2020 National Emissions Inventory Technical Support Document: Nonpoint Non-Combustion Mercury

EPA-454/R-23-001o
March 2023

2020 National Emissions Inventory Technical Support Document: Nonpoint Non-Combustion Mercury

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15.1 Sector Descriptions and Overview

This category includes the following mercury emission categories: Landfills (working face), Switches and Relays, Fluorescent Lamp Breakage, Dental Amalgam, General Laboratory Activities, Thermostats, Thermometers, Fluorescent Lamp Recycling, and Batteries. Human and animal cremation estimates include CAPs as well as mercury and are discussed in section 29 of the TSD.

These sources include a mix of EPA-generated and SLT-submitted emissions for the SCCs listed in Table 15-1. Additional descriptions of the individual types of activities are provided in the source-specific sub-sections below.

Table 15-1: SCCs and descriptions comprising the nonpoint non-combustion Hg sources in the NEI

Description	SCC	Sector	SCC Description
Landfill working face	2620030001	Waste Disposal	Landfills; Municipal; Dumping/Crushing/Spreading of New Materials (working face)
Scrap waste: Thermostats and Thermometers	2650000000	Waste Disposal	Scrap and Waste Materials; Scrap and Waste Materials; Total: All Processes
Shredding: Switches and Relays	2650000002	Waste Disposal	Scrap and Waste Materials; Scrap and Waste Materials; Shredding
Dental Amalgam Production	2850001000	Miscellaneous Non-Industrial NEC	Miscellaneous Area Sources; Health Services; Dental Alloy Production; Overall Process
Fluorescent Lamp Breakage	2861000000	Miscellaneous Non-Industrial NEC	Miscellaneous Area Sources; Fluorescent Lamp Breakage; Non-recycling Related Emissions; Total
Fluorescent Lamp Recycling	2861000010	Miscellaneous Non-Industrial NEC	Miscellaneous Area Sources; Fluorescent Lamp Breakage; Recycling Related Emissions; Total
General Laboratory Activities	2851001000	Miscellaneous Non-Industrial NEC	Miscellaneous Area Sources; Laboratories; Bench Scale Reagents; Total

15.2 EPA-developed estimates

Landfills (working face)

The EPA estimated mercury emissions for landfill working face emissions. While the amount of mercury in products placed in landfills has tended to decrease in recent years, there is still a significant amount of mercury in place at landfills across the country. There are three main pathways for mercury emissions at landfills: (1) emissions from landfill gas (LFG) systems, including flare and vented systems; (2) emissions from the working face of landfills where new waste is placed; and (3) emissions from the closed, covered portions of landfills [ref 1]. Emissions from LFG systems are considered point sources and are already included in the NEI as submissions from S/L/T agencies or from the point source dataset that gap fills these landfill emissions. Lindberg et al. (2005) [ref 1] found that emissions from the closed, covered portions of landfills are negligible and are similar to background soil emission rates. Therefore, this methodology focuses on emissions from the working face of landfills.

The calculations for estimating the emissions from landfills involve first estimating the amount of waste each landfill receives in a year. The total amount of waste in place for each landfill in a county is available from the US EPA's Landfill Methane Outreach Program (LMOP) database [ref 8]. The total amount of waste in place for each landfill is divided by the number of years a landfill is operational to estimate the amount of waste a landfill receives each year. The amount of waste that a landfill receives each year is multiplied by an average emissions factor to calculate the total mercury emissions from landfills for each county.

Switches and Relays

Switches and relays make up the largest potential source of mercury from products that intentionally contain mercury. Mercury is an excellent electrical conductor and is liquid at room temperature, making it useful in a variety of products, including switches used to indicate motion or tilt, as the mercury will flow when the switch is in a certain position, completing the circuit.

While mercury switches in cars were phased out as of the 2002 model year, there are still millions of cars on the road that contain them. The switches and relays in these cars are potential emissions sources when the cars are recycled at the end of their useful lives, which involves crushing and shredding of the car. The shredded material is then sent to an arc furnace to recycle the steel. To avoid double counting point source emissions from arc furnaces, this source category only includes an estimate of nonpoint emissions from crushing/shredding operations.

The calculations for estimating mercury emissions from switches and relays involve first estimating the number of switches unrecovered by the state by taking the difference between the total estimated number of switches available and the total switches recovered in each state. The number of unrecovered switches is then apportioned to each county based on the number of car recycling facilities from the US Census County Business Patterns data for NAICS 423930. The total amount of switches unrecovered by county is multiplied by the emissions factor for mercury to estimate mercury emissions from switches and relays.

Fluorescent Lamp Breakage/Recycling

Fluorescent lights are a potentially significant source of mercury emissions. Although each lamp contains only a small amount of mercury, which has been decreasing in recent years, the increased demand for fluorescent lamps could lead to increases in mercury emissions. Increased demand for fluorescent lamps, particularly compact fluorescents, is driven partly by the phase out of many types of incandescent bulbs from the Energy Independence and Security Act of 2007 (PL 110-140 § 321).

In addition to emissions of mercury from the breakage of fluorescent light bulbs (SCC 2861000000), there is a small amount of emissions from recycling fluorescent bulbs (SCC 2861000010).

The calculations for estimating the emissions from fluorescent lamp breakage and recycling involve first estimating the average life, in hours, of various fluorescent lamp types. Data from a Freedonia Group Industry Study on the U.S. lamp market is used to estimate the total number of lamps that are discarded or recycled. The number of bulbs recycled is calculated using a recycling rate percentage. This number is then subtracted from all bulbs discarded or recycled to determine the number of bulbs discarded. The activity data are allocated to the county-level based on the share of the population present in each county. An emissions factor is calculated using the amount of mercury available in each fluorescent bulb type. The total amount of fluorescent bulbs recycled or discarded is multiplied by the emissions factor for mercury to estimate mercury emissions from fluorescent lamp breakage and recycling.

Dental Amalgam Dental amalgam is used to fill cavities in teeth, and it is composed of approximately 45% mercury [ref 2]; however, the use of dental amalgam is declining due to the increased popularity of composite fillings for teeth [ref 3]. Nevertheless, there is still a small amount of mercury emissions from dental amalgam in restored teeth. There are two potential sources of mercury emissions from dental amalgam: emissions from the preparation of amalgam in dental offices, and emissions directly from restored teeth.

