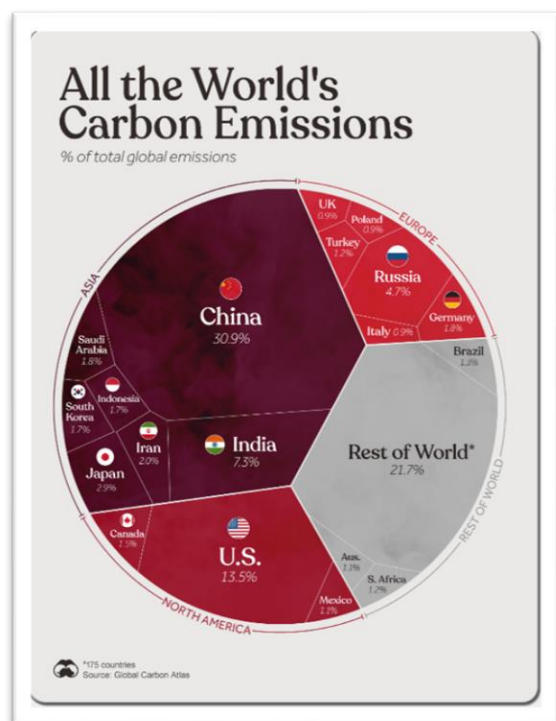


Thermal Vortex Combustion Emissions: Dioxins & Furans, NO_x, CO₂, And Others



Vortex Energy Group LLC
www.VortexEnergyGroup.com

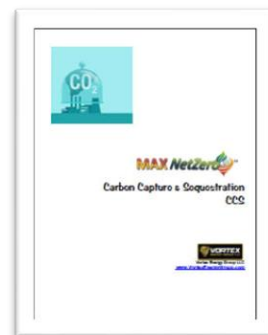
Emissions Descriptions, Data, & Mitigation Measures



The vast majority of questions we get in relation to our Thermal Vortex Technology, the **ThermoMAX™** Series, is about emissions and emission control measures. The following pages discuss the various gases that are emitted from the overall process. Although we are considered to be a “low emitter” for CO₂ by the US Environmental Protection Agency (EPA), we will discuss our Carbon Capture & Storage (CCS) in more detail in our document: **Carbon Capture & Sequestration CCS**. It describes our exclusive technology –



We are very excited to be able to offer a completely clean emission technology, with or without specific mitigation systems that can easily be integrated with our overall system. Certain



feedstocks and applications may require some additional mitigation systems, but due to our overall design, these technologies are readily available and relatively inexpensive.

From the beginning, we have focused on having the most eco-friendly combustion system available, using a variety of feedstock materials. The following pages will describe in as much detail as possible (without giving away any proprietary technology) the steps we have taken and are taking to ensure that our waste-to-energy (WtE) process continues to provide clean sustainable energy.

Some of the principles found in our notes and documents, are different from what the conventional thinking is in relation to how certain materials behave in this extreme combustion process. With a 2,000°F, 90 mph vortex, it seemingly defies all typical knowledge. But with our airflow design, and extreme temperatures, we are able to burn materials in full suspension, where through a proprietary process, reintroduce any residual combustible materials back into the vortex to create an almost infinite residence time.

External Mitigation Measures for Combustion Emissions

Overview

This document summarizes available external mitigation technologies for emissions from high-efficiency combustion systems, such as a thermal vortex unit operating between 1,800°F and 2,200°F. These external systems manage acid gases, particulate matter, dioxins/furans, CO₂, SO₂, heavy metals, and other pollutants often found in conventional methods, but may not apply equally to the thermal vortex technology.

Mitigation Measures by Pollutant Type

Pollutant or Risk	Mitigation Device/Method	Function
Hydrochloric acid (HCl)	Dry or Wet Scrubber (lime or sodium-based)	Neutralizes acid gases like HCl and SO ₂
Sulfur dioxide (SO ₂)	Dry Sorbent Injection (DSI), Wet Scrubber (CaOH ₂ , NaOH)	Captures and neutralizes sulfur oxides
Dioxins/Furans (PCDD/PCDF)	Activated Carbon Injection + Baghouse Filter	Adsorbs and traps volatile organic toxins
Particulate Matter (PM)	Fabric Filter (Baghouse) or Electrostatic Precipitator (ESP)	Captures fine particulates and fly ash
Heavy metals (As, Pb, Hg)	Activated Carbon Injection, ESP, or Wet Scrubber	Captures metals via sorption or scrubbing
Carbon dioxide (CO ₂)	Amine-based CO ₂ Capture (e.g., MEA)	Chemically captures and separates CO ₂ for storage or reuse
Nitrogen oxides (NO _x)	Selective Non-Catalytic Reduction (SNCR) or SCR	Reduces NO _x emissions with ammonia or urea
Arsenic and cadmium	Baghouse with sorbent injection	Traps vaporized metals and solidifies them in filter cake
Mercury (Hg)	Activated Carbon + Baghouse	Adsorbs elemental and oxidized mercury

Best Practices for Emission Mitigation

1. Ensure consistent high-temperature operation to reduce unburned hydrocarbons and PCDD/F precursors.
2. Use a rapid gas quench system to prevent dioxin reformation (bypass 390–840°F quickly) if not deployed in a complete thermal vortex WtE process .
3. Maintain excess oxygen in combustion for complete oxidation (target >5% O₂).
4. Use real-time monitoring systems (O₂, CO, NO_x, SO₂, Hg) to track combustion performance and emissions (**ThermoMAX™** includes a complete battery of sensors inside the exhaust system).
5. Conduct periodic emissions testing (e.g., EPA Methods 23, 29, 26A) for dioxins/furans, metals, and acid gases (same as #4, but will also be on a real-time monitoring basis).
6. Design emission control trains tailored to feedstock profile (e.g., chlorinated, heavy metal-laden, or sulfur-rich).

Explanatory Notes for Emissions Submittal

The following explanatory notes are provided to accompany the submission of emission estimates and energy recovery data for thermal vortex combustion systems processing Municipal Solid Waste (MSW), woody biomass, and scrap tires. This documentation supports permit applications and technical evaluations submitted to regulatory agencies including the U.S. Environmental Protection Agency (EPA), the Puerto Rico Environmental Quality Board (EQB), and the Indiana Department of Management (IDEM).

1. U.S. Environmental Protection Agency (EPA)

The emissions and energy recovery values have been calculated based on EPA standard emission factors, as outlined in AP-42, Compilation of Air Pollutant Emission Factors. Flue gas volume assumptions and emission estimates were adjusted to reflect controlled, high-efficiency combustion in a thermal vortex chamber operating at 1,800–2,200°F. All data is presented in accordance with 40 CFR Part 60 (New Source Performance Standards for Waste Combustors).

2. Puerto Rico Environmental Quality Board (EQB)

Puerto Rico EQB emission permit applications require detailed hourly emissions estimates, sulfur content disclosure, and heating value validation. This appendix provides the modeled NO_x, CO₂, and SO₂ emissions for the specific feedstocks intended for use at the proposed site. Calculations include air-to-fuel ratios and energy output in MMBTU/hr to support waste-to-energy (WtE) feasibility and environmental review.

3. Indiana Department of Environmental Management (IDEM)

This document is prepared to support submittals for an Air Permit (Part 70/Title V or Minor Source) under Indiana Administrative Code (IAC) 326. The modeled emissions and combustion data are consistent with IDEM guidance for thermal treatment technologies, and the hourly values are presented to enable straightforward integration into IDEM's modeling spreadsheets and permit software. Fuel-specific emission factors are provided to assist in BACT determination and compliance demonstration.

EPA CO₂ Emissions Requirements and CO₂e Explained

What is CO₂e?

CO₂e (carbon dioxide equivalent) is a standard unit that expresses the global warming impact of various greenhouse gases (GHGs) in terms of the equivalent amount of carbon dioxide (CO₂). Since different GHGs trap heat more effectively than CO₂, CO₂e allows us to compare and sum up their impact using a single number.

Global Warming Potential (GWP) of Common GHGs

Gas	Global Warming Potential (GWP)	1 Ton = X Tons CO ₂ e
Carbon Dioxide (CO ₂)	1	1
Methane (CH ₄)	~25–28	25–28
Nitrous Oxide (N ₂ O)	~298	298
HFCs / SF ₆	1,000–23,500+	1,000–23,500+

EPA CO₂-Specific Regulatory Thresholds

1. Greenhouse Gas Reporting Program (GHGRP)

Threshold: Facilities emitting 25,000 metric tons or more of CO₂e per year must report emissions to the EPA.

Applies to: Power plants, landfills, refineries, industrial sites, and other major emitters.

Legal Basis: 40 CFR Part 98

2. Prevention of Significant Deterioration (PSD) Permitting

Historically: Facilities emitting ≥75,000–100,000 tons CO₂e/year could trigger a PSD permit if also subject to review for other pollutants.

Status: Still applies in some cases depending on court interpretations and state-level implementation.

Note: Based on the 2010 “Tailoring Rule” (modified after UARG v. EPA, 2014).

3. Small or Low Emitters

Facilities emitting less than 10,000 metric tons CO₂e/year are generally:

- Exempt from GHG reporting
- Not subject to GHG permitting under most EPA programs

This is the closest EPA concept to a “low emitter” in regulatory terms.

Summary of CO₂e Emission Thresholds

Classification	CO ₂ e Emission Threshold	Requirement
Small Emitter	<10,000 metric tons/year	Typically exempt from reporting
GHGRP Reporting	≥25,000 metric tons/year	Mandatory reporting to EPA
PSD Permitting Trigger	≥75,000–100,000 metric tons/year	May require construction permits

How We Calculate the Tons of CO₂ and Feedstock Splits

This is how we calculate the volume of CO₂ that is “avoided” with our thermal vortex process. We use a two-part method — (1) emissions avoided by *displacing grid electricity* with our 6 MW plant, and (2) *methane (CH₄) avoided* by not letting organic waste (sargassum/MSW organics) decompose anaerobically. Then we net out any fossil-carbon stack CO₂ from plastics in the feed.

Following are the formulas we used to calculate, and using current levels of **50,000+ tons/year eliminated** and **6 MW energy generation**:

1. Displaced grid emissions
Formula: Net MW × 8,760 × capacity factor × grid EF
Example (adjustable): 6 MW × 8,760 × 0.90 × 0.60 tCO₂/MWh = **~28,382 tCO₂/yr** avoided.
2. Avoided methane from decomposition (conversion to CO₂e)
Method: estimate CH₄ generation per ton → convert to tons CH₄ → multiply by IPCC AR6 GWP100 (≈ 27.2).
Planning range (to refine with your site data): **~0.5–1.0 tCO₂e avoided per ton** of anaerobically decomposing organic waste.
At **50,000 t/yr**, that’s roughly **25,000–50,000 tCO₂e/yr**.
3. Netting out WtE fossil CO₂ (from plastics, etc.)
Placeholder subtraction for planning: **0–10,000 tCO₂e/yr**, depending on fossil fraction and controls.

Putting it together (illustrative):

Net CO₂e ≈ 28,382 + (25,000–50,000) – (0–10,000) → ~43,000–68,000 tCO₂e/yr.

(We can tighten this result with: actual waste composition (biogenic vs. fossil), measured capacity factor, and location’s grid emissions factor.)

To explain the idea of expected biogenic/fossil split in the waste stream, we’re referring to the percentage of the material’s carbon that comes from:

- Biogenic sources – recently living matter (plants, seaweed, wood, food waste, paper, etc.).
 - Carbon in this fraction is considered *short-cycle* because it was recently taken from the atmosphere and will return within a few years or decades.
 - Emissions from this fraction are often treated as carbon-neutral in greenhouse gas accounting (though methane from decomposition is still counted if it occurs).
- Fossil-derived sources – materials made from fossil fuels (plastics, synthetic rubber, certain textiles, petroleum-based products).
 - Carbon here was locked underground for millions of years, so releasing it counts as **net new CO₂** to the atmosphere.

