Environmental Impact of Fabric Filter Bag Incineration (FFB White Paper)

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Introduction

The issue of disposing used fabric filter bags (FFB) from baghouses of waste to energy (WTE) facilities has recently been revisited by some state regulatory offices. The main issue is to identify the best way to dispose of these used filter bags from WTE facilities. The current practice is to place the spent bags into a closed container and return them into the waste holding pit from where they are fed, by crane into the hopper of the combustion unit where the bags are incinerated along with the incoming waste feed. This follows the accepted waste management hierarchy that shows the preferred management methods of reuse, recycle and recovery of energy to be above disposal (http://www.epa.gov/wastes/nonhaz/municipal/hierarchy.htm). However, this practice has been recently questioned by some state regulatory agencies who specifically are trying to understand if it is better to transport and dispose the spent bags at an off-site hazardous waste treatment, storage and disposal facility (e.g., landfill or incineration) or to process them internally through the combustion facility, as is the current practice in most WTE plants in the U.S. and globally.

The American Society of Mechanical Engineers' (ASME) Research Committee on Energy, Environment, Waste and the Materials and Energy Recovery Division of ASME have jointly investigated this issue. The scope of the investigation focused on the technical data pertaining to combusting the used bags in the furnace of the WTE plant. Also, a screening-level risk assessment of the potential human health risks associated with feeding used filter bags back into the WTE combustion unit was conducted.

It should be noted that a review of the literature on this issue did not produce any publications that explicitly discuss this practice nor the impact of disposal of used FFB. Therefore, this study is the first one to quantify the environmental impacts of disposal of the used filter bags by means of in-plant incineration. Quantitative material balances were conducted for four representative waste-to-energy (WTE) plants to determine the number and weight of filter bags used in one year of operation, the weight of ash attached to used FFB, and the potential change in emissions of lead (Pb), cadmium (Cd) and mercury (Hg), which are considered the three primary metal pollutants of concern. The fourth pollutant of concern is polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo furans (dioxins and furans) that are captured on the activated carbon particles injected in the process gas which are then separated from the gas flow along with fly ash particles on the fabric filter bas of the baghouse; however, when the bags are combusted, these organic compounds are believed to be combusted and destroyed as gases flow through the combustion chamber; therefore, it is believed they do not add to the dioxins/furans that are formed as the process gas is cooled (*de novo* synthesis), during its flow through the boiler.

The calculations estimated the impact of the fly ash that remains on the FFB when being combusted. Specifically, calculations were made of the emission changes associated with introducing into the WTE furnace a certain amount of fly ash carried over in the used bags. Data on chemical concentration were obtained from peer-reviewed published literature, confirmed against actual operating plant data[1], and shown to be in agreement with published information by the U.S. Environmental Protection Agency (USEPA)[2]. The sources quoted in this report are referenced at the end of this document. All tons shown in this report refer to U.S. short tons (1.1 short tons = 1 metric ton).

Data evaluation from U.S. operating plants

Data on filter bag use from four waste-to-energy (WTE) plants operating in Florida and New England were used to quantify the weight of used FFB generated during WTE operation and also the weight of fly ash that they carry back to the furnace. The results of this analysis are shown in Table 1. All of these numbers were provided to the authors by the individual WTE plants, with the exception of the weight of fly ash that is captured in WTE baghouses per ton of MSW combusted. This number varies from plant to plant but the best two sources are provided in the Encyclopedia of Sustainability Science and Technology (Springer publishing)[3]. The excerpt from the encyclopedia is included in Appendix 2. These two sources are Floyd Hasselriis in the U.S. and Juergen Vehlow in the E.U. Both of them report that baghouse fly ash amounts to 2-4% of the weight of MSW. Therefore, the median value of 3%[4] was used in Table 1.

Table 1. Baghouse data for four U.S. WTE plants

	Florida plant	**New England A**	**New England B**	**New England C**
Plant capacity, tons/day	750	750	275	597
Plant capacity, tons/year	247,500	247,500	90,750	197,010
Weight of new filter bag, lb	6.5	6	2.5	3.5
Weight of used filter bag, lb	19.7	17.7	9.5	7.5
Weight of fly ash on bag	13.2	11.7	7.0	4.0
Number of bags used/year	900	720	1140	1370
Weight of fly ash to furnace, tons/year	5.93	4.19	3.98	2.73
Fly ash generated, tons/year (3% of MSW)	7425	7425	2723	5910
Fly ash to furnace with bags as % of fly ash generated by plant	0.08%	0.06%	0.15%	0.05%
Weight of filter bags combusted, tons/year	2.9	2.2	1.4	2.4

Table 1 shows that, on an annual basis, the amount of fly ash that is attached to the used filter bags ranges from 0.05 to 0.15% of the total fly ash captured in the WTE baghouse. For example, the mass balance calculation for the Florida WTE plant shows that a facility processing 247,500 tons of MSW per year generates and captures 7,425 tons of fly ash (3% of MSW). After removal of the used bag from the baghouse, the residual fly ash stuck within the fabric amounts to 13.2 pounds per bag. This particular facility uses approximately 900 bags per year on average although the amount can fluctuate. Therefore, the fly ash carry over is 5.93 tons per year or 0.08% of the fly ash captured. When the used bags are combusted in the furnace, the capture efficiency in the baghouse is estimated to be the same as for particulate matter, i.e. 99.91%, as calculated below.