The calculations for estimating the emissions from dental amalgam include estimating emissions from both dental fillings and dental office preparation. The number of fillings by age group (for dental fillings) and the total mercury sold in dental amalgam (for dental office preparation) are allocated to the county-level based on the share of the population present in each county. The dental filling data by age group are multiplied by the percent of mercury present in dental fillings to determine the amount of mercury from dental fillings. The total amount of mercury from dental fillings and from dental office preparation are multiplied by emissions factors for mercury and summed together to estimate the total mercury emissions from dental amalgam.

General Laboratory Activities

Documentation for previous versions of the NEI have cited personal communications with USGS staff for estimates of the amount of mercury used in general laboratory activities. In discussions with Robert Virta of the USGS (2013), EPA learned that the USGS stopped conducting its survey of the end uses of mercury in the economy in 2002 [ref 4]. However, the Interstate Mercury Education and Reduction Clearinghouse (IMERC) tracks the use of mercury-added chemical products that are sold as a consistent mixture of chemicals [ref 5]. Since this trend indicates that the use of mercury-added chemical products has remained relatively consistent since 2002, the estimate of mercury emissions from general laboratory activities in the 2008 NEI is pulled forward for the 2020 NEI.

Thermostats/Thermometers

Mercury has been used in thermostats to switch on or off a heater or air conditioner based on the temperature of a room. Most of the historic production of mercury thermostats came from three corporations: Honeywell, White-Rogers, and General Electric. In 1998 these corporations formed the Thermostat Recycling Corporation (TRC), a voluntary program that attempts to collect and recycle mercury thermostats as they come out of service [ref 6].

Mercury thermometers have all but been phased out in the United States, with the USEPA and National Institute of Standards and Technology (NIST) working to phase out mercury thermometers in industrial and laboratory settings. NIST issued notice in 2011 that it would no longer calibrate mercury-in-glass thermometers for traceability purposes. EPA issued a rule in 2012 that provides flexibility to use alternatives to mercury thermometers when complying with certain regulations pertaining to petroleum refining, power generation, and PCB waste disposal. Furthermore, thirteen states have laws that limit the manufacture, sale, and/or distribution of mercury-containing fever thermometers [ref 7]. Nevertheless, given the historical prevalence of mercury thermometers, it is likely that a significant amount of mercury remains in thermometers in homes in the United States

The calculations for estimating the emissions from thermostats and thermometers involve first estimating the total number of thermostats disposed and the amount of mercury in thermometers available for release. The number of thermostats disposed and the amount of mercury in thermometers available for release are allocated to the county-level based on the share of the population present in each county. The total number of thermostats disposed and the amount of mercury in thermometers available for release are multiplied by the emissions factor for mercury and summed together to estimate mercury emissions from thermostats and thermometers.

15.2.1 Activity Data

Landfills (working face)

The U.S. EPA’s Landfill Methane Outreach Program (LMOP) maintains a database of the landfills in the United States with information on the total amount of waste in place, as well as the opening and closing years of the landfill and the county where the landfill is located [ref 8]. The average number of tons of waste each landfill receives is estimated by dividing the total waste in place by the number of years the landfill has been operating. Only landfills that were open in the NEI year are included in the analysis.

$$OP_l = 2020 - O_l \tag{1}$$

Where:

OP_l = Total number of years of operation for each landfill *l*
O_l = Year landfill *l* opened

The average number of tons of waste each landfill receives is estimated by dividing the total waste in place by the number of years the landfill has been operating.

$$W_l = \frac{WP_l}{OP_l} \quad (2)$$

Where:

W_l	=	Average tons of waste that landfill *l* receives per year
WP_l	=	Total waste in place in landfill *l*, in tons
OP_l	=	Total number of years of operation for landfill *l*

Some counties have multiple landfills, so emissions within the county are summed in these instances.

$$W_c = \sum_{l=1}^{n} W_l \quad (3)$$

Where:

W_c	=	Average tons of waste from *n* landfills in county *c*
W_l	=	Average tons of waste that landfill *l* receives per year

Switches and Relays

The End of Life Vehicle Solutions Corporation (ELVS) provides information on the estimated number of switches available for recovery in each state and the amount of switches actually recovered [ref 9, ref 10]. The state level number of switches unrecovered is calculated by taking the difference between the total estimated number of switches available and the total switches recovered in each state.

$$UnS_s = TotS_s - RecS_s \quad (4)$$

Where:

UnS_s	=	Total switches unrecovered by state *s*
$TotS_s$	=	Total switches available in state *s*
$RecS_s$	=	Total switches recovered by state *s*

Fluorescent Lamp Breakage/Recycling

Data from a Freedonia Group Industry Study on the U.S. lamp market were used to estimate the number of mercury containing lamps, including compact fluorescents (CFLs), linear, and high impact discharge (HID) lamps, that were discarded or recycled [ref 11]. Bulb sales for 2002, 2007, 2012 and projections for 2020 were obtained from Freedonia; sales for all other years were calculated by extrapolating data. Average rated life (hours) of lamp types is used to calculate lifetimes (years), assuming that CFLs are on for 4 hours per day and all other fluorescents and HIDs are on for 8 hours per day [ref 12, ref 13]. The lifetime data are used to estimate the year in which bulbs that are discarded or recycled in the NEI year would have been purchased.

$$TotB = \sum_b PB_b \quad \text{(FL1)}$$

Where:

TotB	=	Total number of bulbs discarded and recycled, in million units
PB_b	=	Total number of bulb *type b* purchased

According to a 2010 study by Silveira and Chang, the recycling rate for mercury containing lamps in the U.S. is 23% [ref 14].

For fluorescent bulbs recycled:

$$RecB = TotB \times RR \quad \text{(FL2)}$$

Where:

RecB	=	Total number of bulbs recycled, in million units
TotB	=	Total number of bulbs discarded and recycled, in million units
RR	=	Recycling rate for mercury containing lamps in the US

For fluorescent bulbs discarded:

$$DiscB = TotB - RecB \quad \text{(FL3)}$$

Where:

RecB	=	Total number of bulbs recycled, in million units
TotB	=	Total number of bulbs discarded and recycled, in million units
RR	=	Recycling rate for mercury containing lamps in the US

Dental Amalgam

According to a NEWMOA's IMERC factsheet (2015) [ref 15], the amount of mercury in dental amalgam was estimated to be 15.97 tons (31,940 lbs.) in 2013.

