent deposition once released into the atmosphere [7]. Mercury is probably the trace element of most environmental concern, as it tends to bio-accumulate in the food chain once released into the environment. Mercury is primarily emitted as a vapor and is not effectively controlled by the pollution control equipment used during most of the 20th century. However, activated carbon injection in the flue gas results in the adherence of mercury molecules on the carbon particles which are then recovered in fabric bags through which the gas is filtered. This is the control system used in WTE plants that have implemented the MACT regulations.

Total nationwide mercury emissions from coal-fired utilities, as estimated by EPA in its report to Congress in 1998 [12], reached 51.3 tons (short tons) in 1994, which represented approximately 33 percent of the total US emissions. For WTE facilities, emissions of mercury were reduced from 45.2 tons in 1990 to 2.2 tons in 2000. MACT regulation limits concentration of mercury to 0.08 mg/dscm at 7% O<sub>2</sub>. Measured mercury emissions from coal varied from as low as 0.2 lb/trillion BTU to as high as 30.2 lb/trillion BTU (Table 9). Using actual WTE emissions, the estimated mercury emissions from post-MACT WTE facilities are 16.7 lb/trillion BTU and 0.25 lb/gigawatt-hour (Table 10).

Table 9. Measured mercury emission factors for coal combustion

Coal-type	Control Status	Measured Emission Factors
		lb/10 <sup>12</sup> BTU (g/TJ)
Bituminous	Uncontrolled	8.8 (3.8)
Bituminous	MP or MC	29.9 (12.9)
Bituminous	ESP or MP/ESP	8 (3.4)
Bituminous	ESP-2 stage	0.2 (0.1)
Bituminous	WS or MC/WS	18.4 (7.9)
Bituminous	FF	4.6 (2.0)
Sub-bituminous	Uncontrolled	30.2 (13.0)
Sub-bituminous	ESP or MP/ESP	2.7 (12.1)
Lignite	MC	9.6 (4.1)
Lignite	ESP	0.4 (.2)
Anthracite	Uncontrolled	5.3 (2.3)

Source: Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds, EPA-454/R-97-012, Dec. 1997, Table 6-7

Notes: MP: mechanical precipitation, MC: multicyclone, ESP: electrostatic precipitator, WS: wet scrubber

Table 10. Estimated nationwide emission factor of mercury from WTE plants

	Emissions (tons)	Emission Factors			
		lb/10 <sup>12</sup> BTU	g/10 <sup>12</sup> J	lb/GWh	g/MWh
WTE Plants	2.2 <sup>a</sup>	16.7 <sup>b</sup>	7.2 <sup>b</sup>	0.251 <sup>c</sup>	0.114 <sup>c</sup>

Source: <sup>a</sup>EPA, Docket A-90-45, Item VIII-B-3 (post-MACT emissions);

<sup>b</sup>Assumed average heating value of 10,500 BTU/kg MSW, 0.85 availability factor

<sup>c</sup>assumed availability factor of 0.85 (2,590 MW total power generation)

#### 4.5 Dioxin/furan Emissions

The chlorinated dibenzo-p-dioxins (CDD) and chlorinated dibenzofurans (CDF) are formed as unwanted byproducts of certain chemical processes during the manufacture of chlorinated intermediates and in the combustion of chlorinated materials. Dioxin and furans are emitted into the atmosphere from a wide variety of processes such as waste combustion, fossil fuel combustion, iron and steel industries/scrap melting, combustion aided metal recovery, internal combustion engines, carbon regeneration, organic chemical manufacture and use, forest fires and cement manufacture [13]. The toxic equivalent factor (TEF) was established to relate the toxicity of each compound on a 0-1 scale, where 1 is the most toxic dioxin compound known. On the basis of these factors and the prevailing distribution of the different types of dioxin and furans in the flue gas of WTE

facilities, it has been established that the prevailing ratio of total toxic dioxin to toxic equivalence is approximately 50. Which means, 50 grams of total CDD/CDF emission corresponds to about 1 gram of toxic equivalent (TEQ).

Emissions of CDD/CDF from coal-fired plants have increased from 50 gram TEQ in 1987 to 60 gram TEQ in 2002 [14]. With regard to WTE emissions, total CDD/CDF was reduced significantly by 99% from a 1987 emission estimate of 8,877 gram TEQ to just 15 gram TEQ in 2000 and was estimated to be at 12 gram TEQ in 2002 [14]. MACT regulation limits the emission concentration of total dioxin/furan at the source to 30 ng/dscm at 7% O<sub>2</sub>.

The dotted line of Figure 1 [14] shows the post-MACT cumulative emissions of dioxins of the U.S. WTE facilities. The diagonal straight line represents the allowable limit of toxic dioxins (grams TEQ) using the present European Union (E.U.) limit of 0.1 nanogram per cubic centimeter and the cumulative processing rate of MSW. The data of TEQ emissions from all measured sources of dioxins as published by the U.S. EPA can be found in Table 11; it should be noted that dispersed or unknown sources of emissions and flaring of emission from landfill, oil/gas productions and refining are not included [14].