An overall mass balance was completed using data provided by USEPA[2] and the New Jersey Department of Environmental Protection (NJDEP)[5, 6] to estimate the capture efficiency of particulate matter, lead, mercury, and cadmium. For example, USEPA reports that 2.3 tons of Hg were emitted by the entire U.S. WTE industry in 2005 (Table 2). Also, the New Jersey Department of

Environmental Protection (NJDEP) reported in 2009 a mean concentration of 2 mg kg^{-1} (2 ppm) of Hg in MSW for two WTE facilities; this concentration is in agreement with the mercury study for New York Academy of Sciences by the Earth Engineering Center of Columbia University in 2001. Since the MSW tonnage combusted in WTE facilities in 2005 was about 28 million tons (Columbia/BioCycle 2006 SOG survey[7]; also, EPA 2005 Facts and Figures Report[8]), the material balance of Table 2 shows that the average capture efficiency of Hg in WTE baghouses was 95.89%. Similar calculations yield 99.9%+ efficiencies for particulate matter (PM), Pb and Cd.

The capture efficiency of PM was calculated to be 99.91% (Table 2), assuming that the annual fly ash generation rate amounts to 3% of MSW processed, as discussed earlier. To ensure that the calculations made in the Emissions Impact section were conservative, the capture efficiency of 99.91% was used for Pb and Cd and 95.00% for Hg[9].

Table 2. Calculation of WTE capture efficiency using EPA emissions from Large and Small MSW Combustion Facilities in 2005

Pollutant	EPA, 2005 WTE emissions, tons	NJDEP, ppm in MSW	Total MSW input WTE industry, 2005, tons	% capture efficiency
Particulate matter, 3% of MSW	780		840000	99.907%
Lead	5.5	232	6496	99.92%
Mercury	2.3	2	56	95.89%
Cadmium	0.4	15	420	99.90%

Emissions impact

Table 1 showed that the tons of fly ash returned to the furnace ranged from 0.05 to 0.15% of the tons of fly ash captured in the baghouse; therefore, the load of fly ash handled in the baghouse, due to the combustion of the used bags increased by this amount. An alternative calculation was also made to compare the amount of an impurity, e.g. Pb, that is contained in the fly ash returned to the furnace vs. the amount of lead input in the MSW (at the NJDEP estimated concentration of 232 ppm Pb, Table 2). This calculation was made for Pb, Cd, and Hg, for the WTEs presented in Table 1. Table 3 shows that this method of calculation also shows a maximum of 0.15% increase in the emission load handled at the baghouse, when the used bags are returned to the furnace.

Table 3. Change in emissions from combusting used fabric filter bags

Plant Capacity, tons $year^{-1}$		90,750	197,010
Component	concentration mg (kg $ash)^{-1}$	Emissions change	
Pb	5066	0.15%	0.05%
Cd	410	0.15%	0.05%
Hg	25	0.06%	0.02%

Importantly, these two plants represent the best and worst case scenarios. A plant processing 90,750 tons per year typically would return 3.98 tons of fly ash with the spent filter bags. The concentrations of the chemical species were taken as an average of reported literature[5, 10, 11] values that correspond to normal operating systems. This enabled a conservative yet possible emissions change associated with combustion of the filter bags.

To provide some perspective, the reported concentration range for Pb in the fly ash was 200 to 19000 mg-(kg ash)$^{-1}$[10, 11]. Yet, the highest possible concentration for Pb on fly ash is 7480 mg-(kg ash)$^{-1}$ based on an extensive literature search[5, 10, 11] and calculations that balance reported Pb concentrations of incoming MSW. Therefore it was concluded that values higher than 7480 would represent conditions considered out of compliance or anomalies. The entire range is provided in this white paper for completeness and to assure reviewers of this document that all reported concentration ranges were evaluated. The values for Cd are 5-2100 mg-(kg ash)$^{-1}$[10, 11] and for Hg 0.8-52 mg-(kg ash)$^{-1}$[5, 12]. Furthermore using various reported values from multiple peer-reviewed publications and the USEPA website of total emissions output per year of the three chemical species with reported particulate matter capture efficiencies and input concentrations of Pb, Cd and Hg with MSW enabled an independent confirmation of the average concentrations used in Table 3.

On the basis of the data presented in Table 1 and also Table 3, it is evident that at the most, the metal emissions from a WTE would increase by only 0.15% due to the combustion of used bags in the furnace. In addition, it would not be feasible to measure such a small increase with typical analytical instruments. For example, a 0.15% increase in Cd emissions would require that the analytical instrument used to measure this minute difference should be sensitive enough to resolve between 2.1900 and 2.1903 μg Nm^{-3} , i.e. 0.0003 μg Nm^{-3}. Typical monitoring systems following the Code of Federal Regulations (CFR)[13] 40 subparts 260-299 are required to maintain systems with in-stack detection limits for Cd of 0.03 μg Nm^{-3} or two orders of magnitude larger than the calculated change of 0.0003 μg Nm^{-3}.

Finally, this study also examined the increase in the combustion air flow necessary for the combustion of the FFB. This calculation assumed that the combustion of the used bags would be in addition to the total throughput and not displace some MSW tonnage. The typical air flow of 5000 normal cubic meters per ton of MSW combusted (i.e. 5000 Nm^3/ton) was used, and resulted in an increase of process air of 0.0014%. Therefore, the increase in combustion air required to process the additional mass of the filter bag, which consists of synthetic fibers with a molecular formula of $(C_6H_4S)_n$, represents a miniscule increase in the gas flow through the baghouse.

