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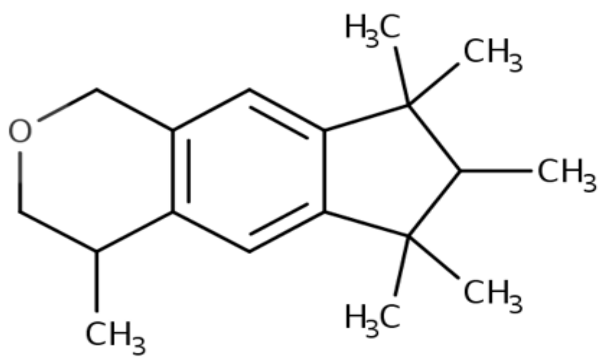
Draft Human Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)

Technical Support Document for the Draft Risk Evaluation

CASRN 1222-05-5



March 2026

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

KEY ABBREVIATIONS AND ACRONYMS

30Q5	Lowest 30-day average flow that occurs (on average) once every 5 years
ACH	Air changes per hour (air exchange rate)
ADC	Average daily concentration
ADD	Average daily dose
ADME	Absorption, distribution, metabolism, and elimination
ADR	Acute dose rate
AF	Assessment factor
APDR	Acute potential dose rate
BCF	Bioconcentration factor
BLS	Bureau of Labor Statistics (U.S.)
CADD	Chronic average daily dose
CASRN	Chemical Abstracts Service Registry Number
CDR	Chemical Data Reporting
CEM	Consumer Exposure Model
ChemSTEER	Chemical Screening Tool for Exposures and Environmental Releases
COU	Condition of use
CPS	Current Population Survey
DTD	Down-the-drain
EPA	Environmental Protection Agency (U.S.)
FDA	Food and Drug Administration (U.S.)
HHCB	1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran
IADD	Intermediate average daily dose
KABAM	K_{OW} (based) Aquatic BioAccumulation Model
K_{OW}	Octanol-water partition coefficient
LADC	Lifetime average daily concentration
MCCEM	Multi-chamber concentration
NAICS	North American Industry Classification System
OAQPS	Office of Air Quality Planning and Standards (EPA)
OCSPP	Office of Chemical Safety and Pollution Prevention (EPA)
OECD	Organisation for Economic Co-operation and Development
OES	Occupational Exposure Scenario
ONU	Occupational non-users
OPPT	Office of Pollution Prevention and Toxics (EPA)
OSHA	Occupational Safety and Health Administration (U.S.)
PESS	Potentially exposed or susceptible subpopulation(s)
PNOR	Particulates not otherwise regulated
POD	Point of departure
POTW	Publicly owned treatment works (wastewater)
PSC	Point Source Calculator
ReCAAP	Rethinking Chronic Toxicity and Carcinogenicity Assessment for Agrochemicals Project

SHEDS-HT	Stochastic Human Exposure and Dose Simulations-High Throughput
SIC	Standard Industrial Code
SIPP	Survey of Income and Program Participation
SWC	Surface water concentration
TRI	Toxics Release Inventory
TSD	Technical support document
TWA	Time-weighted average
TSCA	Toxic Substances Control Act
U.S.	United States
VVWM	Variable Volume Water Model
w/w	Weight by weight
WWT	Wastewater treatment

SUMMARY

This technical support document (TSD) is part of the Toxic Substances Control Act (TSCA) *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (also called the "HHCB draft risk evaluation") (U.S. EPA, 2026i). HHCB (CASRN 1222-05-5) is a fragrance ingredient in cleaning, laundry, and air care products. This draft assessment employs a tiered approach, combining screening-level methods with more refined analyses, which are selected based on the evaluated population as well as the relevant exposure routes and pathways. Tiered approaches enable timely assessments and conserve resources by focusing efforts on chemicals, uses, locations, populations, or exposure pathways and routes with the highest potential risk. This TSD details the exposure analysis supporting the draft risk evaluation conclusions for HHCB conditions of use (COUs) under TSCA, focusing on scenarios with high-end exposure levels for workers, high-end exposure levels for consumers, and more refined exposure estimates for the general population. It considers available monitoring data as well as modeled exposure estimates. These upper-bound and high-end exposure scenarios for HHCB serve as screening-level analyses, and the resulting estimations are expected to be higher than exposure across all COUs in the draft risk evaluation.