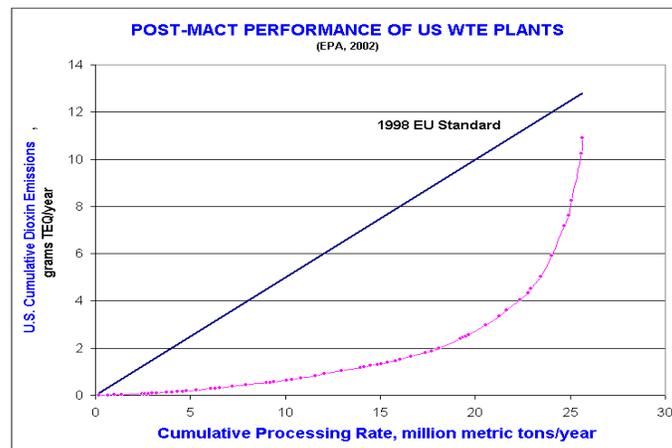


Figure 1. Cumulative dioxin emissions (in grams TEQ) of U.S. WTE facilities in 2000 (each dot represent a WTE facility)

Table 11. Sources of dioxin emissions in the U.S., 1987-2002 (U.S.E.P.A.)

Category	1987 <sup>a</sup>	% Total	1995 <sup>a</sup>	% Total	2002 <sup>a</sup>	% Total
<i>Incineration</i>						
<b>MSW</b>	<b>8877</b>	<b>77</b>	<b>1250</b>	<b>71</b>	<b>12</b>	<b>0.96</b>
Medical Waste	2590	22	488	27	7	0.54
Sewage sludge	6	0.05	14	0.84	14	1.17
Hazardous waste	5	0.04	5	0.33	3	0.03
Total Incineration	11478	82	1758	54	37	3
Backyard barrel burning	604	4	628	19	628	56
Metal smelting	955	6	301	9	35	3
Cement kilns	131	0.94	173	5	25	2
Land-appl'd sewage sludge	76	0.55	76	2	76	6
Pulp and paper	372	2.67	23	0.71	15	1
<b>Coal-fired utilities</b>	<b>50</b>	<b>0.36</b>	<b>60</b>	<b>1</b>	<b>60</b>	<b>5</b>
Industrial wood burning	26	0.19	27	0.85	27	2
Residential wood burning	89	0.64	62	1	62	5
Diesel trucks	27	0.2	35	1	35	3
Other	137	0.98	103	3	100	9
<b>TOTAL</b>	<b>13949</b>	<b>100</b>	<b>3252</b>	<b>100</b>	<b>1106</b>	<b>100</b>

<sup>a</sup>Dioxin/furan emission units of toxic equivalent quantity (TEQ), using 1989 toxicity factors; total may not add up to 100 % due to rounding

## 5. Summary

Nationwide estimates were obtained on the emissions of sulfur dioxide, hydrogen chloride, nitrogen oxides and trace metals such as cadmium, lead and mercury from coal-fired and WTE facilities. The estimates showed that, per unit of thermal energy input and also per unit of power generated, the emissions of sulfur dioxide, particulate matter and nitrogen oxides were lower in WTE facilities than for coal-fired power plants; on the same basis, hydrogen chloride emissions are 5 times higher in WTE as compared to coal-fired utilities and emissions of cadmium, lead and mercury from WTE facilities were comparable to that of coal-fired plants. With regard to dioxin/furans, the emission factors of WTE are considerably higher than for coal-fired utilities. However, in total emission terms, the toxic equivalent dioxin/furan emissions of U.S. coal-fired utilities and also of WTE facilities are a small fraction of the documented total U.S. dioxin emissions: 60 grams TEQ for coal-fired utilities and 15 grams TEQ for the post-MACT WTE power

plants in the year 2000 (i.e., 5% and 1.4% of the U.S. total, respectively) and estimated to be 12 grams TEQ in 2002.

Table 12 shows a comparison of these emissions in terms of percentage share of total emissions, emission factors and percent reduction of emission from WTE from 1990. This paper notes the impact made by MACT regulations in lowering down the emissions of WTE facilities particularly the emissions of mercury, cadmium, lead, and dioxin/furans that have been reduced by 95%, 93%, 91%, and 99% respectively, between the years of 1990 and 2000.

*Table 12. Summary of emission factors of coal-fired and WTE plants*

Emissions (Year 2000)	Percent (%) Share of Total Emissions		Emission Factors				Percent (%) Emissions Reduction from 1990 (Pre-MACT) to year 2000 (Post-MACT)
			In terms of thermal energy input: lb/10 <sup>6</sup> BTU (g/10 <sup>6</sup> J)		In terms of electrical energy output: g/kWh		
	Coal- fired	WTE	Coal-fired	WTE	Coal- fired	WTE	
<b>Acids</b>							
Sulfur Dioxide	64.08	0.03	1.05 (0.45)	0.031 (0.01)	4.9	0.21	86.7
Hydrogen Chloride	---	---	0.04 (0.017)	0.2 (0.087)	---	---	94.3
<b>Nitrogen Oxides</b>	19.55	0.22	0.45 (0.19)	0.35(0.15)	2.1	2.4	17.6
<b>Particulate Matter</b>	2.52	0.003	0.067(0.027)	0.005(0.002)	0.29	0.037	89.8
<b>Trace Metals</b>			lb/10 <sup>12</sup> BTU (g/10 <sup>12</sup> J)		lb/TWh(g/GWh)		
Cadmium			<4.3-18 (<1.8-7.7)	2.5 (1.1)		38 (17)	93
Lead	1.36	0.13	<14-507>	36.1 (10)		250	90.9
Mercury	33 <sup>a</sup>		0.4-29 (0.2-12.9)	16.7 (7.2)		0.25(0.11)	95.1
<b>Dioxin/Furans</b>	5	1	60 <sup>b</sup>	15 <sup>b</sup>			99+

<sup>a</sup>1994 total mercury emissions; <sup>b</sup>in grams TEQ ( grams Toxic Equivalent Quantity)

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