The amount of mercury emissions from restored teeth is estimated using data from the National Institutes of Health's National Institute of Dental and Craniofacial Research, which provides estimates of the average number of filled teeth per person, from the CDC National Health and Nutrition Examination Survey (NHANES), in nine different age brackets: 2-5 years, 6-11 years, 12-15 years, 16-19 years, 20-34 years, 35-49 years, 50-64 years, 65-74 years, and 75 and up [ref 16]. The filling data for the age groups 6-11 years, 12-15 years, and 16-19 years are averaged together as are the filling data for the age groups 65-74 years and 75 and up to match the U.S. Census age category, 5-19 and 65 and up. Table 15-2 lists the average number of filled teeth per person by age group.

Table 15-2: Average number of filled teeth per person and percentage of fillings containing mercury by age group

Age Group	Average Number of Filled Teeth Per Person	Percentage of Fillings Containing Mercury
0–4	0.47	15.8%
5–19	1.756	31.6%
20–34	4.61	40.8%
35–49	7.78	50%
50–64	9.20	62.5%
65+	8.69	75.0%

According to the American Dental Association (ADA 1998) more than 75% of restorations before the 1970s used amalgam, which declined to 50% by 1991 [ref 17]. Using these numbers, it is assumed that 40.8% of the filled teeth for 20-34 age group contain amalgam, 50% of filled teeth in the 35-49 age group, 62.5% of filled teeth in the 50-64 age group, and 75% of filled teeth for people over 65. The BAAQMD memorandum is used to estimate that 31.6% of filled teeth in the 1-19 age group contain amalgam. The Food and Drug Administration has discouraged the use of dental amalgam in children under 6 [ref 18]. While EPA does not have data on the percent of fillings containing dental amalgam for the 0-4 age group, it is assumed that the percentage of fillings containing mercury in this age group is approximately half that of the overall under 20 age group.

Thermostats/Thermometers

A 2002 EPA report estimated that 2-3 million thermostats came out of service in 1994 [ref 19]. A 2013 report from a consortium of environmental groups, which assumed that the estimate from the 2002 EPA report remained viable, estimated that the TRC collects at most 8% of the retired thermostats each year [ref 20]. A literature search revealed no new data that could be used to estimate the number of thermostats coming out of service. Therefore, using this estimate, there are approximately 2.3 million thermostats that are not recycled each year.

$$DispTs = RemTs \times (1 - 0.08) \quad \text{(T1)}$$

Where:

DispTs = Total thermostats disposed
RemTs = Total thermostats removed from service

Data from a NEWMOA's IMERC factsheet suggests that there were 546 lbs. of mercury used in thermometers in 2013 [ref 21]. Using past NEWMOA IMERC thermometer data we forecasted the values for mercury in 2014-2017. Due to a lack of additional data on the amount of mercury used in thermometers, the calculations described below for 2017 were pulled forward for 2020.

The US EPA assumes that the average lifespan of a glass thermometer is 5 years, and that 5% of glass thermometers are broken each year [ref 19]. Therefore, using the pounds of mercury available in thermometers each year there would be an estimated 2,345 pounds of mercury remaining in thermometers in 2017 (accounting for the breakage rate each year). The following equation calculates the total amount of mercury remaining in thermometers for each year during the lifespan of the thermometer. To calculate the value at the 5-year lifespan mark, the following equation (equation T2) needs to be used to calculate the value for years 2 through 5, with each year building upon the previous year (i.e., the calculation needs to be conducted for all years to find the final year 5 data). See Section 15.2.5 for detailed calculations on how to arrive at the final number.

$$HgTm_n = (HgTm_{n-1} \times 95\%) + HgTmSold_n \quad \text{(T2)}$$

Where:

$HgTm_n$ = Amount of mercury remaining in thermometers in year *n*, in pounds
$HgTm_{n-1}$ = Amount of mercury remaining in thermometers in the year prior to year *n*, in pounds
$HgTmSold_n$ = Amount of mercury in thermometers in year 1, in pounds
n = Year

King et al. (2008) [ref 22] estimate that during the period 2000-2006 there were 350 lbs. of mercury from thermometers collected in recycling programs.

Subtracting the amount of mercury removed due to thermometers being collected in recycling programs from the total amount of mercury remaining in thermometers in 2017 estimates the total amount of mercury in thermometer available for release, in tons. Therefore, there were 1,995 lbs. (0.99 tons) of mercury available for release in 2017. As discussed above, due to a lack of updated data on mercury use in thermometers, the amount of mercury calculated for 2017 was pulled forward for 2020.

$$HgTRl = (HgTm_5 - HgTRm) \times \frac{1\ ton}{2{,}000\ lbs.} \quad \text{(T3)}$$

Where:

$HgTRl$ = Amount of mercury in thermometers available for release, in tons
$HgTm_5$ = Amount of mercury remaining in thermometers in year 5, the lifespan of a thermometer, in pounds
$HgTRm$ = Amount of mercury removed in thermometer collections, in pounds

15.2.2 Allocation procedure

Landfills (working face)

The EPA LMOP database provides data at the county level; therefore, no allocation procedure is needed for this source.

Switches and Relays

The number of unrecovered switches is apportioned to each county based on the number of car recycling facilities. The number of car recycling facilities is estimated using establishment data for recyclable material merchant wholesalers (NAICS 423930) from the U.S. Census Bureau's 2020 County Business Patterns (CBP) [ref 23].

The number of car recycling facilities by county from the US Census County Business Patterns data is first summed to the state level.

$$F_s = \sum_c F_c \quad \text{(SR2)}$$

Where:

F_s	=	Total car recycling facilities in state *s*
F_c	=	Total car recycling facilities in county *c*

The share of state car recycling facilities by county is calculated by taking the total number of car recycling facilities in a given county by the total number of car recycling facilities in the state.

$$FracF_c = \frac{F_c}{F_s} \quad \text{(SR3)}$$

Where:

$FracF_c$	=	Total fraction of state car recycling facilities in county *c*
F_c	=	Total car recycling facilities in county *c*
F_s	=	Total car recycling facilities in state *s*

The share of unrecovered switches by county is calculated using the state number of unrecovered switches and the total share of state car recycling facilities by county, calculated above.

$$UnS_c = UnS_s \times FracF_c \quad \text{(SR4)}$$

Where:

UnS_c	=	Total switches unrecovered in county *c*
UnS_s	=	Total switches unrecovered in state *s*
$FracF_c$	=	Total share of state car recycling facilities in county *c*

Fluorescent Lamp Breakage/Recycling

The national-level mercury emissions from fluorescent lamp breakage are allocated to each county based on population.

$$FracP_c = \frac{P_c}{P_{US}} \quad \text{(FL4)}$$

Where:

Frac$P_{c,}$	=	Fraction of total US population in county *c*
P_c	=	Population in county *c*
P_{US}	=	Population in the US

The fraction of total US population in a county is multiplied by the national data for fluorescent bulbs recycled or discarded to calculate the number of fluorescent bulbs recycled or discarded at the county-level.