Reported Practice in European Plants

In August 2006 a The BAT (Best Available Techniques) Reference Document (BREF) entitled Waste Incineration (WI) or BREF-WI reference document[14] was issued by the European Union on best available techniques for waste combustion. The document particularly focuses on the applied techniques regarding incineration of waste such as waste handling, thermal processes, energy recovery, flue gas treatment, process water and treatment of solid residue. To understand accepted best practices two examples of Danish waste to energy (WTE) plants are highlighted. All Danish WTE plants have an environmental approval controlling the plant operations in detail by establishing and monitoring conditions for operation.

Filter bags have a typical life of several years, but seldom all bags are replaced at the same time. Most often damaged bags are replaced in a sequential manner and subsequently disposed. The following two examples gives an idea of the general procedure at plants equipped with bag house filters in Denmark. Importantly no explicit approval or regulation exists for handling of spent bags yet there is an implicit acceptance from the local authorities for an internal handling as described.

Plant 1 (AP in Naestved) Capacity: 130,000 tons per year

This plant's disposal of used bags must be in closed plastic bags before they are put in the waste hopper. The bags are made of Ryton (polyphenylene sulfide) which can be combusted without any problem. Their recently (2012/2013) reassessed environmental permit states "The plants are allowed to incinerate non-hazardous waste from households and industry." The plant continues with disposal of bags as described above because they consider "spent bags with some content of solid residue from flue gas treatment" as non-hazardous. Currently there has not been any measurement to determine if the filter bags contain hazardous substances.

Plant 2 (ARC in Copenhagen) Capacity: 440,000 tons per year

The environmental permit has recently been reassessed for this plant as well. Even though the plant is approved for treatment of several specific hazardous wastes, the permit does not comment on the disposal of spent filter bags. This plant follows a similar procedure as Plant 1 discussed above. The spent fabric filter bags are collected and wrapped in plastic bags to prevent the dispersion of dust. The bags are then transported to the waste hopper via a special waste entry intended for hospital waste.

Therefore the operation of the two WTE facilities in Denmark illustrate the practice of removing the fabric filter bags, enclosing them within plastic bags to prevent dust dispersion, and transport to the waste pit for incineration with the standard waste being processed. While the permits do not specify the protocol for managing the fabric filter bags, the implicit acceptance is important.

<u>Landfill Alternative</u>

The obvious alternative to returning the filter bags to the boiler is to transport the spent bags to a specially permitted landfill or incinerator designated to accept hazardous wastes. While the quantification of potential impacts associated with transporting used fabric filter bags to off-site hazardous waste disposal facilities was not done here, it must be recognized that transportation of hazardous wastes can pose potential risks. For example, there is a potential for an accident during transport and if the containers holding used FFB were ruptured, this could potentially expose the general public to fly ash. There would also be increased vehicle emissions associated with hauling the additional tonnage to a designated landfill or incinerator. The typical long haul transport vehicle carrying approximately 20 tons of material would emit an estimated 180 grams of PM per ton[15] transported which would be completely avoided by returning the bags to the furnace and combusting on site. Moreover the USEPA waste management hierarchy shows the preferred management methods of energy recovery to be above disposal (http://www.epa.gov/wastes/nonhaz/municipal/hierarchy.htm).

<u>Inhalation Health Risk Assessment</u>

A screening-level inhalation risk assessment was conducted in order to evaluate the potential impact of feeding used (FFB) into the waste combustion unit at a waste-to-energy (WTE) plant. The assessment focused on the potential incremental impact associated with the fly ash present on used FFB that may be fed back into the combustion unit. The chemicals addressed were cadmium, lead and mercury. The analysis was performed in general accordance with U.S. Environmental Protection Agency (USEPA) guidance for conducting inhalation risk assessments for waste combustion sources and relied on data provided previously in this white paper. A description of the health risk assessment methodology and its conclusions is provided in Appendix 3.

The screening-level health risk assessment involved calculating downwind annual average and short-term ambient air concentrations associated with FFB feed scenarios at a WTE plant and comparing these concentrations to available health-based reference air levels developed by regulatory and public health agencies. The health-based reference air levels represent concentrations in air below which adverse health effects are not expected to occur. The types of health effects addressed in the risk assessment consisted of excess lifetime cancer risks, chronic long-term non-cancer health effects and acute short-term inhalation health effects.

Two FFB disposal scenarios were addressed: a typical operation scenario, intended to reflect plausible yet conservative FFB disposal conditions at a WTE plant, and a refurbishment scenario, intended to reflect a conservative FFB disposal condition in which a complete refurbishment of one baghouse would occur during the year. Conservative assumptions were incorporated in the analysis to help ensure that risks would be likely to be overestimated and highly unlikely to be underestimated. The results of the screening-level health risk assessment were as follows:

- Excess lifetime cancer risks were calculated to range from 3.6E-12 (4 in one trillion) for the typical scenario to 6.3E-12 (6 in one trillion) for the refurbishment scenario. These excess lifetime cancer risks are more than 1.5 million times lower than USEPA's benchmark cancer risk level of 1E-5 (one in one hundred thousand).
- The results for chronic non-cancer health effects were more than 860,000 times lower (for the refurbishment scenario) and more than 1.5 million times lower (for the typical operation scenario) than the corresponding health-based reference air levels.
- The results for short-term acute inhalation effects were more than 2,700 times lower (for the refurbishment scenario) and more than 37,000 times lower (for the typical operation scenario) than the health-based reference air levels.