HHCB exposure can occur via inhalation, ingestion, or dermal contact; however, EPA focused on inhalation and oral exposures due to the absence of dermal hazard effects. The evaluation employed standard peer-reviewed models to assess exposure, considering factors like chemical production and use volume, processing temperature, and exposure frequency.

EPA estimated that the highest potential HHCB exposure may occur in certain tribal populations through consumption of fish containing HHCB from combined commercial and consumer down-the-drain releases; however, the high-end of this scenario is not widespread and depends on specific, rarely co-occurring conditions. Another significant exposure pathway is occupational: Workers, including women of childbearing age, may experience high-end, condition-specific exposure from inhaling HHCB dust from handling plastic pellets or vapor from heated and concentrated liquids. As the focus was on generating upper-bound or high-end estimates, EPA did not separately estimate occupational non-users or bystanders, because these exposures would be similar or lower than the individuals directly exposed. Oral exposures to workers are not expected because adults are not expected to commonly engage in hand-to-mouth behaviors in occupational settings. Moreover, no reasonably available HHCB COU-specific data suggests oral exposure for workers.

Despite widespread use, consumer products containing HHCB result in relatively low exposure—even under conversative screening levels designed to overestimate exposure. The highest estimated consumer exposures from mist emitted by continuous action air fresheners occur in infants. Direct oral consumer exposures are not expected based on consumer product use patterns, though incidental exposures may occur. Drinking water exposure was also evaluated but is expected to be low and not widespread due to removal during typical water treatment processes. A high-level summary of exposure estimates is provided below in Table S-1.

Table S-1. Summary of HHCB Exposure Estimates

Population (Subpopulation) [a]	Exposure Scenario	Route of Exposure	Highest Estimated Dose (mg/kg-day)
Worker (females 16–21 years)	Formulation of fragrance oils	Vapor inhalation	2.05E−03
Worker (females 16–21 years)	Plastic compounding/converting	Dust inhalation	8.35E−02
Consumer (infants <1 year)	Continuous air fresheners	Mist inhalation	1.27E−03
General population (adults)	Fish consumption	Oral ingestion	1.51E−02
Tribal (adults)	Fish consumption	Oral ingestion	9.27E−02
General population (infants <1 year)	Drinking water	Oral ingestion	7.16E−04

[a] For each population group, there may be a subpopulation generally covering a specific age range where the estimated dose incorporates age-specific factors related to inhalation or ingestion rates and body weights.

Overall, the Agency has moderate to robust confidence in the exposure scenarios, the associated exposure estimates, and the exposure characterization used to inform the draft HHCB risk evaluation.

1 INTRODUCTION

This TSD, also called the "draft human exposure TSD," accompanies the TSCA *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (also called the "draft HHCB risk evaluation") (U.S. EPA, 2026i). EPA applies the best available science using a weight of scientific evidence approach (see *Draft Systematic Review Protocol for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026k)). A basic diagram of the HHCB risk evaluation is shown below in Figure 1-1. This draft TSD is shaded blue and focuses on human exposure, whereas a separate draft TSD addresses physical chemistry, fate and transport, environmental release, and environmental exposure (U.S. EPA, 2026e). Due to overlapping models and assumptions, some results are shared between both documents. More specifically, this draft TSD summarizes human exposure information and refers to the environmental exposure TSD for the detailed approaches and methods.