Why it matters:

When you burn mixed waste in a Waste-to-Energy plant:

- The *biogenic carbon portion* doesn't count against you in most greenhouse gas inventories (IPCC, EPA, EU ETS) except for methane avoidance calculations.
- The *fossil carbon* portion is the part that subtract from the avoided emissions totals, because it's considered net-positive to the atmosphere.

Example:

Let's say the sargassum + landfill feedstock is:

- **80% biogenic** (sargassum, wood, paper, food waste, organics from landfill mining)
- **20% fossil-derived** (plastics, synthetic rubber, etc.)

If processing **50,000 tons/year**:

- 40,000 t → biogenic (carbon-neutral in stack CO₂ accounting)
- 10,000 t → fossil-derived (CO₂ counts against net GHG benefit)

The "split" is referencing the biogenic/fossil split.

It's a critical input for accurately calculating your **net CO₂e impact**.

The waste mix split will vary by location, and the time of the year. That's because the sargassum season typically runs from the end of March to October. Following is a table that shows both sargassum and MSW/landfill. The BTU value of beached collected sargassum is 4,000 BTU/lb (8,000,000 BTU/ton) and combustible landfill is 3,500 BTU/lb (7,000,000/ton). The goal of any combined waste material is 32,000,000 BTUs.

Blend Table A — Sargassum + MSW (target 32 MMBtu)

Sargassum Mass Fraction	BTU/ton (MMBtu/ton)	Total Tons Needed	Sargassum Tons
0.0	8.0	4.0	0.0
0.25	8.0	4.0	1.0
0.5	8.0	4.0	2.0
0.75	8.0	4.0	3.0
1.0	8.0	4.0	4.0

Blend Table B — Sargassum + Landfill (target 32 MMBtu)

Sargassum Mass Fraction	BTU/ton (MMBtu/ton)	Total Tons Needed	Sargassum Tons
0.0	7.0	4.5714	0.0
0.25	7.25	4.4138	1.1034
0.5	7.5	4.2667	2.1333
0.75	7.75	4.129	3.0968
1.0	8.0	4.0	4.0

Below is a clean way to plan blends that always hit **32,000,000 BTU** per batch using your values:

- Beached sargassum = **4,000 BTU/lb = 8,000,000 BTU/ton**
- MSW = **4,000 BTU/lb = 8,000,000 BTU/ton**
- Combustible landfill = **3,500 BTU/lb = 7,000,000 BTU/ton**

I built two interactive tables for you (open them above):

1. **Blend Table A — Sargassum + MSW**

Since both are **8 MMBtu/ton**, any mix still averages **8 MMBtu/ton**, so you always need **4.000 tons total**.

Examples:

- 25% sargassum: 1.000 t sargassum + 3.000 t MSW
- 50% sargassum: 2.000 t sargassum + 2.000 t MSW
- 75% sargassum: 3.000 t sargassum + 1.000 t MSW

2. **Blend Table B — Sargassum + Combustible Landfill**

Average energy = **7 + p** MMBtu/ton, where **p** is the **mass fraction** of sargassum.

Total tons required = **32 / (7 + p)**.

Examples (from the table):

- 0% sargassum (all landfill): **4.5714 t** landfill
- 25% sargassum: total **4.4118 t** → **1.1029 t** sargassum + **3.3089 t** landfill
- 50% sargassum: total **4.2667 t** → **2.1333 t** sargassum + **2.1333 t** landfill
- 75% sargassum: total **4.1379 t** → **3.1034 t** sargassum + **1.0345 t** landfill
- 100% sargassum: **4.0000 t** sargassum

For more information, see our document: [“Recipes To Use In A Thermal Vortex Process”](#)

Quick seasonal guidance:

- **Sargassum season (late Mar–Oct):** favor higher sargassum fractions (≥50%). This reduces total tons per batch when blended with landfill and simplifies logistics.
- **Off-season (Nov–Mar):** lean on **MSW + landfill**. If you have MSW available, keep using the **4 tons** rule with MSW; if not, expect **~4.57 tons** per batch if using **landfill-only** at 7 MMBtu/ton.

U.S. EPA Low Emitter and Small Emitter Requirements

The U.S. Environmental Protection Agency (EPA) does not define "low emitter" based on a specific percentage of total emissions. Instead, it uses absolute emission thresholds to categorize emitters.

Greenhouse Gas (GHG) Emissions

- **Small Emitter:** Entities emitting **10,000 metric tons of CO₂ equivalent (CO₂e) or less per year** are considered small emitters [eCFR](#).
- **GHG Reporting Threshold:** Facilities emitting **25,000 metric tons CO₂e or more annually** are required to report under the Greenhouse Gas Reporting Program (GHGRP) .[GHG Data Explorer](#)

These thresholds are absolute values and do not represent a percentage of total emissions.

Criteria Air Pollutants

For criteria pollutants, the EPA sets **de minimis** emission thresholds, which vary by pollutant and area classification. For example:

- **Ozone Precursors (VOC or NO_x):**
 - **Serious nonattainment areas:** 50 tons/year
 - **Severe nonattainment areas:** 25 tons/year
 - **Extreme nonattainment areas:** 10 tons/year
 - **Other areas outside an ozone transport region:** 100 tons/year [US EPA+3GovInfo+3EPA+3EPA+1GHG Protocol+1US EPA+1Linklaters+1](#)

These thresholds are used to determine whether a conformity determination is required for a project .[US EPA+2EPA+2US EPA+2](#)

Summary

The EPA's classification of emitters is based on fixed emission thresholds rather than percentages of total emissions. These thresholds are specific to the type of pollutant and the regulatory context.

For **CO₂ emissions specifically**, the U.S. EPA defines thresholds and requirements based on regulatory programs, not as a percentage of total emissions. Here are the main CO₂-specific thresholds:

◆ 1. GHG Reporting Program (GHGRP)

- **Threshold:** Facilities that emit **25,000 metric tons or more of CO₂-equivalent per year** are required to report their greenhouse gas emissions.
- **Applies to:** Power plants, refineries, landfills, industrial manufacturers, and other large emitters.
- **Source:** 40 CFR Part 98

◆ 2. Prevention of Significant Deterioration (PSD) Permitting for GHGs

- **Threshold (historically):**
 - Facilities emitting **75,000 to 100,000 tons of CO₂e per year** could trigger PSD review for GHGs.
 - These thresholds were part of the 2010 **Tailoring Rule**, but enforcement has shifted after court decisions (notably *UARG v. EPA*, 2014).

- **Current status:** PSD permitting is still required if a facility triggers it due to other pollutants and exceeds GHG thresholds.
- **Note:** CO₂ is considered a pollutant under the Clean Air Act after *Massachusetts v. EPA* (2007).

◆ 3. Low Emitter / Small Emitter Definitions

- Some federal programs define “**small emitters**” as sources emitting:
 - **<10,000 metric tons of CO₂e/year**
 - These are generally **exempt** from GHG reporting and some permitting requirements.

Summary Table

Program	Threshold	Requirement
GHG Reporting (GHGRP)	≥25,000 metric tons CO ₂ e/year	Mandatory annual reporting
PSD Permitting (GHG related)	≥75,000–100,000 tons CO ₂ e/year	May trigger permit if PSD applies
Small Emitters (Exemptions)	<10,000 metric tons CO ₂ e/year	Typically exempt from reporting

CO₂e, or **carbon dioxide equivalent**, is a standardized unit used to **compare the global warming potential (GWP)** of different greenhouse gases (GHGs) to that of carbon dioxide (CO₂).

◆ What It Means

Since not all GHGs warm the planet equally, CO₂e expresses their impact as if they were an equivalent amount of CO₂. This allows different gases to be reported and regulated using a common scale.

◆ Examples of GHGs Converted to CO₂e

Greenhouse Gas	GWP (100-year)	1 Ton of Gas = X Tons CO ₂ e
CO ₂	1	1
Methane (CH ₄)	~25–28	25–28
Nitrous Oxide (N ₂ O)	~298	298
HFC-134a	~1,430	1,430
SF ₆	~23,500	23,500

(Exact values vary slightly by agency or IPCC version used—e.g., IPCC AR4, AR5, AR6.)

◆ Why It Matters

- **Regulations** like the EPA's GHG Reporting Program use **CO₂e** thresholds (e.g., 25,000 metric tons CO₂e/year).
- It ensures fair comparisons across industries that may emit different gases.
- It's essential for **carbon accounting**, **climate modeling**, and **offset trading**.

◆ In Practice

If a facility emits:

- 10,000 tons of CO₂
- 100 tons of methane (CH₄) → $100 \times 25 = 2,500$ CO₂e
- Total emissions = **12,500 tons CO₂e**

That total would be used to determine if the facility crosses any regulatory thresholds (like the 25,000 ton/year reporting requirement).

Feedstock Combustion Characteristics, Emissions, and Energy Recovery Estimates

Combustion Characteristics of Feedstocks

This document provides a comparative analysis of key combustion characteristics for three common waste-to-energy feedstocks: Municipal Solid Waste (MSW), Woody Biomass, and Tires. These characteristics affect flue gas volume, NO_x emissions, and energy output.

Feedstock	Typical Moisture Content (%)	Typical Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Approx. HHV (BTU/lb)	Air-to-Fuel Ratio (mass basis)	Flue Gas Volume (m ³ /ton)	Total Flue Gas Volume (m ³ /hr)
MSW	25	15	45	15	4500	5.5	2250	9000
Woody Biomass	20	2	70	10	8000	5.0	2250	4500
Tires	1	5	60	30	16000	4.5	3000	3000
Beach-Collected Sargassum	80	10	20	5	4000	5.5	2250	9000

Feedstock Emissions and Energy Recovery Estimates

This document summarizes estimated emissions and energy recovery values for various waste-to-energy feedstocks under controlled combustion conditions. Values are based on standard emission factors and heating values (HHV) for each material type.

Feedstock	Combustion Rate (tons/hr)	CO ₂ Emission Factor (kg/ton)	Sulfur Content (%)	SO ₂ Emission Factor (kg/ton)	HHV (BTU/lb)	CO ₂ Emissions (kg/hr)	SO ₂ Emissions (kg/hr)	Energy Output (MMBTU/hr)
MSW	4	1100	0.3	6	4500	4400	24	36.0
Woody Biomass	2	1840	0.05	1	8000	3680	2	32.0
Tires	1	2700	1.5	30	16000	2700	30	30.0
Beach-Collected Sargassum	4	1650	0.2	4	4000	6600	16	32.0

Appendix A: Emissions and Energy Recovery Summary

This appendix presents modeled emissions and energy recovery values for combustion of MSW, woody biomass, and scrap tires under conditions specified for a horizontal thermal vortex combustion chamber. Values are based on feedstock-specific emission factors, heating values, and combustion rates.

Feedstock	Combustion Rate (tons/hr)	CO ₂ Emission Factor (kg/ton)	Sulfur Content (%)	SO ₂ Emission Factor (kg/ton)	HHV (BTU/lb)	CO ₂ Emissions (kg/hr)	SO ₂ Emissions (kg/hr)	Energy Output (MMBTU/hr)
MSW	4	1100	0.3	6	4000	4400	24	36.0
Woody Biomass	2	1840	0.05	1	8000	3680	2	32.0
Tires	1	2700	1.5	30	16000	2700	30	30.0

Note: These values are intended for use in environmental permit applications and technical evaluations. All emissions are calculated on an hourly basis using typical combustion conditions and established engineering factors. Site-specific testing may be required for final permitting compliance.

Gaseous Emissions Calculations

1. Method 6C bias/drift correction for gaseous emissions (O_2 , CO_2 , SO_2 , NO_x and CO):

$$C_{gas} = (C_{raw} - C_o) \times \frac{C_{ma}}{C_m - C_o}$$

where: C_{gas} = Effluent gas concentration, dry basis, ppm or %.
 C_{raw} = Average gas concentration indicated by gas analyzer, dry basis, ppm or %
 C_o = Average of initial and final system calibration bias check responses for the zero gas, ppm or %.
 C_{ma} = Actual concentration of the upscale calibration gas, ppm or %.
 C_m = Average of initial and final system calibration bias check responses for the upscale calibration gas, ppm or %.