These results demonstrate that disposal of used fabric filter bags in combustion units at a WTE plant, under the scenarios evaluated in this analysis, would not be expected to have adverse public health impacts with a large margin of safety.

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Appendix 1: Calculation detail for emissions change for the best, worst and typical case scenarios.

WORST CASE SCENARIO				
INITIAL ASSUMPTIONS				
Typical capture efficiency		99.91%	99.91%	95% [a]
Flue gas / feed ratio	Nm³/ton	5000		
Flue gas / feed ratio	acm/ton	12326		
Normal Temperature	K	273		
Actual Temperature	K	673		
STANDARD OPERATION				
Plant Capacity	ton/year	90750		
Flue gas	acm/year	1.12E+09		
	Nm³/year	4.54E+08		
		Pb	**Cd**	**Hg**
Concentration - stack gas	µg/acm	11.43	0.89	[b]
	µg/Nm³	28.16	2.19	20
Annual flow - stack gas	kg/year	12.780	0.9949	9.075
Concentration - filter bag inlet	µg/Nm³	30331.5	2361.4	400.0
Annual flow - filter bag inlet	kg/year	13762.90	1071.47	181.50
IMPACT OF USED BAGS				
1 - Bags (without ash)				
Weight of filter bags combusted (highest)	ton/year	1.29		
Relative flue gas	Nm³/year	6464		
		0.0014%		
		Pb	Cd	Hg
Relative increase in annual flow - filter bag inlet	kg/year	0.196055	0.015263	0.002586
2 - Ash on bags				
Weight of fly ash to furnace (highest)	ton/year	3.98		
Kilograms of fly ash returned to furnace				
		Pb [c]	Cd [c]	Hg [d]
Concentration in fly ash	mg/kg	5066	410	25
Percentage that goes to fly ash		100%	100%	100%
Relative increase in annual flow - filter bag inlet	kg/year	20.17	1.63	0.10
3 - Total		Pb	Cd	Hg
Annual flow - filter bag inlet	kg/year	13783.27	1073.12	181.60
Annual flow - stack gas	kg/year	12.799	0.9965	9.080
Emissions change		**0.15%**	**0.15%**	**0.06%**

BEST CASE SCENARIO				
INITIAL ASSUMPTIONS				
Flue gas / feed ratio	Nm³/ton	5000		
Flue gas / feed ratio	acm/ton	12326		
Normal Temperature	K	273		
Actual Temperature	K	673		
STANDARD OPERATION				
Plant Capacity	ton/year	197010		
Flue gas	acm/year	2.43E+09		
	Nm³/year	9.85E+08		
		Pb	**Cd**	**Hg**
Concentration - stack gas	µg/acm	11.425	0.88946	
	µg/Nm³	28.16	2.19	20
Annual flow - stack gas	kg/year	27.74	2.16	19.70
Concentration - filter bag inlet	µg/Nm³	30331.5	2361.4	400.0
Annual flow - filter bag inlet	kg/year	29878.00	2326.06	394.02
IMPACT OF USED BAGS				
1 - Bags (without ash)				
Weight of filter bags combusted (lowest)	ton/year	1.29		
Relative flue gas	Nm³/year	6464		
		0.0007%		
		Pb	Cd	Hg
Relative increase in annual flow - filter bag inlet	kg/year	0.196055	0.015263	0.002586
2 - Ash on bags				
Weight of fly ash to furnace (lowest)	ton/year	2.73		
		Pb	Cd	Hg
Concentration in fly ash	mg/kg	5066	410	25
Percentage that goes to fly ash		100%	100%	100%
Relative increase in annual flow - filter bag inlet	kg/year	13.85	1.12	0.07
3 - Total		Pb	Cd	Hg
Annual flow - filter bag inlet	kg/year	29892.05	2327.20	394.09
Annual flow - stack gas	kg/year	27.76	2.16	19.70
Emissions change		**0.047%**	**0.049%**	**0.018%**

STANDARD OPERATION	**Typical Plant**			
Plant Capacity (nominal)	ton/year	247500		
Fly ash generated (3% of MDSW)	ton/year	7425		
Flue gas	acm/year	3050686813		
	Nm³/year	1237500000		
	0	Pb	Cd	Hg
Concentration - stack gas	µg/acm	11.43	0.89	0
	µg/Nm³	28.16	2.19	20
Annual flow - stack gas	kg/year	34.85	2.71	24.75
Concentration - filter bag inlet	µg/Nm³	30331.5	2361.4	400.0
Annual flow - filter bag inlet	kg/year	37535.18	2922.19	495.00
		Pb varies from 200-19000 [c]	Cd varies from 5-2111	Hg varies from 0.8-52
Calculated conc. of Hg in fly ash	mg/Kg ash	5051	393	63
IMPACT OF USED BAGS				
1 - Bags (without ash)				
Weight of filter bags combusted	ton/year	2.65		
Flue gas associated with combustion	Nm³/year	13268		
% Increase in process gas flow		0.0011%		
		Pb	Cd	Hg
Relative increase in annual flow - filter bag inlet	kg/year	0.4024291	0.0313299	0.0053071
2 - Ash on bags				
Weight of fly ash returned to furnace	ton/year	5.93		
Kilograms of fly ash returned to furnace		5927.61		
		Pb	Cd	Hg
Concentration of impurity in returned fly ash	mg/kg	5066	410	25
Kilograms of impurity returned to furnace	kg/year	30.03	2.43	0.15
Kilograms of impurity in MSW	kg/year	37535	2922	495.00
% Increase in impurity to Baghouse due to recycling of fly ash with filter bags	%	0.08%	0.08%	0.03%

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Appendix 2: Excerpt from Encyclopedia of Sustainability Science and Technology

Waste-to-Energy (WTE): Management of WTE ash in America

Floyd Hasselriis, Hasselriis Associates, Forest Hills, New York, U.S.A.