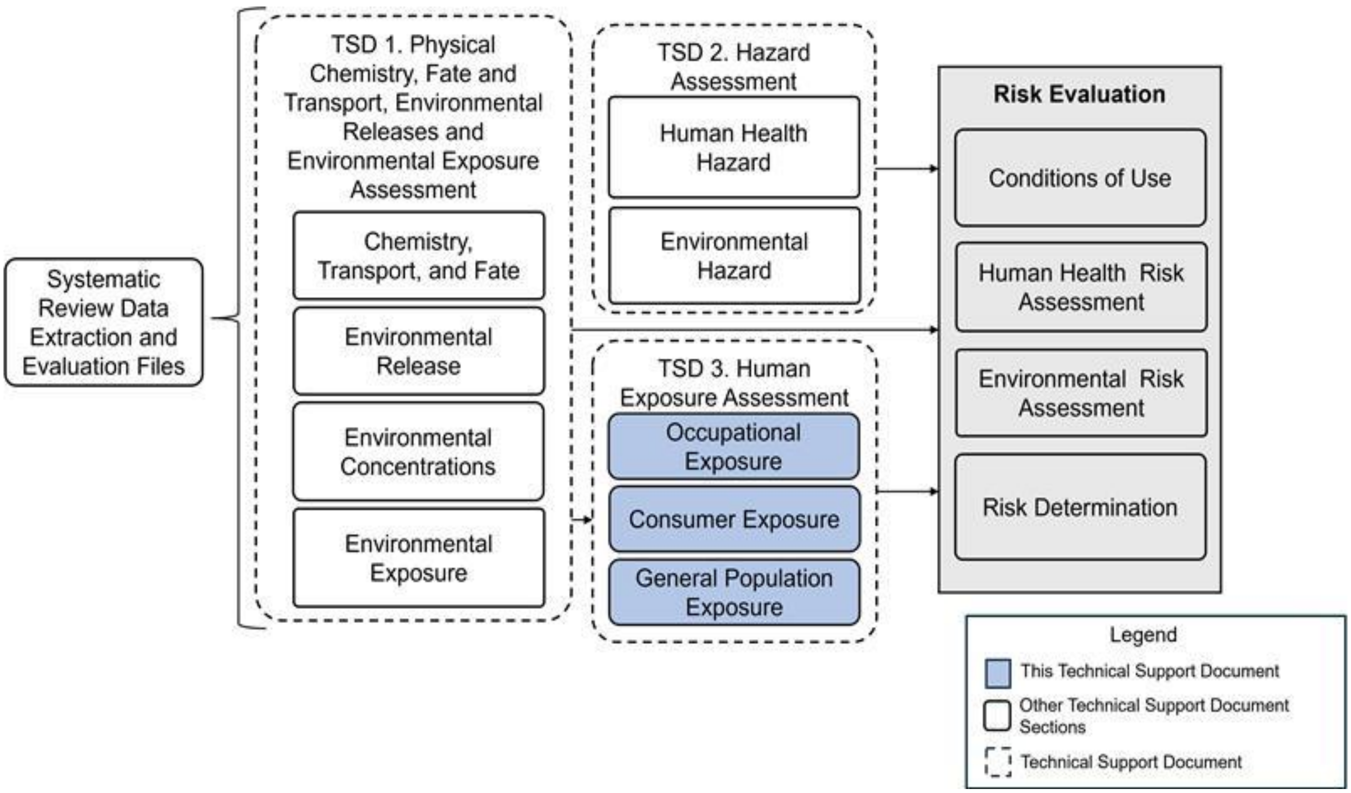


Figure 1-1. Document Map Summary for the Draft HHCB Risk Evaluation

1.1 Conditions of Use

Between 1 and 10 million pounds (lb) of HHCB are produced annually in the United States (see U.S. EPA (2020a) for further details). It is primarily imported for processing into air care, cleaning, laundry, dishwashing and plastic products, but can also be incorporated into fragrance oils sold directly to consumers. HHCB-containing products are regulated under TSCA, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as well as the Federal Food, Drug, and Cosmetic Act (FFDCA). EPA's Office of Pesticide Programs oversees products making pesticidal claims that contain HHCB, whereas personal care products that contain HHCB are overseen by the U.S. Food and Drug Administration (FDA). In this draft assessment, these are collectively referred to as "other sources of HHCB."

Table 1-1 presents the COUs under TSCA that are subject to risk evaluation, including those updated with information submitted to the Agency after the public release of the *Final Scope of the Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB); CASRN 1222-05-5* (also called the "final scope document") (U.S. EPA, 2020c).

Table 1-1. HHCB Conditions of Use (COUs)

Life Cycle Stage	Category	Subcategory
Manufacturing	Domestic manufacturing	Domestic manufacturing
Manufacturing	Importing	Importing
Processing	Incorporation into formulation, mixture or reaction product	Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; other: Fragrance mixtures and fragrance raw materials
Processing	Incorporation into articles	Odor agent in: Plastic materials and resin manufacturing
Processing	Repackaging	Odor agent in: All other chemical product and preparation manufacturing
Processing	Recycling	Recycling
Distribution in commerce	Distribution in commerce	Distribution in commerce
Commercial use	Air care products	Air fresheners for motor vehicles
Commercial use	Air care products	Continuous action air fresheners
Commercial use	Air care products	Instant action air fresheners
Commercial use	Cleaning and furnishing care products	All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)
Commercial use	Laundry and dishwashing products	Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/gel); Dishwashing detergent (unit dose/granule); Dishwashing detergent liquid (hand-wash)
Commercial use	Plastic and rubber articles not covered elsewhere	Plastic and rubber articles
Commercial use	Other use Laboratory chemicals	Laboratory chemicals
Consumer use	Air care products	Air fresheners for motor vehicles
Consumer use	Air care products	Continuous action air fresheners
Consumer use	Air care products	Instant action air fresheners