For fluorescent bulbs discarded:

$$DiscB_c = FracP_c \times DiscB \tag{FL5}$$

Where:

$DiscB_c$	=	Total number of bulbs discarded in county *c*, in million units
$FracP_c$	=	Fraction of total US population in county *c*
DiscB	=	Total number of bulbs discarded in the US, in million units

For fluorescent bulbs recycled:

$$RecB_c = FracP_c \times RecB \tag{FL6}$$

Where:

$RecB_c$	=	Total number of bulbs recycled in county *c*, in million units
$FracP_c$	=	Fraction of total US population in county *c*
RecB	=	Total number of bulbs recycled in the US, in million units

Dental Amalgam

The amount of mercury from dental office preparations, based on the amount of mercury in dental amalgam from NEWMOA's IMERC factsheet [ref 15], are allocated to the county level based on population.

$$FracP_c = \frac{P_c}{P_{US}} \tag{DA1}$$

Where:

$FracP_c$	=	Fraction of total US population in county *c*
P_c	=	Total population in county *c*
P_{US}	=	Total population for the United States

The county-level population fraction is multiplied by the amount of mercury sold for dental amalgam to calculate the total mercury from dental office preparations by county.

$$HgO_c = FracP_c \times HgDA \tag{DA2}$$

Where:

HgO_c	=	Total mercury from dental office preparations in county *c*, in pounds

$FracP_c$	=	Fraction of total US population in county *c*
$HgDA$	=	Total mercury sold for dental amalgam in the US, in pounds

The emissions from filled teeth are allocated to each county by multiplying the county population by the proportion of the national population in each age group, the average number of filled teeth per person, and the fraction of fillings containing mercury (Table 15-3; fraction = percentage/100). The age groups listed in Table 15-3, hereafter referred to as filling groups, are different than official US census bureau age groups; therefore, national fractions of each US census bureau age group were calculated, summed, and multiplied by county level population to estimate the county level population for each filling group. Table 15-3 shows how the US Census age groups correspond to each filling group.

Table 15-3: US Census age groups and filling groups

US Census Age Group	Corresponding Filling Age Group
Under 5	0–4
5–9	5–19
10–14	
15–19	
20–24	20–34
25–29	
30–34	
35–39	35–49
40–44	
45–49	
50–54	50–64
55–59	
60–64	
65–69	65+
70–74	
75–79	
80–84	
85 and up	

First, the share of total population each US Census age group represents to the entire US population is calculated.

$$FracP_a = \frac{P_a}{P_{US}} \quad \text{(DA3)}$$

Where:

$FracP_a$	=	Fraction of the total US population in Census Bureau age group *a*
P_a	=	Total population in Census Bureau age group *a*
P_{US}	=	Total population for the United States

The fraction of the population for each US Census age group is then summed to match the filling groups.

$$FracP_{fg} = \sum_{a} FracP_{a} \quad \text{(DA4)}$$

Where:

$FracP_{fg}$ = Fraction of the total US population in filling group *fg*
$FracP_{a,}$ = Fraction of the total US population in census bureau age group *a*, where age group *a* falls within filling group *fg*

The fraction of population for each filling group is multiplied by the county-level population data to get the total population for each filling group.

$$P_{fg,c} = FracP_{fg} \times P_{c} \quad \text{(DA5)}$$

Where:

$P_{fg,c}$ = Total population in filling group *fg* in county *c*
$FracP_{fg}$ = Fraction of the total US population in filling group *fg*
P_{c} = Total population in county *c*

The filling group county-level population is multiplied by the average number of fillings per person in each filling group to determine the total number of fillings in each filling group in each county.

$$F_{fg,c} = P_{fg,c} \times F_{fg} \quad \text{(DA6)}$$

Where:

$F_{fg,c}$ = Total fillings in filling group *fg* in county *c*
$P_{fg,c}$ = Total population in filling group *fg* in county *c*
F_{fg} = Average number of fillings per person in filling group *fg*

The total fillings in each filling group is then multiplied by the fraction of fillings that contain mercury in each filling group to determine the total number of fillings by filling group in each county.

$$HgF_{fg,c} = F_{fg,c} \times FracHgF_{fg} \quad \text{(DA7)}$$

Where:

$HgF_{fg,c}$ = Total fillings containing mercury in filling group *fg* in county *c*
$F_{fg,c}$ = Total fillings in filling group *fg* in county *c*
$FracHgF_{fg}$ = Fraction of fillings containing mercury in filling group *fg*

Thermostats/Thermometers

The national-level mercury emissions from thermostats and thermometers are allocated to the county level based on population.

$$FracP_c = \frac{P_c}{P_{US}} \quad \text{(T1)}$$

Where:

$FracP_c$	=	Fraction of total US population in county *c*
P_c	=	Total population in county *c*
P_{US}	=	Total population for the United States

The fraction of the US population in the county is multiplied by the national data for thermostats and thermometers to calculate the number of thermostats disposed and the amount of mercury in thermometers available for release at the county-level.

For thermostats:

$$DispTs_c = FracP_c \times DispTs \quad \text{(T2)}$$

Where:

$DispTs_c$	=	Total thermostats disposed of in county *c*
$FracP_c$	=	Fraction of total US population in county *c*
DispTs	=	Total thermostats disposed of in the US

For thermometers:

$$HgTm_c = FracP_c \times HgTmRl \quad \text{(T3)}$$

Where:

$HgTm_c$	=	Amount of mercury in thermometers available for release in county *c*, in pounds
$FracP_c$	=	Fraction of total US population in county *c*
Hg*TmRl*	=	Amount of mercury in thermometers available for release in the US, in tons

15.2.3 Emission factors

<u>Landfills (working face)</u>

The emissions factor for mercury from landfills was developed using an average of mercury emissions factors for the working face of landfills from two different studies [ref 1, ref 24].