Table A2. Quantities of Combustion and Emission Control Residues

	Quantity of waste, 1b/100 lb waste	% of total
Combustion residue		
Bottom Ash (slag)	25.0-35.0	90
Filter dust (fly ash)	2.0-4.0	10
Total:	27.0-39.0	100
Additional residues:		
Wet Scrubber Residue	0.8-1.5	3-4
Spray-dry Scrubber residue	1.6-3.5	6-9
Dry Injection Residue	2.5-4.5	9-12

Source: Thome-Kozmiensky (1989)

Thorne-Kozmiensky, K. (1989) "Measures to Reduce Incinerator Emissions," Recycling International, p. 1009.

Also in Encyclopedia of Sust. : Juergen Vehlow, Management of WTE Ash in Europe, for dsemidry or dry scrubbing, fly ash is 2-4% of MSW

Appendix 3:

SCREENING-LEVEL HUMAN HEALTH RISK ASSESSMENT OF USED FABRIC FILTER BAG FEED INTO A WASTE TO ENERGY PLANT

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Introduction

A screening-level inhalation risk assessment was conducted in order to evaluate the potential impact of feeding used fabric filter bags (FFB) into the waste combustion unit at a waste-to-energy (WTE) plant. This analysis was performed by CPF Associates, Inc. (CPF) at the request of the American Mechanical Society of Engineers (ASME) Research Committee on Energy and the Environment and the Materials and Energy Recovery Division. CPF is an independent Maryland-based scientific and regulatory consulting firm with over 25 years' experience in evaluating the potential impacts of municipal solid waste management technologies.

The analysis was performed in general accordance with U.S. Environmental Protection Agency (USEPA) guidance for conducting inhalation risk assessments for waste combustion sources (USEPA 2005). This involved calculating downwind annual average and short-term ambient air concentrations associated with different FFB feed scenarios at a WTE plant and comparing these concentrations to available health-based reference air levels developed by regulatory and public health agencies. The health-based reference air levels represent concentrations in air below which adverse health effects are not expected to occur. This assessment focused on the potential incremental impact associated with the fly ash present on used FFB that may be fed back into the combustion unit. The chemicals selected for evaluation were those addressed in the White Paper (cadmium, lead and mercury).

Health-Based Reference Air Levels

Health-based reference air levels were compiled for each chemical from a hierarchy of data sources recommended in USEPA guidance (USEPA 2005). These reference air levels have been developed by independent regulatory or public health agencies at levels intended to ensure protection of public health, and they include values for evaluating both chronic, long-term risks as well as acute, short-term risks. The reference air levels used to evaluate chronic risks are referred to as either inhalation unit risk factors, used to predict excess lifetime cancer risks, or inhalation reference concentrations (RfCs) and reference exposure levels (RELs), used to predict the potential for long-term non-cancer effects. Acute reference air concentrations were also compiled and used to predict the potential for short-term inhalation health effects. In addition, the National Ambient Air Quality Standard (NAAQS) for lead was included as a reference air level for both long-term and short-term risk evaluation. Table 1 presents the reference air levels used in this assessment.

Table 1 Health-Based Reference Air Levels for Evaluated Chemicals (a)							
Compound	**Chronic Health-Based Levels (Annual Averages)**			**Short-Term Health Based Levels**			
	Value	**Units**	**Type of Level / Source**	**Value**	**Units**	**Averaging Time**	**Type of Level / Source**
Cadmium	2.0E-05	mg/m3	Non-Cancer Chronic REL / CALEPA	0.1	mg/m3	1 hour	AEGL-1 (interim) / USEPA
	1.8E-03	(µg/m3)$^{-1}$	Cancer Inhalation Unit Risk Factor / USEPA:IRIS				
Lead (b)	1.5E-04	mg/m3	NAAQS / USEPA	0.15	mg/m3	1 hour	PAC-1 / DOE
				1.5E-04	mg/m3	Quarterly (3-Month Average)	NAAQS / USEPA
Mercury (inorganic)	3.0E-04	mg/m3	Non-Cancer RfC / USEPA:IRIS	6.0E-04	mg/m3	1 hour	Acute REL / CALEPA

AEGL-1 = Acute exposure guideline level (level 1)
CALEPA = California Environmental Protection Agency
DOE = Department of Energy
NAAQS = US National Ambient Air Quality Standard
PAC-1 = Protective action criteria (level 1)
REL = Reference exposure level
RfC = Reference concentration

(a) Sources: CALEPA RELs (CALEPA 2013); USEPA RfC and unit risk factor (USEPA 2013a); DOE PAC-1 (DOE 2012); USEPA AEGL-1 (USEPA 2012a); USEPA NAAQS (USEPA 2012b).
(b) Neither USEPA nor CALEPA have developed a chronic reference air concentration for lead, but USEPA has recommended that the quarterly 3-month NAAQS be used as a screening level for evaluating chronic long-term exposures (USEPA 2013b). The quarterly NAAQS is also often used as a screening level for 24-hour average air concentrations. This is a conservative approach for assessing lead in air (i.e., will tend to overestimate potential risks), because modeled air concentrations for a 24-hour averaging time will be greater than those for a longer-term 3-month averaging time.