Life Cycle Stage	Category	Subcategory
Consumer use	Cleaning and furnishing care products	All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)
Consumer use	Laundry and dishwashing products	Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/gel); Dishwashing detergent (unit dose/granule); Dishwashing detergent liquid (hand-wash)
Consumer use	Plastic and rubber products not covered elsewhere	Plastic and rubber articles
Consumer use	Chemical substances in treatment products	Ion exchangers; Liquid water treatment products; Solid powder water treatment products
Disposal	Disposal	Disposal

1.2 Source Data and Evaluation

EPA applies best available science using a weight-of scientific evidence approach (see *Draft Systematic Review Protocol for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran [HHCB]*) (U.S. EPA, 2026k). Data used in this exposure assessment were identified through a search for sources with relevant information on HHCB. These sources were evaluated per the strategies presented in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2021a). The documentation of the evaluation of these sources is included in the following supplemental documents:

- *Draft Data Quality Evaluation and Data Extraction Information for Environmental Release and Occupational Exposure for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026c)
- *Draft Data Quality Evaluation Information for General Population, Consumer, and Environmental Exposure for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026d)
- *Draft Data Extraction Information for General Population, Consumer, and Environmental Exposure for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026b)

Generally, sources with data quality ratings of medium or higher were considered; however, lower scoring sources are considered and were used and noted in rare cases. Additionally, relevant data may have been submitted directly to the Agency, added to the docket during public comment periods, or identified through internet searches.

1.3 Chemistry, Transport, and Fate Properties

HHCB is a colorless, viscous liquid with a strong musk odor at room temperature. It is expected to be moderately persistent in surface water and sediments but not in air—especially if released during daytime hours. HHCB is likely to bind to soils without leaching, remaining bound to the soil. It has been shown to concentrate in fish, particularly non-edible tissues, and has been detected in human milk. This summary is largely based on empirical data, including available monitoring data, and is supported by theoretical data.

Table 1-2 provides the physical and chemical properties of HHCB; additional details can be found in the *Draft Physical Chemistry, Fate and Transport, Environmental Release, and Environmental Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-Hexamethylcyclopenta[γ]-2-Benzopyran (HHCB)* TSD (also called the "Draft HHCB Environmental Exposure Assessment") (U.S. EPA, 2026e).

Table 1-2. Selected Physical and Chemical Properties for HHCB

Property	Value[a]	Reference
Molecular formula	$C_{18}H_{26}O$	N/A
Molecular weight	258.41 g/mol	N/A
Density	1.0054 g/cm^3 at 20°C	O'Neil et al. (2013)
Vapor pressure	5.45 E−04 mm Hg at 25°C	MacGillivray (1996)
	1.99 E−03 mm Hg at 47°C	Wootitunthipong and Chickos (2019)
	2.81 E−02 mm Hg at 77°C	Wootitunthipong and Chickos (2019)
Water solubility	1.75 mg/L at 25 °C	Edwards (1996)
Octanol/water partition coefficient (log K_{OW})	5.9 (unitless)	U.S. EPA (2019)
Henry's Law constant	1.06E−04 atm·m^3/mole at 25 °C	U.S. EPA (2012)
Viscosity	12,914 centipoise (cP)	NLM (2018)
Bioconcentration factor (BCF)	1,584 L/kg	Balk and Ford (1999)

[a] Measured values
Additional details on the basis for each of these values are provided in the *Draft Physical Chemistry, Fate and Transport, Environmental Release, and Environmental Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026e).