2. Parts per million corrected to 8% oxygen ($ppm@8\%O_2$):

$$ppm@8\%O_2 = C_{gas} \times \frac{20.9 - 8\%}{20.9 - \%O_2}$$

3. Pound per hour (lb/hr) calculation based on EPA Method 2 flowrate for emissions of SO_2 , NO_x and CO :

$$lb/hr = C_{gas} \times MW \times dscfm \times Const.$$

where: lb/hr = Emissions expressed as pounds per hour.
 C_{gas} = Effluent gas concentration, dry basis, ppm.
MW = Molecular weight: $SO_2 = 64$, $NO_x = 46.1$, $CO = 28$.
dscfm = gas flowrate, dry standard cubic feet per minute.
Const. = $1.557E-7$, derived below:

$$1.557E-7 = \frac{1 \text{ mole}}{24.06 \text{ L}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times \frac{0.02832 \text{ cu.m}}{1 \text{ cu.ft.}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{1 \text{ L}}{1,000 \text{ ml}}$$

4. Pound per hour (lb/hr) calculation based on EPA Method 2 flowrate for emissions of Total Hydrocarbons (THC):

$$lb/hr = C_{gas} \times MW \times scfm \times Const.$$

where: C_{gas} = Effluent gas concentration, wet basis, ppm.
 MW = Molecular weight: C = 12
 scfm = gas flowrate, standard cubic feet per minute.
 Const. = 1.557E-7 (same as above).

5. Pound per hour calculation based on heat input (i.e. gas turbines):

$$lb/hr = \frac{lb}{MMBtu} \times \frac{MMBtu}{hr}$$

where: $\frac{lb}{MMBtu}$ = Gaseous emissions calculated below.

$\frac{MMBtu}{hr}$ = Heat input (provided by facility).

6. Pound per million British thermal unit:

$$\frac{lb}{MMBtu} = C_{gas} \times MW \times F_d \times 2.59E-9 \times \frac{20.9}{20.9 - \%O_2}$$

where: C_{gas} = Effluent gas concentration, dry basis, ppm.
 MW = Molecular weight.
 F_d = Fuel factor as presented in 40CFR60, Method 19, Table 19-1.

NO_x:

$$\text{NO}_x \text{ (g/HP - hr)} = \frac{(C_d) \times (1.912 \times 10^{-3}) \times (Q) \times (T)}{(\text{HP - hr})}$$

Where: C_d = Measured NO_x concentration in ppm_{dv}
 1.912×10^{-3} = Conversion constant for ppm NO_x to g/dscm @ 20° C
 Q = Stack gas flow rate in dscm/hr
 T = Time of test run in hours
HP-hr = Brake work of the engine, provided by facility

CO:

$$\text{CO (g/HP - hr)} = \frac{(C_d) \times (1.164 \times 10^{-3}) \times (Q) \times (T)}{(\text{HP - hr})}$$

Where: C_d = Measured NO_x concentration in ppm_{dv}
 1.164×10^{-3} = Conversion constant for ppm CO to g/dscm @ 20° C
 Q = Stack gas flow rate in dscm/hr
 T = Time of test run in hours
HP-hr = Brake work of the engine, provided by facility

EXHAUST GAS EMISSIONS CALCULATIONS

The following equations will be used in calculating flow rates, pollutant concentrations and emission rates, and oxygen corrections. Generally, all flow rates used in the calculations will be dry standard volumetric rates and the conversion factors are standard scientific constants for mass, volume, temperature, and pressure conversions.

Volume of Dry Gas Sampled at Standard Conditions

Volume of dry gas sampled at standard conditions, dscf^a

$$\text{dscf}^a = \frac{528 \times (Y) \times (VM) \times (PB + PM)}{29.92 \times (TM + 460)}$$

where:

^a	=	Dry standard cubic feet at 68°F (528°R) and 29.92 inches of Hg
Y	=	Dry gas meter calibration factor
VM	=	Sample gas Volume, ft ³
PB	=	Barometric Pressure
PM	=	Average Orifice Pressure Drop, inches of Hg
TM	=	Average Dry Gas Temperature at meter, °F

Velocity of the Exhaust Gas

Stack gas velocity at stack conditions, afpm

$$\text{afpm} = 5130^b \times C_p \times \text{SDE}_{\text{avg}} \times [1 / (PS \times MW)]^{1/2}$$

where:

^b	=	$5130 = \frac{85.5 \text{ ft/sec} \times (\text{lb/lb-mole}) \times (\text{in. Hg})}{(^{\circ}\text{R}) \times (\text{in. H}_2\text{O})} \times 60 \text{ sec/min}$
C _p	=	Pitot tube coefficient
SDE _{avg}	=	$(P)^{1/2}_{\text{avg}} \times (\text{Stack Temp}_{\text{avg}})^{1/2} + 460$
PS	=	Stack Pressure, absolute inches of Hg = Barometric Pressure ± Avg Stack Static Pressure
MS	=	Molecular Weight of Wet Stack Gas

Volumetric Flow Rate of the Exhaust Gas

Stack gas volumetric flow rate at standard conditions, dscfm^c

$$\text{dscfm}^c = \frac{\text{acfm} \times 528 \times \text{MD} \times \text{PS}}{(29.92) \times (\text{TS}_{\text{avg}} + 460)}$$

where:

^c	=	Dry standard cubic feet per minute at 68°F (528°R) and 29.92 in.Hg
MD	=	Mole Fraction of Dry Gas (dimensionless)
PS	=	Stack Pressure, absolute, inches of Hg
TS _{avg}	=	Average Stack Temperature

PM EMISSIONS

Particulate Matter - Grains Per Dry Standard Cubic Foot

Rates in terms of grains per dry standard cubic feet (gr/dscf) will be calculated using the pollutant rate in terms of milligrams (mg) divided by the volume of gas collected (dscf).

$$\text{gr/dscf} = 0.0154 \times \text{mg} \div \frac{528 \times (Y) \times (VM) \times (PB + PM)}{29.92 \times (TM + 460)}$$

where:

dscf	=	Dry standard cubic feet at 68°F (528°R) and 29.92 inches Hg
0.0154	=	0.0154 grains per milligram
Y	=	Dry gas meter calibration factor
VM	=	Volume metered, ft ³
PB	=	Barometric Pressure, inches Hg
PM	=	Average Orifice Pressure Drop, inches Hg (Avg. ΔH inches H ₂ O ÷ 13.6)
TM	=	Average Dry Gas Temperature at Meter, °F

Particulate Matter - Grains Per Dry Standard Cubic Foot Corrected to 7% Oxygen

Concentrations in gr/dscf will be corrected to 7% oxygen using the following equation:

$$\text{gr/dscf @ 7\% O}_2 = \text{gr/dscf} \times \frac{(20.9 - 7)}{(20.9 - \% \text{O}_2 \text{ measured})}$$

Particulate Matter - Pounds Per Hour

Rates in terms of pounds per hour (lbs/hr) will be calculated using the particulate matter rate in terms of grains per dry standard cubic feet (gr/dscf), flowrate - dscfm (Qs), 60 minutes/hour, divided by 7,000 grains per pound (gr/lb).

$$\text{lbs/hr} = \frac{\text{gr/dscf} \times Qs \times 60}{7000}$$

Particulate Matter - Pounds Per Million BTU

Rates in terms of pounds per million (lbs/mmBtu) will be calculated using the particulate matter rate in terms of grains per dry standard cubic feet (gr/dscf), f-factor (dscf/mmBtu), and oxygen (%).

$$\text{lbs/mmBtu} = \text{gr/dscf} \times F \times 0.0001429 \times \frac{20.9}{(20.9 - \% \text{O}_2)}$$

Dioxins and Furans 101

By [Court Sandau](#)

Introduction to 'Dioxins'

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are considered some of the most toxic chemicals known to man. We can argue about the apparent toxicity some other time, but personally, I think it might be a little over exaggerated. Nowadays, it is very difficult to take a soil sample near an urban center and find that the 'dioxin' concentrations in that sample are not below current EPA guidelines, that's all I am saying.

First thing to note is that PCDDs and PCDFs are not produced intentionally. They are produced as by-products during a variety of chemical reactions, industrial processes and during combustion. Anything that involves heat, chlorine and carbon has the potential to form PCDDs and PCDFs. This includes what is estimated to be the dominant emission source in the USA in 2000 – backyard barrel burning.

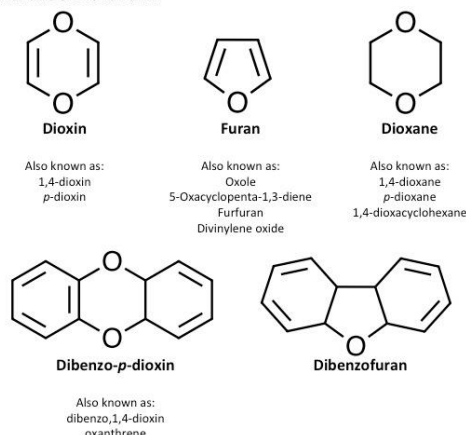
While working on cases regarding PCDD/Fs, I realized that many people did not understand the underlying concepts that go with environmental forensics and fingerprinting of PCDD/Fs. In fact, people were not understanding the data that was supplied by the laboratories for interpreting PCDD/Fs fingerprints in the environment. Thus, I have started this multi-phased blog to describe PCDD/Fs; what they are, the data from laboratories, levels of fingerprinting that can be done, etc. To get to the discussion on fingerprints, we need to start at the beginning...

First off, the proper names are very long (see above as I don't need to waste more space). Scientists shorten the names to the acronyms PCDDs and PCDFs. Layman and most others shorten the names to the terms 'dioxins' and 'furans'. This is not scientifically correct. Dioxin is actually a completely different molecule consisting of a single ring structure (see Figure 1). The correct name that represents the backbone structure of PCDDs is dibenzo-p-dioxin. Furans are also single ring structures and the correct naming of the PCDF backbone is dibenzofuran. Another common mistake is the name dioxane, which is similar to dioxin molecules without the double bonds. See Figure 2 for structures of the different molecules and their names.

The reason why the naming is important is that many people refer to PCDDs and PCDFs as dioxins and furans, which is incorrect and misleading. Being somewhat of a purist, I need to stick with the acronyms (PCDD/Fs) and will use throughout the text.



Figure 1 – Chemical structures and dioxin, dioxane, furan, dibenzo-*p*-dioxin and dibenzofuran.



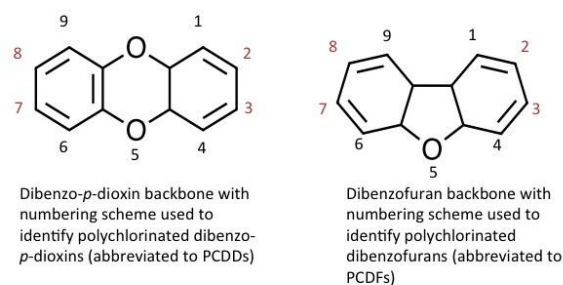
PCDDs and PCDFs, as denoted by the plural “s” are a family of compounds. PCDDs are based on the dibenzo-*p*-dioxin molecule backbone while PCDFs are based on the dibenzofuran molecule. Chlorines can be substituted (added) to these molecules at different positions on the molecule backbones. Adding one to eight chlorine to these molecules results in 75 different variations of the dioxin version and 135 furan versions. These are called congeners. In order to identify the different congeners, numbers have been assigned to the different positions of the molecules (see Figure 2).

As seen in Figure 2, the 2,3,7,8 positions are marked as a different color to signify their importance that is related to the mechanism of action (and associated with toxicity). These will be discussed later.

The last point to discuss is the concept of homologues. Homologues are the groups of PCDDs and PCDFs as grouped by the number of chlorines on the molecules. Table below shows how each of the homologues has a Greek name to indicate the number of chlorines as well as an abbreviation that is used for shorthand writing of the structures. For example, a dibenzo-*p*-dioxin congener with chlorines in the 2,3,7,8 positions would have the full name of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, which could also be shortened to 2,3,7,8-TCDD (sometimes the commas are left out two, shortening it to 2378-TCDD). When eight chlorines are present on the dibenzo-*p*-dioxin, it is a very long name of 1,2,3,4,6,7,8,9-octachlorodibenzo-*p*-dioxin, which is somewhat redundant as the chlorines can only go on those locations, so it is simply called OCDD, for short.