Calculation of Potential Downwind Ambient Air Concentrations

Downwind air concentrations were calculated by estimating emission rates associated with two different FFB use scenarios for each selected chemical, and then multiplying these emission rates by air dispersion modeling results.

Used Fabric Filter Bag Scenarios

Two FFB scenarios were considered in order to address a range of potential use conditions at a WTE plant. Under each scenario, the number of used FFB bags fed into the combustion unit was estimated on an annual, daily and 1-hour basis. These averaging times were selected to correspond to the averaging times for the reference air levels for cadmium, lead and mercury. Measured data on the feed rates of used FFB to WTE combustion units are limited, thus assumptions based on the data provided from four WTE plants were made in order to develop these estimates. Although there are uncertainties related to these assumptions, they provide a reasonable starting point for this evaluation, biased towards producing a conservative (i.e., health protective) estimate.

- *Typical operation scenario*: The typical operation scenario was intended to reflect plausible yet conservative FFB disposal conditions at a WTE plant. This scenario assumed that, on average, 1,033 used FFB would be fed into the combustion unit over the course of a year. This number was based on the average of the four values for number of bags used/year shown in Table 1 in the

White Paper. On an average daily basis, this could translate into roughly 3 used FFB being fed into the combustion unit. Over a 1-hour period, it was also assumed that 3 used FFB would be fed to the combustion unit.

- *Refurbishment scenario*: The refurbishment scenario was intended to reflect a conservative FFB disposal condition in which a complete refurbishment of one baghouse would occur during the year. Each baghouse at a WTE plant can contain over 1,000 bags and each is typically changed out every several years. For this analysis, it was assumed that one baghouse containing 1,800 FFB would be refurbished during one operating year. On an annual average basis, it was thus assumed that the 1,800 FFB would be fed to the combustion unit. Over a single day, it was conservatively assumed that one-fifth of the 1,800 bags changed out during a baghouse refurbishment could be fed into the combustion unit (i.e., 360 bags/day). Over a 1-hour period, it was assumed that 30 FFB could be fed into the combustion unit.

Emission Rates

Emission rates for each FFB scenario were calculated based on the number of bags assumed to be fed into the WTE plant combustion unit (described above) as well as the following additional inputs:

- the concentration of each chemical in fly ash contained in the FFB (5,066 mg/kg for lead, 410 mg/kg for cadmium and 25 mg/kg for mercury, as provided in White Paper Table 3),
- the weight of fly ash on used FFB (4.07 kg/bag, based on the average of four values provided in White Paper Table 1), and
- the removal efficiency for each chemical at the WTE plant (0.9991 for lead and cadmium, and 0.95 for mercury, as provided in White Paper Appendix 1).

The resulting emission rates calculated for the two scenarios and the different averaging times are shown in Table 2.

Table 2
Emission Rates Associated with FFB Disposal Scenarios at WTE Plant

Compound	Averaging time	Emission Rate (g/sec) (a)	
		Typical Scenario	Refurbishment Scenario
Cadmium	Annual	4.92E-08	8.57E-08
	1-hour average	1.25E-06	1.25E-05
Lead	Annual	6.08E-07	1.06E-06
	24-hour average	6.44E-07	7.73E-05
	1-hour average	1.55E-05	1.55E-04
Mercury	Annual	1.67E-07	2.90E-07
	1-hour average	4.24E-06	4.24E-05

(a) Emissions were calculated based on estimated annual, daily and hourly feed of used FFB into the WTE plant combustion unit. The averaging times addressed for each chemical correspond to the averaging times for the available health-based reference air levels.

Ambient Air Concentrations

The emission rates were multiplied by dilution factors derived from air dispersion modeling results in order to calculate maximum downwind ambient air concentrations associated with the different FFB use scenarios. The air dispersion modeling results were obtained from air quality analyses performed for several WTE facilities in the US. Specifically, maximum modeling results expressed as unitized concentrations (i.e., $\mu g/m^3$ per 1 g/sec) were compiled from air quality studies conducted over the past decade for WTE facilities in Florida, Maryland, Minnesota, Pennsylvania, Hawaii and Ontario (CDM 2005, Covanta/AMEC 2009, MPCA 2006, ENSR 2006, Jacques Whitford 2009, Malcolm Pirnie 2002, Malcolm Pirnie 2008, Malcolm Pirnie 2010). Only the maximum results for each averaging time were used, which is a conservative approach since modeling results would be lower at other locations in the WTE plant vicinities. The average of the compiled maximum unitized concentrations for each averaging time was used in conjunction with the emission rates in this screening assessment. These averages were as follows: 0.041 $\mu g/m^3$ per 1 g/sec (annual average), 0.71 $\mu g/m^3$ per 1 g/sec (24-hour average) and 3.8 $\mu g/m^3$ per 1 g/sec (1-hour average).

The resulting modeled maximum air concentrations associated with the two FFB scenarios are shown in Table 3.

Table 3.
Ambient Air Concentrations Associated with FFB Disposal at WTE Plant

Chemical	Averaging time	Air Concentration (mg/m^3)	
		Typical Scenario	Refurbishment Scenario
Cadmium	Annual	2.02E-12	3.51E-12
	1-hour average	4.76E-09	4.76E-08
Lead	Annual	2.49E-11	4.34E-11
	24-hour average	4.57E-10	5.49E-08
	1-hour average	5.88E-08	5.88E-07
Mercury	Annual	6.83E-12	1.19E-11
	1-hour average	1.61E-08	1.61E-07

Risk Assessment

Potential inhalation risks associated with the two FFB scenarios were evaluated by combining the modeled maximum air concentrations with the health-based reference air levels. Different approaches were employed to conduct this evaluation depending on the type of health effect (cancer or non-cancer) and on the averaging time (long-term or short-term).