1.4 Environmental Release

HHCB is released to air, water, and land across its COUs. As noted in Section 1.2, HHCB is not persistent in air and does not leach in soil; therefore, the release assessment focused on direct discharges to surface water and indirect discharges to publicly owned treatment works (POTWs) or private wastewater treatment (WWT) facilities. The full analysis of environmental releases is provided in the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e). Releases to water were evaluated from industrial, commercial, and consumer uses, for individual COUs and combined, as follows:

- **Industrial[1]:** 2023 Toxics Release Inventory[2] (TRI) data were used to determine daily releases from industrial facilities. These facilities did not discharge HHCB directly to surface water;

[1] Industrial releases refer to releases from industrial sites (*i.e.,* sites that manufacture 1 or more chemicals, formulations, or articles). The corresponding COUs are under the lifecycle stages of manufacturing, processing, or industrial use.
[2] TRI is a mandatory program administered by EPA for select chemicals that require companies to report the waste management on a yearly basis if they meet the reporting criteria. The Agency added HHCB to the list of select chemicals in 2023.

instead, HHCB-containing waste was sent off-site to WWT or POTW facilities, with treated effluent subsequently released to receiving waters.

- **Commercial and consumer:** Daily HHCB release rates were estimated from down-the-drain discharges to POTWs from commercial and consumer product uses, with treated effluent subsequently released to receiving waters.
- **Combined:** A single POTW may receive HHCB-containing waste from industrial, commercial, and consumer uses across multiple COUs, in addition to other sources of HHCB (*e.g.,* personal care products regulated by FDA). The draft assessment reports daily HHCB release rates for a combined commercial plus consumer down-the-drain scenario.[3]

1.5 Environmental Concentrations

1.5.1 Surface Water Concentrations

The Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e) reports surface-water detections that are not COU-specific. In summary, surface water concentrations were estimated with the Point Source Calculator (PSC; v1.05), which applies the Variable Volume Water Model (VVWM) to account for partitioning among the water column, porewater, sediment, and degradation. Inputs include HHCB physical-chemical properties (see Table 1-3), daily mass releases, and site-specific parameters (harmonic mean flow, water body characteristics, and weather).

Table 1-3. PSC Model Inputs (Chemical Parameters)

Parameter	Value [a]
K_{OC}	7,762.5 mL/g
Water column Half-life	556 days at 25 °C
Photolysis half-life	0.154 days
Hydrolysis half-life	9,999 days at 25 °C
Benthic half-life	9,999 days at 25 °C
Molecular weight	258.41 g/mol
Vapor pressure	0.000545 torr
Solubility	1.75 mg/L at 25 °C
Henry’s Law constant	1.06E−04 atm m^3/mol at 25 °C
Heat of Henry	45,727 J/mol
Reference temperature	25 °C
[a] Selected values for these parameters are described in the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e).	

Maximum daily average concentrations from the Draft HHCB Environmental Exposure Assessment TSD are summarized below in Table 1-4 (U.S. EPA, 2026e). These estimates reflect the highest modeled combined commercial plus consumer population-based down-the-drain release at POTW (95th

[3] Industrial releases were not included in the combined POTW scenario due to the low number of sites sending waste to POTWs and low release rates for those sites as detailed within the Draft Environmental Exposure Assessment for HHCB (U.S. EPA, 2026e).

percentile) and assume 92% HHCB removal during wastewater treatment (based on empirical data) prior to discharge. Percentile rankings are based on site-specific population and receiving-water body characteristics from the 2022 Clean Watershed Needs Survey (CWNS; accessed December 1, 2025). The P95 POTW scenario means only 5% of POTWs nationwide would yield higher surface water concentrations. This protective scenario uses concentrations immediately downstream of POTW effluent, producing high-end, site-specific values; HHCB concentrations farther downstream (and nationally) are expected to be lower.

Table 1-4. Estimated Surface Water Concentrations

Down-the-Drain Scenario	Estimated Concentration (µg/L) [a]
Total Commercial (P95 POTW Scenario)	6.62
Total Consumer (P95 POTW Scenario)	18.8
Combined Total (P95 POTW Scenario)	25.4
Ambient surface water	Measured concentration (µg/L) [a]
Highest monitored concentration: California, 2021 (NWQMC, 2025)	25.5

P95 = 95th percentile receiving water body concentration; POTW = publicly owned treatment works
Values summarized from the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e).
[a] A treatment removal efficiency for HHCB of 92% was applied to these modeled releases.
[b] Estimated HHCB concentrations represent total (dissolved and suspended HHCB) in the water column.
[c] Estimated HHCB concentrations based on use of the lowest 30-day average flow that occurs (on average) once every 5 years (30Q5 flow) to estimate the protective high-end concentration applied for human exposure, especially fish ingestion.