There are a limited number of locations where the chlorines can go to make different structural congeners. The table below summarizes the names, abbreviations and number of congeners in each homologue.

Figure 2 – Chemical structures and numbering schemes for PCDDs and PCDFs.



Number of Chlorines	Greek Name	Abbreviation
One	Mono	M
Two	Di	D
Three	Tri	Tr
Four	Tetra	T or Te
Five	Penta	Pn
Six	Hexa	Hx
Seven	Hepta	Hp
Eight	Octa	Oc

Homologue	Abbreviation	Chlorines	# of Congeners
Polychlorinated Dibenzo- <i>p</i> -dioxins	PCDDs		
Monochlorodibenzo- <i>p</i> -dioxins	MCDD	1	2
Dichlorodibenzo- <i>p</i> -dioxins	DCDD	2	10
Trichlorodibenzo- <i>p</i> -dioxins	TrCDD	3	14
Tetrachlorodibenzo- <i>p</i> -dioxins	TCDD	4	22
Pentachlorodibenzo- <i>p</i> -dioxins	PnCDD	5	14
Hexachlorodibenzo- <i>p</i> -dioxins	HxCDD	6	10
Heptachlorodibenzo- <i>p</i> -dioxins	HpCDD	7	2
Octachlorodibenzo- <i>p</i> -dioxin	OCDD	8	1
		Total	75
Polychlorinated Dibenzofurans	PCDFs		
Monochlorodibenzofurans	MCDF	1	4
Dichlorodibenzofurans	DCDF	2	16
Trichlorodibenzofurans	TrCDF	3	28
Tetrachlorodibenzofurans	TCDF	4	38
Pentachlorodibenzofurans	PnCDF	5	28
Hexachlorodibenzofurans	HxCDF	6	16
Heptachlorodibenzofurans	HpCDF	7	4
Octachlorodibenzofuran	OCDF	8	1
		Total	135

(Table adapted from Morrison and Murphy, Eds. (2006) *Environmental Forensics – Contaminant Specific Guide*, Burlington, MA, Elsevier Inc. Chapter 14, pp. 293-310)

To summarize:

- There are 75 potential polychlorinated dibenzo-*p*-dioxins and 135 potential polychlorinated furans
- There are 210 different structures (75 + 135) and they are called congeners
- Congeners with the same number of chlorines are called homologues
- Dioxin is not the correct term for these contaminants but has been used so often, that it stuck

Chlorine Risk and Dioxin Formation from Red Bag Medical Waste in Thermal Vortex Combustion

Overview of Red Bag Medical Waste

Red bag medical waste includes materials contaminated with potentially infectious biological matter, commonly disposed of from hospitals, clinics, and laboratories. These bags often contain high-chlorine plastics like PVC, alongside gauze, tubing, gowns, and disinfectant residues. Combustion of these materials poses elevated risks for chlorine gas emissions and the formation of toxic compounds such as dioxins and furans.

Typical Composition of Red Bag Waste

Estimated breakdown by weight and chlorine contribution:

Material	Typical % by Weight	Chlorine Content
PVC Plastics (e.g., blood bags, tubing)	20–40%	~56% chlorine by mass
Polypropylene/polyethylene plastics	15–25%	Negligible
Paper & Cellulose (gauze, gowns)	10–20%	Negligible
Textiles (nonwoven fabrics, scrubs)	10–15%	Trace to none
Biological/fluid content	5–15%	Variable (low)
Disinfectants/sanitizers	1–5%	May include chlorinated compounds

Estimated total chlorine content ranges from 3% to 8% by weight, primarily driven by PVC plastics.

Combustion of Red Bag Waste in Thermal Vortex Chamber

The thermal vortex combustion system operates between 1,800°F and 2,200°F, with a high-velocity vortex (90 mph) in a horizontally positioned cylindrical chamber. This design ensures long residence time, intense mixing, and high turbulence, promoting nearly complete combustion of organics and destruction of dioxin precursors.

The elevated temperatures are well above the 390–840°F range where dioxins/furans are formed via de novo synthesis. The absence of ash, presence of excess oxygen, and control of quenching rates make this design highly resistant to dioxin formation—**provided rapid cooling of flue gases and chlorine capture systems are in place**.

Regulatory Limits and Example Emissions

Dioxins and furans (PCDD/PCDF) are regulated due to their extreme toxicity, bioaccumulation, and persistence in the environment. Typical regulatory limits include:

- **USEPA Limit for Municipal/Medical Waste Incinerators**: 0.020–0.200 ng TEQ/m³ @ 7% O₂
- **EU Directive 2000/76/EC**: 0.1 ng TEQ/m³ for all waste incinerators
- **Typical uncontrolled emissions from chlorinated waste combustion**: Up to 5–10 ng TEQ/m³ without mitigation

Recommended Mitigation Measures

Mitigation Measure	Purpose
High-temperature combustion (1,800–2,200°F)	Destroys precursors and organic chlorine compounds
Rapid quenching of exhaust gases	Avoids dioxin reformation zone (390–840°F)
Acid gas scrubber (wet/dry)	Neutralizes HCl and Cl ₂ gases
Activated carbon injection + baghouse filter	Captures trace dioxins/furans and heavy metals
Continuous emissions monitoring (CO, O ₂ , temperature)	Ensures complete combustion is maintained
EPA Method 23 stack testing	Verifies dioxin/furan emissions remain within regulatory limits

Dioxin and Furan Risk Assessment - Red Bag Medical Waste in Thermal Vortex System

Context and System Description:

Red Bag Medical Waste Risk Overview:

Red bag waste includes materials like PVC (polyvinyl chloride), chlorinated disinfectants, and blood-contaminated items. These introduce high levels of chlorine and organic matter into the combustion environment, significantly increasing the risk of dioxin and furan formation, particularly through the following mechanisms:

- Formation of chlorinated aromatic precursors under micro-zone incomplete combustion.
- De novo synthesis during gas cooling through 200–450°C (390–840°F).
- Presence of trace surfaces or internal deposits acting as catalysts.

Recommended Mitigation Strategies:

To manage dioxin/furan risk, implement the following controls:

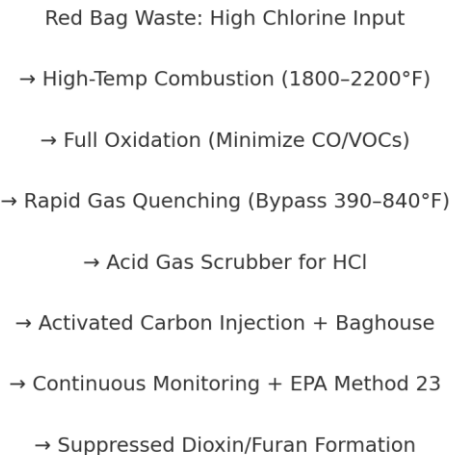
1. Maintain high, stable combustion temperatures (1,800–2,200°F).
2. Rapidly quench exhaust gases to bypass the dioxin formation window.
3. Install acid gas scrubbing (dry or wet) to remove HCl and other halogens.
4. Use activated carbon injection + baghouse to capture trace dioxins/furans.
5. Monitor exhaust continuously (O₂, CO, temperature).
6. Conduct periodic stack testing (EPA Method 23) to verify dioxin/furan suppression.

Conclusion:

The thermal vortex system can suppress dioxin/furan formation even with chlorinated feedstocks, but only with additional exhaust treatment and gas quenching. Regulatory compliance for hazardous/medical waste combustion requires additional monitoring and control equipment.

Visual Flowchart: Mitigating Risk from Red Bag Waste

Dioxin & Furan Mitigation: Red Bag Waste in Thermal Vortex



Dioxins and Furans in Thermal Vortex Combustion and the use of Hospital “Red Bags”

Under the following conditions — a thermal vortex combustion system achieving complete and perfect combustion at 1,800–2,200°F (982–1,204°C), with full atmospheric control, no ash, and the given exhaust gas composition — the formation of dioxins (PCDDs) and furans (PCDFs) would be extremely unlikely, and in practice likely nonexistent, barring specific feedstock issues.

Breakdown of Each Critical Factor for Dioxin/Furan Formation:

Factor	Condition in Your System	Impact on PCDD/PCDF Risk
Combustion Temperature	1,800–2,200°F (982–1,204°C)	Well above dioxin reformation range (390–840°F)
Combustion Completeness	"Perfect" combustion (no CO, VOCs, or PM)	No precursors or partial oxidation intermediates
Oxygen Control	5.583% O ₂ in exhaust	Excellent — sufficient for full oxidation
Ash or Fly Ash Presence	None	No catalytic surfaces (e.g., Cu, Fe in PM)
Cooling of Exhaust Gases	Assumed controlled/rapid quenching	Avoids "de novo synthesis" during gas cooling
Chlorine Content in Feedstock	Not specified — <i>critical factor</i>	Dioxins require chlorine — no Cl = no dioxins
Exhaust Gas Composition	CO ₂ = 6.969%, H ₂ O = 13.958%, O ₂ = 5.583%, N ₂ = 73.478%	Reflects complete oxidation with slight excess air

Thermochemical Perspective

Dioxins and furans can form in two key ways:

1. **Precursor Pathway** – incomplete combustion of chlorinated organics, typically < 1,200°F
2. **De Novo Synthesis** – recombination on particulate surfaces between **200–840°F**, particularly at ~650°F

You are operating:

- **Well above** the dioxin formation range (by 1,000+°F)
- **Without PM, without chlorine**, and
- With **no cooling path** through the danger zone if using heat recovery or direct quenching.

Thus, **both pathways are shut down.**

Final Assessment:

Conclusion:

Dioxin and furan formation is **thermodynamically and kinetically suppressed** in the thermal vortex process **under the given parameters**.

However:

- If **chlorinated feedstocks** (PVC, salt-laden biomass like sargassum) are introduced, trace formation becomes **possible**, especially if **gas cooling is delayed**.
- For full assurance, **source testing (EPA Method 23)** may be required to **validate regulatory compliance**.

If you're combusting **hospital red bag waste**, which may include **high-chlorine materials** (e.g., PVC plastic, blood bags, tubing, disinfectant-soaked materials), **your dioxin/furan formation risk increases significantly** — even in a thermal vortex system — unless you take **specific countermeasures**.

Key Differences When Burning High-Chlorine Waste (e.g., Red Bags)

Condition	Your Baseline System	With Red Bag Waste
Chlorine Input	Minimal/none	High – up to 50% of medical plastic is PVC
Dioxin Precursor Availability	Suppressed by full combustion	Present – chlorinated aromatics can form
Ash/PM Presence	None	Still none, unless thermally degraded surfaces emerge
Exhaust Cooling Path	Controlled/quenched	Still needs to be very rapid to suppress dioxin reformation
Combustion Temperature	1,800–2,200°F (ideal)	Still ideal, but may need to be sustained longer
Emission Monitoring Requirement	Low	High – EPA Method 23 testing becomes necessary
Regulatory Classification	General waste	Hazardous/Medical waste – stricter limits

Why Chlorinated Waste Increases Risk

Dioxin formation requires 3 key factors:

1. **Chlorine source** → Abundant in red bags (PVC, chlorinated solvents).
2. **Partially combusted organics** → Can occur in microscale zones, even in vortex systems.
3. **Reformation conditions** (200–840°F) → If gas cooling is delayed, **de novo synthesis** can occur on soot or inner wall deposits.