Lindberg et al. (2005) [ref 1] measured mercury emissions from the working face of four landfills in Florida and determined an average emissions factor of 2.5 mg/ton of waste, or 5.51×10^{-6} lbs./ton of waste placed in a landfill annually. Babineau et al. (2016) [ref 24] determined that the average mercury content of municipal solid waste (MSW) in Minnesota is 0.00175 lbs./ton[1]. It is assumed that 0.1% of mercury from MSW in landfills is volatized to the air, so the emissions factor from Babineau et al. [ref 24] is estimated to be 1.75×10^{-6} lbs./ton of waste. The emissions factors are available in the "Wagon Wheel Emission Factor Compendium" on the 2020 NEI Supporting Data and Summaries site.

Switches and Relays

The response to comments for the 2007 EPA Significant New Use Rule on Mercury Switches (72 Fed. Reg. 56903), suggests that the weighted average amount of mercury in switches is 1.2 grams (0.0026 lbs.) [ref 25]. A report by Griffith et al. (2001) [ref 26] shows that 60% of mercury in switches is released at the shredding operation, while 40% is sent to arc furnaces for smelting. Therefore, the emissions factor for switches is 60% of the emissions factor reported in the 2007 EPA Significant New Use Rule on Mercury Switches response to comment document. Emission factors for this source is provided in the "Wagon Wheel Emission Factor Compendium" on the 2020 NEI Supporting Data and Summaries site

Fluorescent Lamp Breakage/Recycling

The average amount of mercury in a CFL has been studied extensively, with the amount of mercury in each CFL commonly reported as 1.27–4.0 mg (2.63 mg average, Table 15-4). Linear fluorescent bulbs contain more mercury than CFLs, with a range of 8.3 to 12 mg per bulb (10.15 average, Table 15-5). Data from the USGS suggests that there is an average of 17 mg of mercury per HID bulb [ref 27].

Table 15-4: Mercury used in CFLs (mg/bulb) as determined by three different studies

Study	Average Amount of Mercury per CFL (mg)	Source
Li and Jin (2011)	1.27	[ref 28]
Arendt and Katers (2013)	4.00*	[ref 29]
Singhvi et al. (2011)	2.63	[ref 30]
Average	**2.63**	--

*Adjusted from 4.5 mg to 4 mg due to increased market penetration of Energy Star CFLs with a lower Hg content.

Table 15-5: Mercury used in linear fluorescent bulbs (mg/bulb) as determined by two different studies

Study	Average Amount of Mercury per Linear Fluorescent Bulb (mg)	Source
Aucott et al. (2004)	12.0	[ref 31]
NEMA (2005)	8.3	[ref 32]
Average	**10.2**	--

[1] The average Hg content of MSW in Minnesota listed in the reference document as 0.87 parts per million (ppm). A conversion factor of 0.002 is used to convert from ppm to lbs./ton – resulting in an average Hg content of 0.00175 lbs./ton.

Cain et. al (2007) [ref 33] provides the most comprehensive materials flow analysis of mercury intentionally used in products. Their analysis estimates that 10% of all mercury used in fluorescent light bulbs is eventually released to the atmosphere after production and before disposal, with the majority being released during transport to the disposal facility.

The emissions factor for CFL, linear, and HID bulbs are calculated by multiplying the average amount of mercury per bulb discussed above by 10%.

$$EF_{b,p} = Hg_b \times 0.10 \tag{FL4}$$

Where:

$EF_{b,p}$ = Emissions factor by bulb *b* for pollutant *p*, in mg/bulb
Hg_b = Average mercury content per bulb *b*, in mg

The emissions factors for all three bulb types can be found in Table 15-6 and are also provided in the "Wagon Wheel Emission Factor Compendium" on the 2020 NEI Supporting Data and Summaries site

Table 15-6: Mercury emissions factors for CFLs, linear fluorescents and HIDs

Bulb type	Pollutant	Pollutant Code	Emissions Factor	Emissions Factor Units
CFL	Mercury	7439976	0.263	mg/bulb
Linear	Mercury	7439976	1.015	mg/bulb
HID	Mercury	7439976	1.7	mg/bulb

A weighted average of all three emissions factors is calculated to estimate total emissions from all fluorescent lamp breakage. The first step estimates the fraction each bulb represents of the total amount of bulbs discarded and recycled.

$$FracTotB_b = \frac{PB_b}{TotB} \tag{FL5}$$

Where:

$FracTotB_b$ = Fraction of bulb type *b* discarded and recycled
PB_b = Total number of bulb type *b* discarded and recycled, in million bulbs
$TotB$ = Total number of bulbs discarded and recycled in the US, in million bulbs

A weighted emissions factor for fluorescent lamp breakage is then calculated by multiplying the fraction the bulb type represents of the total number of bulbs by the bulb type-specific emissions factor.

$$EF_{br,p} = \left(\sum\nolimits_b EF_{b,p} \times FracTotB_b\right) \times \left(2.2 \times 10^{-6} \frac{lbs.}{mg}\right) \tag{FL6}$$

Where:

$EF_{br,p}$ = Weighted emissions factor for pollutant *p* for fluorescent bulb breakage, *br*, in lbs./bulb
$EF_{b,p}$ = Emissions factor for bulb type *b* and pollutant *p*, in mg/bulb (see Table 15-6)
$FracTotB_b$ = Fraction of the number of bulb type *b* discarded and recycled

Dental Amalgam

US EPA (1997) estimates that 2% of mercury used in dental offices is emitted to the air [ref 34].

Richardson et al. (2011) [ref 35] estimate emissions from filled teeth of approximately 0.3 µg/day of mercury per filled tooth, or 2.4×10^{-7} lbs. per year per filled tooth. The emissions factors used for estimating mercury emissions from dental amalgam are provided in the "Wagon Wheel Emission Factor Compendium" on the 2020 NEI Supporting Data and Summaries site.

Thermostats/Thermometers

The 2002 EPA report estimates that there are 3 grams of mercury per thermostat [ref 19]. Cain et al. (2007) [ref 33] estimate that 1.5% of mercury in "control devices," including thermostats, is emitted to the air before it is disposed of at a landfill or incinerator. Therefore, the amount of mercury emitted is 0.045 grams per thermostat, or 9.92×10^{-5} lbs. per thermostat [ref 28].