Chronic long-term excess lifetime cancer risks

Potential excess lifetime cancer risks were calculated for cadmium, the only chemical assessed with a cancer inhalation unit risk factor. Cancer risks reflect the upper bound probability that an individual may develop cancer over a 70-year lifetime under the assumed exposure conditions. In this case, the exposure conditions assume inhalation of maximum annual average air concentrations continuously over a lifetime (i.e., 24 hours/day, 365 days/year for 70 years). The risks are referred to as "upper bound" because they are not likely to be underestimated and, in fact, may range from as low as zero to the upper bound value.

The excess lifetime cancer risk was calculated by multiplying the annual average cadmium concentration (in units of $\mu g/m^3$) by its inhalation unit risk factor (in units of $(\mu g/m^3)^{-1}$). The resulting cancer risk was evaluated relative to the USEPA combustion risk assessment guidance benchmark level of 1E-5. An additional lifetime cancer risk of 1E-5 (1 in one hundred thousand or 1 in 100,000), for example, means that an individual could have, at most, a one in 100,000 chance of developing cancer over a 70-year lifetime under the evaluated exposure conditions. In comparison, each person in the U.S. has a background risk of developing cancer over a lifetime of about one in three. The cadmium excess lifetime cancer risks were calculated to range from 3.6E-12 (4 in one trillion) for the typical scenario to 6.3E-12 (6 in one trillion) for the refurbishment scenario. These excess lifetime cancer risks are more than 1.5 million times lower than USEPA's benchmark cancer risk level of 1E-5.

Chronic long-term non-cancer health effects

The potential for long-term non-cancer health effects was assessed by calculating a hazard quotient for each chemical and comparing this result to USEPA-identified health-based benchmark HQ levels. The HQ was calculated by dividing each chemical's annual average air concentration by its corresponding long-term reference air level. The hazard quotient (HQ) values were evaluated relative to the commonly used USEPA regulatory non-cancer benchmark level of 1.0. HQ values less than 1.0 are not expected to result in adverse health effects. In addition, the HQs were also compared to the supplemental USEPA benchmark level of 0.25 which is often used for combustion source risk assessments. The resulting HQ values were more than 860,000 times lower (for the refurbishment scenario) and more than 1.5 million times lower (for the typical operation scenario) than the USEPA benchmark levels, indicating that adverse chronic non-cancer health effects would not occur under the evaluated scenarios for used FFB at a WTE plant.

Acute short-term inhalation health effects

The potential for short-term inhalation health effects was assessed for all three chemicals using available short-term reference air levels. Similar to the long-term non-cancer assessment approach, an acute hazard quotient was calculated by dividing each chemical's maximum modeled short-term air concentration (i.e., 1-hour or 24-hour average) by the corresponding acute reference air level. The acute HQ values were evaluated relative to the commonly used short-term regulatory benchmark level of 1.0 (i.e., HQs below 1.0 are not expected to result in health effects). The resulting acute HQ values were more than 2,700 times lower (for the refurbishment scenario) and more than 37,000 times lower (for the typical operation scenario) than the benchmark levels, indicating that adverse short-term acute inhalation health effects would not occur under the evaluated scenarios for used FFB at a WTE plant.

Risk Summary

A summary of the risk assessment results is shown in Table 4. This table presents the risk assessment results for cancer and non-cancer effects as well as the benchmark risk levels for human health protection. All of the calculated risk assessment results were well below the benchmark risk levels. This demonstrates that potential air impacts associated with the two FFB scenarios evaluated here will not have adverse impacts on human health.

Table 4.
Screening-Level Inhalation Risk Assessment Results

Chemical	Scenario	Excess Lifetime Cancer Risk	Hazard Quotient (HQ) for Chronic Long-Term Non-Cancer Health Effects	Hazard Quotient (HQ) for Acute Short-Term Inhalation Health Effects
Cadmium	Typical Operation Scenario	3.6E-12	1.0E-7	4.8E-8
	Refurbishment Scenario	6.3E-12	1.8E-7	4.8E-7
Lead	Typical Operation Scenario	--	1.7E-7	3.0E-7 (24-hour) 3.9E-7 (1-hour)
	Refurbishment Scenario	--	2.9E-7	3.7E-4 (24-hour) 3.9E-6 (1-hour)
Mercury	Typical Operation Scenario	--	2.3E-8	2.7E-5

	Refurbishment Scenario	--	4.0E-8	2.7E-4
Benchmark Risk Level	--	1E-5	0.25 – 1.0	1.0

-- = Not applicable.

Discussion of Uncertainties

The results of any risk assessment inherently reflect some uncertainty due to a variety of factors. In accordance with standard risk assessment practice, this section discusses some of the key uncertainties affecting this analysis. In general, uncertainties in risk assessments, including this screening-level assessment, are addressed by using conservative (i.e., health protective) assumptions which collectively are expected to produce risk results much more likely to be overestimated than underestimated.