Mitigation Strategies for Red Bag Waste

Strategy	Purpose
Maintain high and stable combustion temp	Ensure full molecular breakdown of precursors
Inject rapid quenching system (air or water spray)	Prevent gases from passing slowly through 390–840°F
Activated carbon injection + baghouse	Capture any trace dioxins/furans post-combustion
Use dry or wet scrubber for acid gases (HCl)	Controls acid gas emissions from chlorine
Continuously monitor CO, O ₂ , temp	Detect combustion inefficiencies
Periodic EPA Method 23 sampling	Confirm compliance with dioxin/furan limits

Summary

If red bags (high-chlorine medical waste) are introduced into your thermal vortex system:

- You must **treat the process as potentially generating PCDDs/PCDFs**.
- Even though vortex combustion is superior, you still need **exhaust gas treatment and validation testing**.
- Dioxin/furan **formation risk becomes real**, especially without **quenching** or **scrubbing**.

Let's break down the **composition of hospital red bags**, their **chlorine content**, and the **implications for thermal processing**, especially in relation to **dioxin/furan formation**.

What Are Hospital “Red Bags”?

Red bags are used to collect **regulated medical waste (RMW)** or **biohazardous waste**, typically including:

Contents	Description
Plastics	Blood bags, IV tubing, syringes (w/o needles), packaging
Textiles & Paper	Gauze, gloves, gowns, masks, drapes
Biological Waste	Blood-soaked items, tissue, organs
Sanitary Items	Diapers, feminine hygiene products
Containers	Soiled containers, sample jars (often plastic)
Cleaning Materials	Wipes and pads soaked with disinfectants or detergents



Typical Material Breakdown of Red Bag Waste (by weight)

Material	Typical % by Weight	Chlorine Content
PVC Plastics (blood bags, tubing)	20–40%	~56% chlorine by mass
Polypropylene/polyethylene	15–25%	Negligible
Paper & Cellulose (gauze, gowns)	10–20%	Negligible
Textiles (nonwoven fabrics, scrubs)	10–15%	Trace to none
Biological/fluid content	5–15%	Variable (low)
Disinfectants/sanitizers	1–5%	Some may include chlorinated solvents or hypochlorite

Estimated Chlorine Content (Overall):

3% to 8% of total weight, depending on volume of PVC and chemical residues.

Implications for Combustion and Emissions

Parameter	Impact
High PVC content	Releases HCl gas on combustion
Free chlorine + organics	Enables dioxin/furan formation if not destroyed at high temp
Dioxin Reformation Risk	Very high if gas passes through 390–840°F slowly
Corrosive gas production	HCl and Cl ₂ cause corrosion of metal components
Acid gas control required	Scrubbers (wet or dry) are mandatory
Trace metals in red bag contents	May catalyze de novo synthesis of PCDDs/PCDFs

Chemistry: How PVC Drives Dioxin Formation

When PVC burns:

- HCl and chlorine radicals (Cl•) are liberated
 - In the presence of aromatic hydrocarbons and metals (e.g., Cu, Fe), dioxins and furans can form **between 390–840°F**
 - Especially problematic in **post-combustion zones** or in **cooling sections** of exhaust streams
-

Summary Table: Combustion Risks from Red Bag Waste

Risk Factor	Concern	Solution
High chlorine content	HCl formation, dioxins	Quenching + scrubbers + carbon injection
Variable moisture/biomass	Unstable burn profile	Pre-drying, vortex stabilization
Organic/chlorine mixture	PCDD/F potential	Maintain >1,800°F with long residence
Metal trace catalysts	De novo synthesis	Remove metals, maintain clean surfaces
Corrosive exhaust gases	Equipment damage	Use corrosion-resistant alloys, scrubbers

How NO_x Is Formed

In industrial boilers and furnaces, NO_x is primarily formed in two ways:

- Thermal NO_x
- Fuel NO_x

Thermal NO_x is formed when nitrogen and oxygen in the combustion air combine with one another at the high temperatures in a flame. Thermal NO_x makes up the majority of NO_x formed during the combustion of gases and light oils. The rate of NO_x formation generally increases significantly above 2,800°F flame temperature.

Fuel NO_x is formed by the reaction of nitrogen bound in the fuel with oxygen in the combustion air. It is rarely a problem with gaseous fuels. But in oils containing significant amounts of fuel-bound nitrogen, fuel NO_x can account for up to 50% of the total NO_x emissions.

A third and generally less important source of NO_x formation is **Prompt NO_x** which forms from the rapid reaction of atmospheric nitrogen with hydrocarbon radicals. Prompt NO_x is generally considered minor compared to the overall quantity of NO_x generated from combustion. However, as NO_x emissions are reduced to extremely low limits, the contribution of this source becomes more important.

NO_x emissions from boilers are influenced by many factors. The most significant factors are flame temperature the amount of nitrogen in the fuel, excess air level and combustion air temperature. **Also, a longer residence time at high temperatures results in higher NO_x.**

Most NO_x control technologies for industrial boilers with inputs less than 100 MMBtu/hr, reduce thermal NO_x and have little affect on fuel NO_x. Fuel NO_x is most economically reduced in commercial and industrial boilers by switching to cleaner fuels (fuels containing less fuel-bound nitrogen), if available.

Note:

Thermal NO_x refers to NO_x formed through high temperature oxidation of the diatomic nitrogen found in combustion air. (Milton R. Beychok (March 1973). "NOX emission from fuel combustion controlled" - [Oil & Gas Journal](#): 53–56.) The formation rate is primarily a function of temperature and the [residence time](#) of nitrogen at that temperature. At high temperatures, usually above 1300 °C (2600 °F), molecular nitrogen (N₂) and oxygen (O₂) in the combustion air dissociate into their atomic states and participate in a series of reactions.

NO_x Emissions in Thermal Vortex Combustion: Mitigation and Control

1. Overview

In high-temperature combustion systems such as a thermal vortex chamber (1,800°F to 2,200°F), nitrogen oxides (NO_x) can form even under complete combustion and optimal atmospheric control. This is primarily due to the thermal NO_x pathway, governed by the Zeldovich mechanism.

2. The Zeldovich Mechanism

The Zeldovich mechanism explains how thermal NO_x forms at high temperatures. It involves the direct reaction of atmospheric nitrogen (N₂) and oxygen (O₂) in the combustion chamber. The reactions are:

1. $\text{N}_2 + \text{O} \rightarrow \text{NO} + \text{N}$
2. $\text{N} + \text{O}_2 \rightarrow \text{NO} + \text{O}$
3. $\text{N} + \text{OH} \rightarrow \text{NO} + \text{H}$

These reactions are highly temperature-dependent, and NO formation increases exponentially at temperatures above ~1,800°F (980°C).

3. NO_x Emissions Conversion

The following table shows NO_x levels in ppm converted to mg/Nm³:

NO _x Level (ppm)	NO _x Concentration (mg/Nm ³)
150.0	307.90
30.0	61.58

4. Post-Combustion NO_x Control Options

4.1 Selective Catalytic Reduction (SCR)

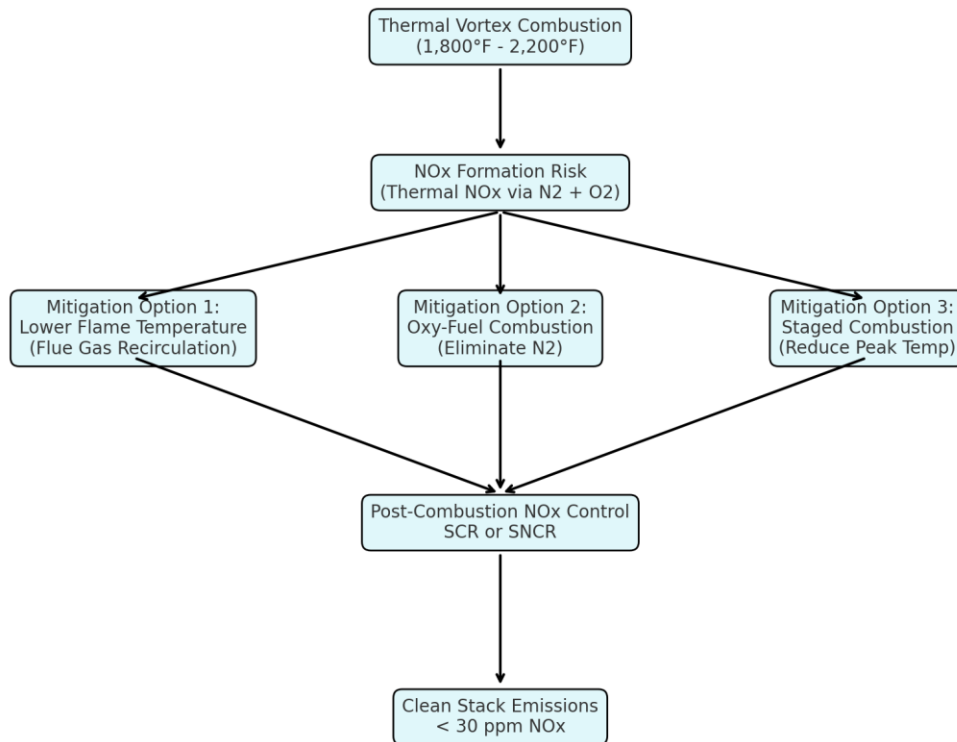
SCR involves injecting ammonia or urea into the flue gas in the presence of a catalyst. It is highly efficient, removing 70–95% of NO_x emissions. The optimal temperature range is 550–850°F (290–450°C).

4.2 Selective Non-Catalytic Reduction (SNCR)

SNCR also uses ammonia or urea, but without a catalyst. It is simpler and less expensive, with 30–70% efficiency. It operates at a higher temperature range of 1,600–2,100°F (870–1,150°C).

5. Mitigation Flowchart

The following flowchart illustrates possible pathways for NO_x mitigation in a thermal vortex system.



NO_x Emissions: Health Impacts, Environmental Effects, and Regulatory Standards

1. Human Health Impacts

Nitrogen oxides (NO_x), particularly NO₂, are linked to numerous health problems:

- Respiratory irritation, asthma, and coughing
- Reduced lung function and development in children
- Cardiovascular effects and elevated blood pressure
- Increased sensitivity among vulnerable groups (children, elderly)

2. Environmental Concerns

Environmental degradation from NO_x emissions includes:

- Ground-level ozone (smog) formation
- Acid rain from nitric acid formation
- Eutrophication in water bodies from nitrogen deposition
- Formation of PM_{2.5} particles contributing to air pollution

3. Regulatory Emission Limits

Combustion sources are regulated to prevent NO_x overproduction:

Agency / Jurisdiction	Source Type	NO _x Limit
US EPA (40 CFR Part 60)	Municipal Waste Combustors	≤ 150 ppm
California (BACT)	Waste-to-Energy Facilities	≤ 45 ppm
Indiana (IDEM)	General Combustion Sources	≤ 100 ppm
EU (IED)	Incineration Plants	≤ 200 mg/Nm ³ (~95 ppm)

4. Ambient Air Quality Standards (NO₂)

Ambient NO₂ exposure is regulated to protect human health:

Agency	Averaging Time	Limit	Comment
US EPA (NAAQS)	1-hour	100 ppb	Primary health-based standard
US EPA (NAAQS)	Annual	53 ppb	Chronic exposure limit
WHO	1-hour	200 µg/m ³ (~107 ppb)	Health guideline
WHO	Annual	40 µg/m ³ (~21 ppb)	Stricter than US EPA

5. Summary Infographic

The visual summary below highlights the key health, environmental, and regulatory aspects of NO_x emissions:

Health Impacts of NO_x

- Respiratory irritation, asthma, coughing
- Reduced lung development in children
- Cardiovascular strain and blood pressure risk
- Vulnerable populations: elderly, children

Environmental Impacts of NO_x

- Ground-level ozone (smog) formation
- Acid rain (nitric acid in atmosphere)
- Nutrient overload in lakes (eutrophication)
- PM2.5 particulate formation

Regulatory Emission Limits (Combustion Sources)

- US EPA (MWCs): ≤ 150 ppm
- California BACT: ≤ 45 ppm
- Indiana IDEM: ≤ 100 ppm
- EU (IED): ≤ 200 mg/Nm³ (~95 ppm)

Ambient Air Quality Standards (NO₂)

- US EPA: 100 ppb (1-hour), 53 ppb (annual)
- WHO: 200 µg/m³ (~107 ppb, 1-hour)
- WHO: 40 µg/m³ (~21 ppb, annual)

Post-Combustion NO_x Control Strategies for Thermal Vortex Systems

This document provides guidance on selecting and implementing NO_x reduction strategies for thermal vortex combustion systems operating at high temperatures (1,800–2,200°F). It includes a decision tree for control selection, an integrated SNCR design concept, and a cost-benefit comparison table for SCR vs. SNCR systems.