Leopold (2002) [ref 19] estimates that 5% of thermometers are broken each year. EPA assumes that the remaining 95% of thermometers that are not broken are still in use and therefore do not contribute to emissions. Cain et al. (2007) [ref 33] estimate that 10% of mercury from thermometers is emitted to the air before disposal in a landfill Therefore the emissions factor is estimated to be 10 lbs. of mercury emissions per ton of mercury in thermometers.

The emissions factors used for estimating mercury emissions from thermostats and thermometers are provided in the "Wagon Wheel Emission Factor Compendium" on the 2020 NEI Supporting Data and Summaries site.

15.2.4 Controls

There are no controls assumed for these sources.

15.2.5 Emissions

Landfills (working face)

The total mercury emissions from landfills, in pounds, is estimated by multiplying the average tons of waste that each landfill receives per year by the average emissions factor. The emissions are reported at the county level for the county that the landfill is located in.

$$E_{p,c} = W_c \times EF_p \quad (1)$$

Where:

$E_{p,c}$ = Annual emissions of pollutant *p* in county *c*, in lbs.
W_c = Average tons of waste from all landfills in county *c*

EF_p = Average emissions factor for pollutant *p*, in lbs./ton

Switches and Relays

The total county-level mercury emissions from switches and relays, in pounds, is estimated by multiplying the total switches unrecovered for each county by the emissions factor.

$$E_{s,p,c} = UnS_c \times EF_{s,p} \qquad \text{(SR5)}$$

Where:

$E_{s,p,c}$ = Annual emissions of pollutant *p* in county *c* from switches and relays, *s*, in lbs.
UnS_c = Total switches unrecovered by county *c*
$EF_{s,p}$ = Emissions factor for pollutant *p* for switches and relays, *s*, in lbs./switch

Fluorescent Lamp Breakage/Recycling

The total county-level mercury emissions for fluorescent lamp breakage and recycling, in pounds, is estimated by multiplying the total fluorescent lamps broken or recycled for each county by the emissions factor.

For fluorescent lamp breakage:

$$E_{br,p,c} = (DiscB_c \times 1{,}000\ units) \times EF_{br,p} \qquad \text{(FL4)}$$

Where:

$E_{br,p,c}$ = Annual emissions of pollutant *p* from fluorescent bulb breakage, *br*, by county *c*, in lbs.
$DiscB_c$ = Total number of bulbs discarded for county *c*, in million units
$EF_{br,p}$ = Weighted emissions factor for pollutant *p* for fluorescent bulb breakage, *br*, in lbs./bulb

For fluorescent lamp recycling:

$$E_{r,p,c} = (RecB_c \times 1{,}000\ units) \times EF_{r,p} \qquad \text{(FL5)}$$

Where:

$E_{r,p,c}$ = Annual emissions of pollutant *p* from fluorescent lamp recycling, *r*, by county *c*, in lbs.
$RecB_c$ = Total number of bulbs recycled for county *c*, in million bulbs
$EF_{r,p}$ = Weighted emissions factor for pollutant *p* for fluorescent bulb recycling, *r*, in lbs./bulb

Dental Amalgam

The total county-level mercury emissions for dental amalgam from fillings, in pounds, is estimated by multiplying the total number of fillings containing mercury for each county by the emissions factor.

$$E_{f,p,c} = \sum_{fg} HgF_{fg,c} \times EF_{f,p} \tag{DA7}$$

Where:

$E_{f,p,c}$ = Annual emissions of pollutant *p* from dental fillings, *f*, by county *c*, in lbs.
$HgF_{fg,c}$ = Total fillings containing mercury in filling group *fg* in county *c*
$Ef_{f,p}$ = Emissions factor for pollutant *p* from dental fillings, *f*, in lbs./tooth filled

The total county-level mercury emissions for dental office preparation, in pounds, is estimated by multiplying the total pounds mercury from dental office preparations for each county by the emissions factor.

$$E_{o,p,c} = HgO_c \times EF_{o,p} \tag{DA8}$$

Where:

$E_{o,p,c}$ = Annual emissions of pollutant *p* from dental office preparations, *o*, by county *c*, in lbs.
HgO_c = Total mercury from dental office preparations by county *c*, by pounds
$EF_{o,p}$ = Emissions factor for pollutant *p* for dental office preparations, *o*, by lbs./lb.

The emissions from dental fillings and dental office preparations are summed to get the total mercury emissions from dental amalgam.

$$E_{da,p,c} = E_{f,p,c} + E_{o,p,c} \tag{DA9}$$

Where:

$E_{da,p,c}$ = Annual emissions of pollutant *p* from total dental amalgam, *da*, by county *c*, in lbs.
$E_{f,p,c}$ = Annual emissions of pollutant *p* from dental fillings, *f*, by county *c*, in lbs.
$E_{OP,p,c}$ = Annual emissions of pollutant *p* from dental office preparations , *o*, by county *c*, in lbs.

Thermostats/Thermometers

The total county-level mercury emissions for thermostats, in pounds, is estimated by multiplying the total number of thermostats disposed in each county by the emissions factor.

$$E_{ts,p,c} = DispTs_c \times EF_{ts,p} \tag{T1}$$

Where:

$E_{ts,p,c}$ = Annual emissions of pollutant *p* for thermostats in county *c*, in lbs.
$DispTs_c$ = Total thermostats disposed in county *c*
$Ef_{ts,p}$ = Emissions factor for pollutant *p* for thermostats, *ts*, in lbs./thermostat

The total county-level mercury emissions for thermometers, in pounds, is estimated by multiplying the total amount of mercury remaining in thermometers over their lifespan for each county by the emissions factor.

$$E_{t,p,c} = HgTm_c \times EF_{t,p} \quad \text{(T2)}$$

Where:

$E_{t,p,c}$ = Annual emissions of pollutant *p* for thermometers in county *c*, in lbs.
$HgTm_c$ = Amount of mercury remaining in thermometers over their lifespan in county *c*, in lbs.
$EF_{t,p}$ = Emissions factor for pollutant *p* for thermometers, in lbs./ton

The emissions from thermostats and thermometers are summed to get the total mercury emissions.

$$E_{tt,p.c} = E_{ts,p,c} + E_{t,p,c} \quad \text{(T3)}$$

Where:

$E_{tt,p,c}$ = Annual emissions of pollutant *p* for thermostats and thermometers in county *c*, in lbs.
$E_{ts,p,c}$ = Annual emissions of pollutant *p* for thermostats in county *c*, in lbs.
$E_{tm,p,c}$ = Annual emissions of pollutant *p* for thermometers in county *c*, in lbs.