There are four types of uncertainty generally associated with a risk assessment (USEPA 2005, Finkel 1990):

- Uncertainties in parameter values (variable uncertainty)
- Model uncertainty
- Decision-rule uncertainty
- Variations in physical and biological processes (variability)

Variable uncertainty results from complexities in assigning numerical values to input parameters used in the risk assessment. Variable uncertainty may be reduced through additional research or analysis (i.e., better data). Uncertain variables in this risk assessment include the number of used FFB fed to a combustion unit at a WTE plant, chemical concentrations and amounts of fly ash present in used FFB, WTE plant removal efficiencies, and health-based reference air levels. Although inputs related to FFB fed to a WTE plant were generally biased in a direction intended to overestimate potential risks, additional real-world data could help to reduce this uncertainty. The reference air levels used in this analysis were derived by independent regulatory and public health agencies to be protective of public health and typically include safety factors to help ensure that risks will not be underestimated.

Model uncertainty is associated with models used in the risk assessment. The types of models incorporated into this risk assessment include animal models used as surrogates for testing the human toxicity of chemicals, dose-response models used to develop reference air levels, and mathematical air dispersion models used to calculate ambient air concentrations associated with WTE plant emissions. The models used by regulatory agencies to derive reference air levels typically incorporate health-protective assumptions. The air modeling data used in this assessment were based on maximum air concentrations calculated for a number of WTE plants. The air models used to derive these concentrations have been developed and recommended by regulatory agencies, and they are widely accepted for use in assessing the potential impact of emissions to air. By relying only on maximum modeling results, this screening-level evaluation is biased towards overestimation of potential impacts. Although a site-specific modeling analysis for an individual WTE plant could produce different results, it is unlikely that the difference would be so large as to change the overall conclusions of this assessment.

Decision-rule uncertainty relates to uncertainties stemming from decisions applied in the risk assessment. Examples include the decision to evaluate cadmium, lead and mercury in this screening-level assessment and the decision to use reference air levels derived by regulatory agencies to evaluate risks. The three chemicals selected for analysis are among those typically of most concern in fly ash and are appropriate surrogates for an initial screening-level assessment. Since results for these chemicals associated with FFB use at WTE plants were well below benchmark risk levels, evaluation of additional chemicals does not appear to be warranted. The reference air levels used in this assessment, as noted above, incorporate safety factors intended to compensate for uncertainty by ensuring that risks are unlikely to be underestimated. Additionally, use of reference air levels to assess potential inhalation risks is a widely accepted and well-recognized practice in the US and worldwide.

Variability is related to variations in physical and biological processes, such as the natural differences in how much people weigh or how much air they breathe. In this assessment, single point values were used as inputs for calculating risks and, as such, this screening-level risk assessment does not reflect variability. Variable inputs could include the number of used FFB disposed at a WTE plant and the level of inhalation exposure assumed to occur to a person. On the other hand, some of the inputs used in this analysis for variable parameters were intentionally selected to reflect high-end values which would, in turn, produce risk results more likely to be overestimated than underestimated. For example, the refurbishment scenario incorporated high-end assumptions related to the number of used FFB bags that may be fed into a WTE plant combustion unit on a daily and 1-hour basis. Additionally, the inhalation exposure assumptions conservatively assumed continuous exposure to maximum potential air concentrations. When considered together, the combination of these single point values is expected to be more likely to overestimate risks than underestimate risks.

Alternative Disposal Scenarios

If used FFB were not able to be fed back into a WTE plant, one alternative disposal option could be to ship them to an off-site permitted hazardous waste landfill or hazardous waste incinerator.

In the US, the total amount of waste received from off-site sources at hazardous waste incinerators or hazardous waste landfills and surface impoundments was 549,843 tons/year and 916,764 tons/year, respectively, based on 2011 data (USEPA 2012c). Based on the data in Table 1 of the White Paper, the amount of used fabric filter bags that could require off-site shipment for disposal is roughly 540 tons/year. This value was calculated based on the average weight of the used fabric filter bags across the four plants noted in Table 1 and applying this average to all 85 WTE plants currently operating in the US (i.e., 6.4 tons/year used FFB per plant * 85 plants). This comparison shows that used FFB would, on average, account for less than 0.1% of the total quantity of hazardous waste shipped to off-site facilities in the US.

Additionally, as long as a hazardous waste disposal facility is properly permitted and operated, it is unlikely that disposal of used fabric filter bags at such a facility would present a risk to public health. In the US and Canada, hazardous waste incinerators and landfills are specifically designed and operated to be able to safely accept a wide variety of hazardous materials. These facilities must obtain and maintain numerous permits from Federal, state and local agencies in order to be allowed to operate. The permits generally include air quality, groundwater and surface water protection programs that require daily, weekly, quarterly and annual inspections, environmental monitoring, and regular submission of operating and monitoring reports to regulatory authorities.

The need to transport FFB to an off-site permitted disposal facility could, however, result in some additional impacts that would not exist if they were handled within the WTE plant. Shipment would result in potential impacts in the form of air emissions from transportation vehicles and potential increases in vehicle-related accidents, injuries and fatalities, as these risks are directly correlated to vehicle miles travelled (U.S. Department of Transportation 2013).

Conclusions

This screening-level inhalation risk assessment evaluated the potential impacts associated with disposal of used fabric filter bags in a WTE plant. Two different scenarios involving different numbers of FFB fed into the WTE plant were assessed. In general, conservative assumptions were incorporated to help ensure that risks would be likely to be overestimated and highly unlikely to be underestimated. This analysis determined that disposal of used fabric filter bags in combustion units at a WTE plant would not be expected to have adverse public health impacts with a large margin of safety.

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