1. Decision Tree: Selecting a NO_x Control System

Use the following decision logic to determine the most appropriate NO_x mitigation system for the application:

- Is the flue gas temperature between 550–850°F?
 - YES: Consider SCR (Selective Catalytic Reduction)
 - NO: Continue
- Is the flue gas temperature between 1,600–2,100°F?
 - YES: Consider SNCR (Selective Non-Catalytic Reduction)
- Are NO_x emission limits < 50 ppm?
 - YES: SCR recommended (high-efficiency control)
 - NO: SNCR may suffice for moderate reduction needs
- Is catalyst maintenance acceptable?
 - NO: Use SNCR
 - YES: Use SCR

2. Integrated SNCR Design for Thermal Vortex Units

SNCR is a favorable solution for vortex systems due to the compatible temperature range. Key integration steps include:

- Injection Port Placement:
 - Install ammonia or urea injection nozzles immediately downstream of the combustion zone (within 1,600–2,100°F zone).
- Control System:
 - Use a temperature sensor and control algorithm to ensure injection only occurs in optimal temperature ranges.
- Mixing Enhancement:
 - Utilize vortex momentum and turbulence to improve reagent dispersion without added mechanical mixers.
- Ammonia Storage:
 - Include containment, dosing pump, and safety interlocks to manage ammonia slip risk.

Expected NO_x reduction: 30–70%

3. Cost-Benefit Comparison: SCR vs. SNCR

Feature	SCR	SNCR	Comment
NO _x Removal Efficiency	70–95%	30–70%	SCR is best-in-class
Temp Range	550–850°F	1,600–2,100°F	SNCR matches vortex temp
Complexity	High	Moderate	SCR requires catalyst & controls
Ammonia Use	Yes	Yes	Both require ammonia or urea
Catalyst Required	Yes	No	Cost and maintenance factor
Installation Cost	\$\$\$	\$	SCR can be 2–3x more expensive
O&M Costs	High	Moderate	SCR has ongoing catalyst replacement
Regulatory Benefit	★★★★	★★	SCR favored in strict air districts

NO_x Mass Emissions Table (Separated by PPM Level)

This table presents modeled NO_x mass emissions based on estimated concentrations of 200 ppm and 350 ppm. Each feedstock is shown with consistent combustion input (tons per hour), but different NO_x concentrations to reflect potential variability in combustion conditions. The values below can be used for permitting estimates under both low and high NO_x scenarios.

1. NO_x Mass Emission Estimates

Based on typical combustion of various feedstocks in a thermal vortex chamber, the following emission estimates were calculated:

Feedstock @ PPM	NO _x (ppm)	NO _x (kg/hr)	NO _x (lb/hr)
MSW (4 tons/hr) @ 200 ppm	200	3.69	8.15
MSW (4 tons/hr) @ 350 ppm	350	6.47	14.25
Woody Biomass (2 tons/hr) @ 200 ppm	200	1.85	4.07
Woody Biomass (2 tons/hr) @ 350 ppm	350	3.23	7.13
Tires (1 ton/hr) @ 200 ppm	200	1.23	2.72
Tires (1 ton/hr) @ 350 ppm	350	2.72	5.99

Flame Temperature

- Higher peak temps accelerate NO formation (Zeldovich mechanism).
 - The vortex chamber operates at 1,800–2,200°F — already within the range where thermal NO_x spikes exponentially.
 - A 100°F increase can significantly increase NO_x output.
-

Excess Air or Oxygen Levels

- Higher oxygen = more available O₂ to react with N₂.
 - If the system is running lean (more air than stoichiometric), it raises NO_x formation.
 - Tighter control of O₂ or using flue gas recirculation reduces this.
-

Vortex Turbulence / Mixing

- More mixing = better combustion... but also more uniform high-temperature zones.
 - In our chamber, a 90 mph vortex ensures extreme turbulence.
 - This may enhance NO_x in some areas by keeping gases hot longer.
-

Residence Time at High Temperatures

- Longer exposure to >1,800°F = more NO_x.
 - If combustion gases linger in the hot zone, thermal NO_x has more time to form.
-

Result: Why Use a Range (200–350 ppm)?

The actual NO_x ppm will depend on how the system is configured:

Scenario	Estimated NO _x (ppm)
Optimized control, cool flame core	~200 ppm
Average vortex operation	~250–300 ppm
High flame temp, no mitigation	~350 ppm+

Summary

“Variability in combustion conditions” means shifts in:

- Flame temperature
- Air/O₂ ratio
- Turbulence & mixing
- Residence time
- Startup/load transients

Each of these directly impacts how much NO_x forms from N₂ + O₂, regardless of feedstock.

2. Regulatory Standards and Health Thresholds

The following table summarizes regulatory and health-based NO_x limits for stationary combustion sources:

Regulatory Body	Limit Type	NO _x Limit
US EPA (40 CFR Part 60)	New Source Performance Standard (NSPS) for MWCs	< 150 ppm (dry basis)
US EPA	Permit limit (typical)	< 100 ppm
California Air Resources Board	BACT Standard for MSW Incinerators	< 45 ppm
World Health Organization	1-hour ambient limit (health-based)	200 µg/m ³ ≈ 0.107 ppm

Note: Regulatory limits vary by jurisdiction, fuel type, and technology classification. Permitting should consider stack height, dispersion modeling, and cumulative emissions impact.

Thermal Vortex Combustion of Seawater Contaminated Sargassum – Salt Behavior Report

Introduction

This report examines the chemical and operational behavior of salt (primarily sodium chloride, NaCl) present in seawater-contaminated sargassum during combustion in a horizontally positioned thermal vortex chamber operating at 2,000°F with a 90 mph vortex under conditions of complete and perfect combustion. It also evaluates regulatory implications, emission products, and mitigation strategies.

Operating Conditions

Parameter	Value
Chamber Orientation	Horizontal
Temperature	2,000°F (1,093°C)
Vortex Speed	90 mph
Combustion Type	Complete and Perfect
Exhaust Gases	<i>CO₂</i> : 6.979%, <i>H₂O</i> : 13.958%, <i>O₂</i> : 5.583%, <i>N₂</i> : 73.478%

Salt Behavior and Chemical Reactions

At 2,000°F, sodium chloride (NaCl) melts and may begin to partially volatilize in the vortex chamber. The intense turbulence in the vortex promotes disassociation, whereby the high kinetic energy and shear forces help break down molecular bonds. Sodium and chlorine may dissociate into reactive species that form hydrogen chloride (HCl), sodium oxide (Na₂O), and metal chlorides in the presence of other combustion byproducts.

Emissions Profile and Regulatory Limits

Compound	Regulatory Limit	Notes
Hydrogen Chloride (HCl)	2 ppmv	Corrosive and regulated acid gas (EPA MACT)
PM2.5 with Na salts	< 10 mg/dscm	Fine particulates from alkali condensation
Corrosive condensates	Neutralization required	Impacts ducts and heat exchangers

Recommended Mitigation Strategies

- Spray quenching or wet scrubbing (neutralize HCl with lime or NaOH)
- Use chloride-resistant refractory materials
- Cyclone + baghouse/ESP to capture alkali particulates
- Dewater and rinse sargassum prior to combustion
- Inject limestone or kaolin to bind sodium/chlorine

Conclusion

Salt from seawater on sargassum introduces chlorine, which produces corrosive and regulated emissions like HCl and alkali oxides. While the thermal vortex's complete combustion and high temperature prevent dioxin formation, acid gases and corrosion risks remain. Proper emission control, materials selection, and pre-treatment are essential.

Translating Arsenic from Sargassum Feed to Air (Feed → Stack → Ambient)

1. Feedstock: Sargassum Arsenic Content

(Arsenic is a chemical element with a symbol of “As” and an atomic number of 33)

- Typical range: **20 – 150 mg As/kg dry weight**
- Example basis: **100 mg/kg (0.01%)**
- Inorganic fraction often **60–80%** (most toxic form)

2. Stack Emissions (WtE Combustion Example)

Emission Fraction	Stack Concentration	Equivalent (micrograms/Nm³)
0.1% of As emitted	0.0167 mg/Nm³	16.7 µg/Nm³
1% of As emitted	0.167 mg/Nm³	167 µg/Nm³
5% of As emitted	0.833 mg/Nm³	833 µg/Nm³

Reference: Typical EU Waste Incineration BAT-AELs for total metals: ~0.05–0.1 mg/Nm³ (well below 1%).
Modern baghouses + ACI routinely meet this.

3. Ambient Air Concentrations (After Dilution)

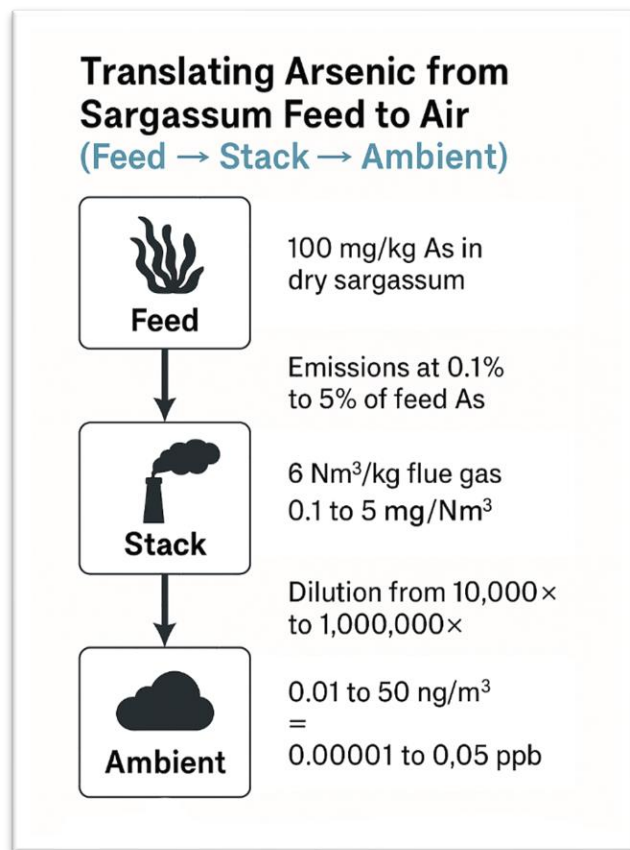
Stack → Ambient Dilution	Ambient As (µg/m³)	Approx. ppb (by mass)	ng/m³	Comment
10k : 1	0.0017	0.0017	1,700	Very close to stack source
100k : 1	0.00017	0.00017	170	Typical near-field plume
1,000k : 1	0.000017	0.000017	17	Regional average

4. Health & Regulatory Benchmarks

Reference	Limit	Equivalent in ppb	Context
EU target ambient air (annual)	6 ng/m³	0.006 ppb	Public exposure standard
Typical industrial ambient	10–50 ng/m³	0.01–0.05 ppb	Observed near heavy industry
OSHA PEL (workplace)	10 µg/m³	10 ppb	8-hour occupational limit
EPA IRIS cancer risk goal (10 ⁻⁶ ELCR)	0.00023 µg/m³	0.00023 ppb	Risk-based benchmark

5. Key Insights

- **Feed → Stack → Ambient:** Only a small fraction ($\ll 1\%$) of feedstock As can produce measurable airborne concentrations.
- **Controls:** Activated Carbon Injection + Baghouse capture $>99\%$ of metal vapors.
- **Benchmarking:** Even conservative 1% release diluted $1,000\times$ remains near 0.017 ng/m^3 —below EU 6 ng/m^3 limit.
- **Speciation:** Inorganic As (As(III), As(V)) dominates toxicity—speciation testing is key.
- **Transparency:** Public outreach should cite both **EU targets** and **IRIS risk values** to demonstrate alignment with best international standards.