15.2.6 Example calculations

Landfills (working face)

Table 15-7 lists sample calculations to determine the mercury emissions from a landfill. In this example the county only has one landfill, so equation 3 is only including this one value. The values in these equations are demonstrating program logic and are not representative of any specific NEI year or county.

Table 15-7: Sample calculations for mercury emissions from landfills

Eq. #	Equation	Values	Result
1	$OP_l = 2017 - O_l$	$2017 - 1979$	38 years that the landfill will be open
2	$W_l = \frac{WP_l}{OP_l}$	$\frac{4{,}845{,}027\ tons}{38\ years}$	127,501 average tons of waste per year for the landfill
3	$W_c = \sum_c W_l$	N/A; there is only one landfill in the county	111,191 average tons of waste per year for the county
4	$E_{p,c} = W_c \times EF_{p,}$	$127{,}501\ tons\ \times (3.63 \times 10^{-6})\ \frac{lbs.}{tons}$	0.46 pounds of mercury for the county

Switches and Relays

Table 15-8 lists sample calculations to estimate the mercury emissions from switches and relays. The values in these equations are demonstrating program logic and are not representative of any specific NEI year or county.

Table 15-8: Sample calculations for mercury emissions from switches and relays

Eq. #	Equation	Values	Result
1	$UnS_s = TotS_s - RecS_s$	$22{,}000\ switches\ available\ - 618\ switches\ recovered$	21,382 unrecovered switches in the state
2	$F_s = \sum_{cs} F_c$	$\sum All\ facilities\ in\ Connecticut$	85 car recycling facilities in the state
3	$FracF_c = \frac{F_c}{F_s}$	$\frac{18\ facilities\ in\ the\ county}{85\ facilities\ in\ the\ state}$	0.2118 share of state car recycling facilities in the county
4	$UnS_c = UnS_s \times FracF_c$	$21{,}382\ unrecovered\ switches \times 0.2118\ share\ of\ state\ facilities$	4,528 unrecovered switches in the county
5	$E_{s,p,c} = UnS_c \times EF_{s,p}$	$4{,}528\ switches\ \times\ 0.00156 \frac{lbs.}{switch}$	7.06 pounds of mercury from switches and relays in the county

Fluorescent Lamp Breakage/Recycling

Table 15-9 lists sample calculations to estimate the mercury emissions from fluorescent lamp breakage. The values in these equations are demonstrating program logic and are not representative of any specific NEI year or county.

Table 15-9: Sample calculations for mercury emissions from fluorescent lamp breakage

Eq. #	Equation	Values	Result
1	$TotB = \sum_b PB_b$	$\sum all\ bulbs\ recycled\ or\ discarded$	1,485 million bulbs discarded and recycled in the US
2	$RecB = TotB \times RR$	$1{,}485\ million\ recycled\ and\ discarded\ bulbs\ \times 23\%\ recycling\ rate$	341 million bulbs recycled in the US
3	$DiscB = TotB - RecB$	$1{,}485\ million\ recycled\ and\ discarded\ bulbs - 341\ million\ recycled\ bulbs$	1,143 million bulbs discarded in the US
4	$FracP_c = \frac{P_c}{P_{US}}$	$\frac{895{,}388\ people\ in\ the\ county}{318{,}857{,}056\ people\ in\ the\ US}$	0.272% of total US population is in the county
5	$DiscB_c = FracP_c \times DiscB$	$0.00272 \times 1{,}143\ million\ bulbs$	3.109 million fluorescent bulbs discarded in the county
6	$RecB_c = FracP_c \times RecB$	$0.00272\ \times 341\ million\ bulbs$	0.928 million fluorescent bulbs recycled in the county
7	$EF_{b,p} = Hg_b \times 0.10$	$CFL: 2.63\ mg\ Hg\ \times 10\%$ $Linear: 10.2\ mg\ Hg\ x\ 10\%$ $HID: 17\ mg\ Hg\ x\ 10\%$	0.263 mg Hg/CFL bulb 1.02 mg Hg/linear bulb 1.7 mg Hg/HID bulb
8	$FracTotB_b = \frac{PB_b}{TotB}$	$CFL: \frac{722\ million\ CFL\ bulbs}{1{,}485\ million\ bulbs\ total}$ $Linear: \frac{583\ million\ Linear\ bulbs}{1{,}485\ million\ bulbs\ total}$ $HID: \frac{180\ million\ HID\ bulbs}{1{,}485\ million\ bulbs\ total}$	48.6% of total for CFL 39.2% of total for Linear 12.1% of total for HID

Eq. #	Equation	Values	Result
9	$EF_{br,p} = \left(\sum_b EF_{b,p} \times FracTotB_b\right) \times \left(2.2 \times 10^{-6} \frac{lbs.}{mg}\right)$	$\left(\left(0.263 \frac{mg}{bulb} \times 48.6\%\right) + \left(1.02 \frac{mg}{bulb} \times 39.2\%\right) + \left(1.7 \frac{mg}{bulb} \times 12.1\%\right)\right) \times \left(2.2 \times 10^{-6} \frac{lbs.}{mg}\right)$	1.61 x 10^{-6} lbs. Hg/bulb weighted emissions factor for mercury for fluorescent lamp breakage
10	$E_{br,p,c} = (DiscB_c) \times EF_{br,p}$	$3{,}109{,}617\ bulbs \times \left(1.61 \times 10^{-6} \frac{lbs.Hg}{bulb}\right)$	5.0 lbs. of mercury from fluorescent lamp breakage in the county
11	$E_{r,p,c} = (RecB_c) \times EF_{r,p}$	$928{,}846\ bulbs \times \left(1.94 \times 10^{-9} \frac{lbs.Hg}{bulb}\right)$	1.8 x 10^{-4} lbs. of mercury from fluorescent lamp recycling in the county

Dental Amalgam

Table 15-10 lists sample calculations to determine the mercury emissions from dental amalgam. The example will show the process for the 5-19 age group, with the total sum of emissions in the final step. The values in these equations are demonstrating program logic and are not representative of any specific NEI year or county.

Table 15-10: Sample calculations for mercury emissions from dental amalgam

Eq. #	Equation	Values	Result
1	$FracP_c = \frac{P_c}{P_{US}}$	$\frac{895{,}338\ people\ in\ the\ county}{329{,}164{,}967\ people\ in\ the\ US}$	0.272% of total US population is in the county
2	$HgO_c = FracP_c \times HgDA$	$0.272\% \times 31{,}940$ lbs.	86.88 lbs. total mercury from dental office preparations in the county

Eq. #	Equation	Values	Result
3	$FracP_a = \frac{P_a}{P_{US}}$	5 to 9: $\frac{20{,}304{,}238\ people, 5\ to\ 9\ age\ group}{325{,}719{,}178\ people\ in\ the\ US}$ 10 to 14: $\frac{20{,}778{,}454\ people, 10\ to\ 14\ age\ group}{325{,}719{,}178\ people\ in\ the\ US}$ 15 to 19: $\frac{21{,}131{,}660\ people, 14\ to\ 19\ age\ group}{325{,}719{,}178\ people\ in\ the\ US}$	6.23% of total US population for 5-9 age group 6.38% of total US population for 10-14 age group 6.49% of total US population for 14-19 age group
4	$FracP_{fg} = \sum_a FracP_a$	$\sum 6.23\% + 6.38\% + 6.49\%$	19.1006% of total US population for 5-19 age group
5	$P_{fg,c} = FracP_{fg} \times P_c$	$19.1006\% \times 895{,}338\ people\ in\ Hartford\ County, CT$	171,025 people in the 5-19 age group in the county
6	$F_{fg,c} = P_{fg,c} \times F_{fg}$	$171{,}025\ people\ 5-19\ in\ the\ county \times 1.756\ fillings, 5-19\ age\ group$	300,433 fillings in the 5-19 age group in the county
7	$HgF_{fg,c} = F_{fg,c} \times FracHgF_{fg}$	$300{,}433\ fillings, 5-19\ age\ group \times 31.6\%$	94,936 total fillings containing mercury in the 5-19 age group in the county

Eq. #	Equation	Values	Result
8	$E_{f,p,c} = \sum_{fg} HgF_{fg,c} \times EF_{f,p}$	$94{,}936 fillings\ with\ mercury, 5-19\ age\ group \times \left(2.4 \times 10^{-7} \frac{lbs.}{tooth\ filled}\right)$	0.023 pounds of mercury emissions from fillings in the 5-19 age group (0.722 pounds of mercury in all age groups) in the county
9	$E_{o,p,c} = HgO_c \times EF_{o,p}$	$86.88\ lbs. \times 0.02 \frac{lbs.}{lb.}$	1.74 pounds of mercury emissions from dental office preparations in the county
10	$E_{da,p,c} = E_{f,p,c} + E_{o,p,c}$	$0.722\ pounds + 1.74\ pounds$	2.46 pounds of mercury from dental amalgam in the county

Thermostats/Thermometers

Table 15-11 lists sample calculations to determine the mercury emissions from thermostats and thermometers. The values in these equations are demonstrating program logic and are not representative of any specific NEI year or county.

Table 15-11: Sample calculations for mercury emissions from thermostats and thermometers

Eq. #	Equation	Values	Result
1	$DispTs = RemTs \times (1 - 8\%)$	$2{,}500{,}000\ thermostats\ removed\ from\ ser$ $\times 92\%$	2,300,000 thermostats disposed of in the United States
2	$HgTm_n = (HgTm_{n-1} \times 95\%) + HgTm_1$	$y = 1: 546\ lbs \times 95\%$ $y = 2: (518.7\ lbs. \times 95\%) + 532\ lbs.$ $y = 3: (1{,}024\ lbs. \times 95\%) + 523\ lbs.$ $y = 4: (1{,}496\ lbs. \times 95\%) + 514\ lbs.$ $y = 5: (1{,}935\ lbs. \times 95\%) + 506\ lbs.$	2,345 pounds of mercury available for release in thermometers

Eq. #	Equation	Values	Result
3	$HgTRl = (HgTm_5 - HgTRm) \times \frac{1\ ton}{2{,}000\ lbs.}$	$2{,}345\ lbs. - 350\ lbs. \times \frac{1\ ton}{2{,}000\ lbs.}$	0.99 tons of total mercury in thermometers available for release
4	$FracP_c = \frac{P_c}{P_{US}}$	$\frac{895{,}388\ people\ in\ the\ county}{329{,}164{,}967\ people\ in\ the\ US}$	0.272% of total US population is in the county
5	$DispTs_c = FracP_c \times DispTs$	$0.272\% \times 2{,}300{,}000\ thermostats$	6,256 thermostats disposed in the county
6	$HgTm_c = FracP_c \times HgTmRl$	$0.272\% \times 0.99\ tons$	0.0027 tons of mercury from thermometers available for release in the county
7	$E_{ts,p,c} = DispTs_c \times EF_{ts,p}$	$6{,}256\ thermostats \times \left(9.92 \times 10^{-5} \frac{lbs.}{thermostat}\right)$	0.62 pounds of mercury emissions from thermostats in the county
8	$E_{t,p,c} = HgTm_c \times EF_{t,p}$	$0.0027\ tons \times 10 \frac{lbs.}{ton}$	0.027 pounds of mercury emissions from thermometers in the county
9	$E_{tt,p.c} = E_{ts,p,c} + E_{t,p,c}$	$0.62\ lbs. + 0.027\ lbs.$	0.647 pounds of mercury emissions from thermostats and thermometers in the county

15.2.7 Improvements/Changes in the 2020 NEI

There are no methodology changes from the 2017 NEI development. However, activity information has been updated to year 2020 for state-level data on the number of recyclers, number of switches recovered, and the amount of mercury recovered, as well as the number of switches available for recovery.

15.2.8 Puerto Rico and U.S. Virgin Islands

For landfills, Puerto Rico and the U.S. Virgin Islands use the same methodology as the rest of the U.S. However, for all other sources, because insufficient data exists to calculate emissions for the counties in Puerto Rico and the US Virgin Islands, emissions are based on two proxy counties in Florida: 12011, Broward County for Puerto Rico and 12087, Monroe County for the US Virgin Islands. The total emissions in pounds for these two Florida counties are divided by their respective populations creating a pound per capita emission factor. For each Puerto Rico and US Virgin Island County, the pound per capita emission factor is multiplied by the county population (from the same year as the inventory's activity data) which serves as the activity data. In these cases, the throughput (activity data) unit and the emissions denominator unit are "EACH".

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United States Environmental Protection Agency	Office of Air Quality Planning and Standards Air Quality Assessment Division Research Triangle Park, NC	Publication No. EPA-454/R-23-001o March 2023