Bottom Line: With proper control and dilution, even high-As sargassum feedstocks can be safely combusted within international air-quality benchmarks.

Sargassum Arsenic Translator (ppb–stack–feed)

Feed As (mg/kg DW)	Emission fraction label	Emitted As (mg/kg feed)	Flue gas (Nm ³ /kg feed)	Stack As (mg/Nm ³)	Stack As (µg/Nm ³)	Dilution label	Ambient As (ng/m ³)	Ambient As (µg/m ³)	Ambient As (ppb, ~by mass)
100	0.1%	0.1	6	0.016667	16.66667	10k:1	1.666667	0.001667	0.001667
100	0.1%	0.1	6	0.016667	16.66667	100k:1	0.166667	0.000167	0.000167
100	0.1%	0.1	6	0.016667	16.66667	1,000k:1	0.016667	0.000017	0.000017
100	1%	1	6	0.166667	166.6667	10k:1	16.66667	0.016667	0.016667
100	1%	1	6	0.166667	166.6667	100k:1	1.666667	0.001667	0.001667
100	1%	1	6	0.166667	166.6667	1,000k:1	0.166667	0.000167	0.000167
100	5%	5	6	0.833333	833.3333	10k:1	83.33333	0.083333	0.083333
100	5%	5	6	0.833333	833.3333	100k:1	8.333333	0.008333	0.008333
100	5%	5	6	0.833333	833.3333	1,000k:1	0.833333	0.000833	0.000833

Sulfur Dioxide Content in Emissions of Certain Waste Materials

Combustion of certain waste materials can produce **high levels of sulfur dioxide (SO₂)**, especially those with a high sulfur content. Here are key categories of such waste:

Waste Materials That Emit High Sulfur Dioxide When Burned

1. Coal and Coal Byproducts

- **Bituminous and lignite coal** have higher sulfur content than anthracite.
- **Coal fines, tailings, and rejects** used in waste-to-energy or industrial combustion can release large amounts of SO₂.

2. Industrial Waste

- **Petroleum-based sludge and refinery waste:** These often contain sulfur compounds.
- **Chemical manufacturing byproducts:** Sulfuric acid production residues, metal sulfides.

3. Tires and Rubber Products

- Especially those containing **vulcanized rubber**, which includes sulfur compounds as part of the curing process.

4. Plastics Containing Sulfur

- Some **thermosetting resins** and specialized polymers (e.g. **thiol-based plastics**) include sulfur in their structure.

5. Oil and Petroleum Wastes

- **Crankcase oils**, bunker fuels, and heavy fuel oils often have high sulfur concentrations.
- Waste from **shipping or maritime industries** using heavy fuel oil (HFO) is a major SO₂ emitter.

6. Certain Organic Wastes

- **Animal manures** (especially poultry litter) and **slaughterhouse waste**, depending on diet and feed additives.
- **Sewage sludge**, which may accumulate sulfur from industrial or municipal sources.

7. Construction and Demolition Waste

- Especially **gypsum board (drywall)** when mixed with organic materials can result in SO₂ and even **H₂S** formation under certain conditions.

Chemical Note:

When these sulfur-containing materials are burned, sulfur is oxidized primarily to:

- **SO₂** (sulfur dioxide)
- Under certain conditions (e.g., catalytic presence), further oxidation to **SO₃** (which forms sulfuric acid in the atmosphere)

Sulfur Content and SO₂ Emission Potential of Waste Materials

Waste Material	Typical Sulfur Content (%)	SO ₂ Emission Potential	Notes
Bituminous Coal	1.0 – 4.0	High	Major source of SO ₂ in power generation
Lignite Coal	0.5 – 3.0	Moderate to High	Used in WtE but requires scrubbers
Refinery Sludge	2.0 – 6.0	Very High	Hazardous waste; requires special handling
Used Motor Oil	0.5 – 1.5	Moderate to High	Common in incineration of automotive waste
Scrap Tires	1.0 – 2.5	High	Often used in cement kilns; emits SO ₂ & other toxics
Vulcanized Rubber	1.5 – 2.5	High	Sulfur used in curing adds to SO ₂ emissions
Plastic with Thiol Groups	Up to 3.0	Moderate to High	Specialty plastics, problematic in municipal streams
Poultry Manure	0.3 – 1.2	Moderate	Emissions depend on feed additives
Sewage Sludge	0.5 – 2.0	Moderate	Can contain industrial sulfur residues
Gypsum Board (Mixed with Organic Waste)	Low (source-dependent), but can produce H ₂ S and SO ₂	Variable, depending on combustion conditions	SO ₂ released if organic material is present

Health-based Ambient Limits and Common Stack Limits for WtE/Combustion

Below is a compact “field brief” with the numbers people usually quote (and the ones they *should*). We split it into: (1) health-based **ambient** limits, (2) common **stack** limits for WtE/combustion, and (3) quick “both-sides” talking points so we’re ready for crossfire!

Quick reference: what counts as “unsafe” in air

Pollutant	Health-based ambient guideline (public exposure)	U.S. regulatory standard (NAAQS)	Notes
NO ₂	WHO: 10 µg/m ³ annual, 25 µg/m ³ 24-h	100 ppb 1-h (98th %ile, 3-yr avg), 53 ppb annual	WHO is stricter than the U.S. NAAQS; both are widely cited. World Health Organization
SO ₂	WHO: 40 µg/m ³ 24-h (10-min guideline unchanged at 500 µg/m ³)	75 ppb 1-h (99th %ile, 3-yr avg)	WHO raised its 24-h value from 20→40 µg/m ³ in 2021 after re-evaluation. World Health Organization
Arsenic (As) in ambient air	EU target: 6 ng/m ³ annual (PM ₁₀)	(No U.S. NAAQS)	U.S. risk managers use IRIS cancer unit risk; EU sets a numeric target. EUR-Lex
Dioxins + Furans (PCDD/F)	No ambient “ppm/ppb” standard; risk is managed by intake (diet dominates). EFSA TWI: 2 pg TEQ/kg-week (very strict)	(No U.S. NAAQS)	Ambient air is minor exposure; food chain control & stack limits matter most. European Food Safety Authority

Typical combustion/WtE stack limits we’ll hear

- **Dioxins/Furans (as I-TEQ): 0.1 ng I-TEQ/Nm³ @ 11% O₂** — this is the EU Industrial Emissions Directive (and aligned with Stockholm Convention guidance) and has become the global benchmark for modern incinerators. U.S. MACT limits are in the same ballpark by source category. eippcb.jrc.ec.europa.eu
- **NO_x & SO₂ (WtE):** Values vary by permit and BAT, but the EU WI BAT-AELs drive NO_x ~50–150 mg/Nm³ and SO₂ ~10–50 mg/Nm³ (daily averages) for best-available control. Permits in the U.S. often translate to similar or lower numbers when SCR/FGD is fitted. eippcb.jrc.ec.europa.eu
- **Arsenic:** Typically controlled under total metals or specific metal limits with activated carbon + baghouse; jurisdictional limits vary, but compliance is demonstrated via metals suites and very low Parts-Per-Million fuel/ash specs, not an ambient NAAQS. (EU ambient target above is often referenced.) eippcb.jrc.ec.europa.eu

Toxicology “anchors” people cite

- **Dioxins/Furans:**
 - Health risk is usually framed as **TEQ intake** (not ambient ppm): **EFSA 2018 TWI = 2 pg TEQ/kg-week** (very conservative). Historical WHO/JECFA values were higher (1–4 pg/kg-day; older literature and risk papers may still quote ~1–10 pg/kg-day as an RfD-style band). [European Food Safety Authority](https://www.efsa.europa.eu/)

- **Arsenic (inorganic):**
 - **EPA IRIS inhalation unit risk** (cancer potency) is commonly used to derive risk-based air concentrations; tables often cite an IUR on the order of $\sim 4.3 \times 10^{-3} (\mu\text{g}/\text{m}^3)^{-1}$. ATSDR has **no chronic inhalation MRL** for inorganic arsenic (reflecting data limits), so risk tools lean on IRIS and site-specific assessments. [NCBI](#)

Where opponents usually push (and how to respond)

Dioxins/Furans

- **Critic's claim:** "Incinerators make dioxin; any spike is unacceptable."
Our response: Modern plants design around the "de novo window" ($\approx 200\text{--}450^\circ\text{C}$) by keeping **primary combustion hot ($\geq 850\text{--}1100^\circ\text{C}$), oxygen-rich, with ≥ 2 s residence**, then **rapid quench + activated carbon injection + high-efficiency baghouse**. This is how facilities demonstrate $\leq 0.1 \text{ ng I-TEQ}/\text{Nm}^3$ in continuous performance tests. Cite EU WI BREF and BAT. eippcb.jrc.ec.europa.eu
- **Critic's claim:** "Ambient dioxin levels are unsafe."
Our response: Public exposure is overwhelmingly **dietary**; well-controlled stacks are a **minor** contributor to intake. Regulators manage risk with **intake limits (EFSA TWI)** plus stringent **stack TEQ limits**; continuous improvements have cut PCDD/F from modern plants by orders of magnitude versus 1990s' sources. [European Food Safety Authority](#)

NO_x

- **Critic:** "NO_x drives asthma; NAAQS too lax vs WHO."
Us: Acknowledge: **WHO annual = $10 \mu\text{g}/\text{m}^3$** is tighter than **U.S. annual = 53 ppb ($\sim 100 \mu\text{g}/\text{m}^3$)**. Use **low-NO_x burners + staged combustion + SCR** to hit BAT-AELs (often $\leq 100 \text{ mg}/\text{Nm}^3$), then show modeled downwind concentrations vs **both** WHO and NAAQS. [World Health Organization](#)

SO₂

- **Critic:** "SO₂ spikes irritate lungs."
Us: Point to our **1-hour modeled design value** vs the U.S. **75 ppb** form (99th %ile over 3 years). Also reference WHO **24-h $40 \mu\text{g}/\text{m}^3$** ; with **wet/dry FGD** and sulfur-lean fuels/feeds, modeled ambient typically sits well below both. [EPA](#)

Arsenic

- **Critic:** "There's no safe level."
Us: Cancer risk is managed via **IRIS unit risk** and **permit-by-rule metals limits**; show site-specific risk calculations (e.g., **excess lifetime cancer risk $\leq 10^{-6}$ – 10^{-5}** policy targets) and monitoring plans. Note the **EU $6 \text{ ng}/\text{m}^3$ annual** target as a recognizable benchmark for ambient. [NCBI](#)

What to put in our permits / fact sheets

- **Standards we'll meet:** Quote **U.S. NAAQS for NO₂ (1-h 100 ppb; annual 53 ppb)** and **SO₂ (1-h 75 ppb)**, and **EU $6 \text{ ng}/\text{m}^3$** for arsenic as a comparative ambient target where helpful. Include **WHO 2021** values for additional public-health context to show we're designing to a stricter yardstick. [EPA](#)

- **Emission controls:** Name the specific tech (e.g., SCR for NO_x, FGD for SO₂, **ACI+baghouse** for dioxins/metals), not just “best available control.” Tie them to **EU WI BAT-AELs** (strong credibility). eippcb.jrc.ec.europa.eu
- **Dioxin assurance:** Commit to the **0.1 ng I-TEQ/Nm³ @ 11% O₂** limit with commissioning and periodic stack tests + continuous surrogates (CO, temp, O₂) and **rapid quench** SOPs to avoid de novo formation. eippcb.jrc.ec.europa.eu
- **Risk framing for arsenic:** State we’ll evaluate **modeled ambient As** against **EU 6 ng/m³** and disclose a **site-specific cancer risk calc using IRIS IUR**, keeping **ELCR ≤10⁻⁶–10⁻⁵**. [EUR-Lex](http://eur-lex.europa.eu)

One-liners we can use in Q&A

- “We designed to meet **WHO 2021** health guidelines *and* U.S. NAAQS, not just one or the other.” [World Health Organization](http://www.who.int)
- “For dioxins/furans we’re at the global benchmark of **≤0.1 ng I-TEQ/Nm³** with **ACI + baghouse** and **rapid quench**, the same standard underpinning the EU IED and Stockholm guidance.” eippcb.jrc.ec.europa.eu
- “Arsenic risk is handled with the **IRIS unit risk method** and verified against **6 ng/m³** ambient targets used in the EU.” [NCBI](http://ncbi.nlm.nih.gov)

What the literature says about arsenic in sargassum

Here are representative findings on arsenic concentrations in different sargassum / seaweed samples:

Study / Location	Type (drift / beach / holopelagic)	Total As (mg/kg dry)	Inorganic As fraction / notes
Pelagic sargassum arriving in Barbados	Drift / sea	(varies)	Inorganic As is a “consistent and substantial percentage” of total As. PubMed
Mexican Caribbean beach (S. fluitans III)	Beach / stranded	~ 62.2 mg/kg (Dec) to ~ 89.0 mg/kg (Mar)	After processing, they reduced to as low as 0.8 mg/kg. MDPI
Element concentrations in pelagic Sargassum (Mexican)	Drift / harvested	24 – 172 mg/kg DW	86 % of samples exceeded 40 mg/kg (animal feed limit). PMC
General review of Sargassum spp.	Mixed (drift, beached)	80–150 ppm (i.e. mg/kg) often observed	These are “regularly observed” ranges. Sargcoop
Sargassum washed onto beaches, Mexico, 2018	Beached	29.0 – 65.7 mg/kg	Exceeds French food safety seaweed recommendations. Environmental Protection Agency
Composting sargassum (end product)	Processed / composted	6.64 – 26.5 mg/kg	These end-compost values sometimes exceed Florida soil cleanup targets. Helena Solo-Gabriele

Study / Location	Type (drift / beach / holopelagic)	Total As (mg/kg dry)	Inorganic As fraction / notes
Decomposition release study	In situ decomposition	~ 40.5 mg/kg released out of 76.9 mg/kg over 180 days	Implies arsenic becomes mobile during biomass breakdown. ScienceDirect

A few additional useful points:

- In **brown algae / Sargassum**, a high share (often **69 % to 85 %**) of the total arsenic is in **inorganic forms (As(III), As(V))** or species considered more toxic. [MDPI](#)
- Some seaweed species (not always Sargassum) primarily carry **organic arsenic species (arsenosugars, arsenolipids)**, which are less acutely toxic. [SpringerLink](#)
- There is temporal and spatial variation—“month, year, ocean sub-origins” sometimes *do not* strongly drive the As concentration in some studies. [PubMed](#)
- During decomposition of sargassum, arsenic becomes mobilized studies show significant release over months. [ScienceDirect](#)

So, in rough terms: **tens to low hundreds of mg As per kg dry weight** is common in many sargassum samples, and often a substantial proportion is in the inorganic (more toxic) fraction.

What “dangerous” means in this context & how to interpret for emissions / decomposition

To go from “mg As per kg seaweed” to “dangerous in emissions / air / risk,” we need to consider:

1. Mass flux & emissions pathway

Even if sargassum has, say, 100 mg As/kg dry, if only a small fraction volatilizes or becomes aerosol during combustion or decomposition, the actual airborne arsenic might be low — or conversely, if we burn large mass, the arsenic flux may be high.

2. Speciation & bioavailability

Inorganic arsenic (As(III), As(V)) is much more toxic than many organic arsenic species. If the biomass has, say, 70% inorganic As, that greatly increases risk potential (vs if most As is in benign organic forms). Many Sargassum species have high proportions of inorganic As. [MDPI](#)

3. Release during decomposition

Studies show that when sargassum decomposes (onshore, in piles, in compost), arsenic becomes mobilized—leaching into groundwater, volatilizing in some cases, or being redistributed. For example, one study showed that out of 76.9 mg/kg, ~40.5 mg/kg was released over 180 days. [ScienceDirect](#)

4. Health / regulatory benchmarks

To judge “dangerous,” we compare airborne concentrations ($\mu\text{g}/\text{m}^3$ or ng/m^3) or soil / leachate concentrations vs regulatory or health benchmarks. For arsenic in air, we know from ambient air studies that background levels are often **fractions of ng/m^3** and in industrial zones perhaps a few ng/m^3 or tens of ng/m^3 . (E.g. remote ~0–1 ng/m^3 , rural ~0.2–1.5 ng/m^3 , urban 0.5–3 ng/m^3 , industrial site up to ~50 ng/m^3). [Wikipedia](#)

5. Cumulative exposure & risk targets

One often uses **cancer risk models** (e.g. EPA IRIS inhalation unit risk) to map an airborne concentration

to an incremental lifetime cancer risk. If using sargassum emissions, we'd need to assess how much arsenic is emitted, how it disperses, what fraction is inorganic, and add that exposure to other arsenic sources.

A rough illustrative scenario

Let's walk through a rough hypothetical:

- Suppose there's a stockpile of **1000 tons dry sargassum** with **100 mg As/kg** (i.e. 0.1 g As per kg) => that's **100 kg of arsenic total** in that stockpile.
- If we burn it or decompose it, assume (conservatively) 1% of arsenic becomes airborne (as particulates, vapors) → we'd emit **1 kg arsenic** into air over time.
- If that is emitted into a stack / plume, we'd model dispersion; maybe it dilutes to, say, 1 ng/m³ over the nearby community (just illustrative).
- Compare that 1 ng/m³ airborne As to ambient benchmarks (for example, background is often sub-ng/m³, but regulatory risk modeling might permit a few ng/m³ depending on site) → see whether it contributes a significant risk.

This example shows that even “relatively high” biomass arsenic may or may not lead to dangerously high airborne levels, depending on emission fraction, dispersion, and speciation.

What a skeptic would say if pushed:

- **“Those arsenic in sargassum levels are alarming!”** — Yes, on a dry weight basis, levels of tens to over a hundred mg/kg are well documented in many studies.
- **“But that doesn't translate to dangerous air concentrations necessarily.”** — Correct; the critical question is what fraction becomes airborne / volatilized or in particulate, and how well controls / stacking / dispersion work.
- **“Don't forget decomposition release!”** — Even if the biomass isn't burned, decomposition can solubilize arsenic (leachate, vapor, gas) and mobilize it into water or ambient air.
- **“Speciation matters!”** — If much of the arsenic is in less toxic organic forms, risk is lower; but many Sargassum species have significant inorganic arsenic fractions.
- **“We must model emissions + dispersion + exposure”** — We can't just cite mg/kg; we must tie that into a fate and transport model to compare to air/soil/water toxicity benchmarks.

1. Basic Conversion Reference

1 µg/m³ = 1 microgram per cubic meter of air

To convert to **ppb**, we use the relationship between concentration by mass (µg/m³) and by volume (ppb). For gases, it depends on molecular weight and temperature/pressure, but for **metals like arsenic (in particulate form)**, the most practical conversion is this:

$$1 \mu\text{g}/\text{m}^3 \approx 1 \text{ppb} \times \frac{M_{\text{air}}}{M_{\text{As}}} \times \frac{10^3 \text{ L}}{\text{m}^3} \quad 1 \mu\text{g}/\text{m}^3 \approx 1 \text{ppb} \times \frac{M_{\text{air}}}{M_{\text{As}}} \times 10^3$$

However, since arsenic in air is measured as **mass of particulate metal per m³**, and not a gas-phase molecule, we can use a more intuitive comparison:

- $1 \mu\text{g}/\text{m}^3 = 1000 \text{ ng}/\text{m}^3$
- $1 \text{ ng}/\text{m}^3 = 0.001 \mu\text{g}/\text{m}^3$

And in environmental chemistry, when someone says “**ppb in air**”, they often mean **ppb by mass**:

$1 \text{ ppb} \approx 1 \mu\text{g of pollutant per } 1000 \text{ g of air} \approx 1 \mu\text{g}/\text{m}^3 \approx 1 \text{ ppb (by mass)}$
 $1 \text{ ppb} \approx 1 \mu\text{g of pollutant per } 1000 \text{ g of air} \approx 1 \mu\text{g}/\text{m}^3 \approx 1 \text{ ppb (by mass)}$

So for arsenic particulates, we can safely interpret $1 \mu\text{g}/\text{m}^3 \approx 1 \text{ ppb}$.

2. Ambient Arsenic Concentrations (Converted to ppb)

Environment Type	Arsenic (ng/m ³)	Arsenic (μg/m ³)	Approx. ppb (by mass)	Notes
Remote / Background	0.1 – 0.5 ng/m ³	0.0001 – 0.0005 μg/m ³	0.0001 – 0.0005 ppb	Open ocean or pristine areas
Rural / Urban Average	0.5 – 3 ng/m ³	0.0005 – 0.003 μg/m ³	0.0005 – 0.003 ppb	Typical urban ambient
Industrial / Smelter vicinity	10 – 50 ng/m ³	0.01 – 0.05 μg/m ³	0.01 – 0.05 ppb	Hotspot or metal-processing region
WHO / EU “target” air level	6 ng/m ³ annual mean	0.006 μg/m ³	0.006 ppb	Used as annual limit value in EU

So typical **background As levels are in the 0.0001–0.01 ppb range**, and even industrial areas seldom exceed **0.05 ppb** in air.

3. Hypothetical Sargassum Emission Scenario in ppb

Let’s reuse the rough scenario from before:

Scenario:

- **1000 metric tons of dry sargassum**
- **100 mg As/kg (0.01%) total arsenic**
- **1% becomes airborne during burning/decomposition**
- That equals **1 kg arsenic emitted total**.

Assume this 1 kg As disperses in a **1 km × 1 km × 100 m air layer** (a rough near-source mixing volume = 10^8 m^3).

$1 \text{ kg} = 10^6 \text{ mg} = 10^9 \mu\text{g}$
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 $10^9 \mu\text{g} \div 10^8 \text{ m}^3 = 10 \mu\text{g}/\text{m}^3 \approx 10 \text{ ppb (by mass)}$
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That’s a **localized 10 ppb** spike—massive compared to ambient (< 0.01 ppb)—but such a confined mixing volume is unrealistically small. With realistic dispersion (say 100× larger air volume), it falls quickly:

Mixing Volume (m³)	Mean Conc. (µg/m³)	Approx. ppb	Comment
10 ⁸ (dense local plume)	10	10 ppb	Extremely high, short-term
10 ⁹ (moderate dispersion)	1	1 ppb	Still 100–1000× above background
10 ¹⁰ (regional mixing)	0.1	0.1 ppb	Order-of-magnitude over typical urban
10 ¹¹ (wide dispersion)	0.01	0.01 ppb	Approaches industrial background range

So depending on plume spread and control systems, **emissions could theoretically range from sub-ppb to a few ppb in near-field air.**

4. Toxicological & Regulatory Context in ppb

Reference / Benchmark	Value	Equivalent in ppb	Context
EU Target Ambient Air Level	6 ng/m³	0.006 ppb	Annual average
OSHA workplace PEL (8 h TWA)	10 µg/m³	10 ppb	Occupational exposure, not public
EPA IRIS unit-risk goal (10 ⁻⁶ cancer risk)	~0.00023 µg/m³	0.00023 ppb	Risk-based “safe” level
Industrial area typical	10–50 ng/m³	0.01–0.05 ppb	Real-world baseline

So, to stay clearly below long-term health concern, we’d want **ambient arsenic near facilities to remain under ~0.01 ppb (10 ng/m³)**, and ideally in the single-ng/m³ range.

5. Key Takeaways

- 1. **Sargassum arsenic content (≈ 20–150 mg/kg)** is high enough that even a small volatilization fraction can spike local airborne As by orders of magnitude above background.
- 2. **Typical “safe” ambient air levels** are around **0.005–0.01 ppb (5–10 ng/m³)** annual average.
- 3. **Occupational limits** are 1000× higher (≈ 10 ppb = 10 µg/m³).
- 4. **Emission controls** (e.g., ACI + baghouse) are essential if sargassum is thermally processed, to capture heavy metals including arsenic.