Available surface water monitoring data for HHCB in the United States is summarized in the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e). In summary, Water Quality Portal (WQP) (NWQMC, 2025) records indicate ambient surface water concentrations generally align with the conservative modeled estimates; the maximum measured concentration (25.5 µg/L) was observed downstream of a large POTW during low-flow conditions. POTW influent, or effluent concentrations ranged from non-detect to 13 µg/L, whereas other locations (not representative of the modeled scenarios) ranged from non-detect to 6.7 µg/L. A detailed summary of measured ambient surface water concentrations is also provided in the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e) (see Section 4.3.1 of that TSD; not repeated in this assessment/TSD for brevity).

1.5.2 Fish Concentrations

The Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e) summarizes HHCB fish tissue concentrations detected in monitoring studies; however, these observed concentrations cannot be linked back to specific COUs. The maximum reported fish-tissue concentration is 2.1 mg/kg (see Table 1-5), measured as a whole-fish value in common carp from Phoenix, Arizona. In general, species that dwell in sediment-laden waters (*e.g.,* catfish, perch, carp) and organisms with higher lipid content have higher tissue concentrations of HHCB. Modeled surface water concentrations were used to calculate HHCB in fish, with results also reported in Table 1-5. These estimates represent down-the-drain releases from consumer and commercial TSCA products to a low-flow (30Q5) receiving-water conditions at an effluent outfall. Fish-tissue concentrations are provided for the whole fish using EPA's K_{OW} (based) Aquatic BioAccumulation Model (KABAM) (U.S. EPA, 2009) to account for complex environmental and biological relationships; details are provided in Appendix G of the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e). Steady-state fish tissue concentrations are estimated to be reached in approximately 20 days (U.S. EPA, 2026e). Estimates are refined using EPA's KABAM (U.S. EPA, 2009) to account for complex environmental and biological relationships; details are provided in Appendix G of the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e).

Table 1-5. Estimated Surface Water and Fish HHCB Concentrations

Exposure Scenario	Surface Water Concentration (SWC) (µg/L) [a]	Fish Tissue Estimation Approach	Fish Tissue Concentration (mg/kg)
Consumer Plus Commercial Combined DTD (P95 POTW)	25.4	KABAM	8.5 (whole fish)
Highest Measured Concentration (California POTW)	25.5 µg/L	KABAM	8.5 (whole fish)
Highest monitored fish tissue	No paired sampling	N/A	2.10 (common carp, whole fish)

DTD = down-the-drain; KABAM = K_{OW} (based) Aquatic BioAccumulation Model; POTW = publicly owned treatment works
[a] A treatment removal efficiency for HHCB of 92–99% was applied to these modeled releases.

The highest estimated fish-tissue concentration is 8.5 mg/kg (whole fish), representing combined consumer and commercial POTW discharges across applicable COUs under a conservative P95 POTW scenario. Details of the selection of this high-end scenario are provided in the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e) and not repeated herein. This analysis is focused on a high-end exposure scenario to serve as a screening value for other potential exposures of a lower magnitude. In the screening-level analysis for the general population, subsistence fishers and tribal fishers, the highest monitored fish concentration and high-end modeled surface water estimates and fish concentrations are presented for comparison. The values are broadly consistent (same order of magnitude) which increases confidence in the estimated concentrations from KABAM—though the two scenarios (*i.e.,* measured and modeled) do not fully align due to differences in sample frequency, site-specific conditions, and fish species. However, they do provide confidence in the results; in particular, the estimated concentrations are higher than the highest measured concentration in the fish.

1.6 Human Health Hazard

Several conclusions in the *Draft Human Health and Environmental Hazard Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (also called the "Draft HHCB Human Health and Environmental Hazard Assessment") (U.S. EPA, 2026h) impact the scope of the exposure assessment for HHCB. These key findings include (1) no acute hazard for any route (no acute exposure estimates); (2) no dermal hazards (risk estimates were not calculated, though dermal exposures are presented in Appendix C for transparency); and (3) per the Rethinking Chronic Toxicity and Carcinogenicity Assessment for Agrochemicals Project (ReCAAP) framework (Hilton et al., 2022), no cancer hazard value was derived (*i.e.,* no LADDs were calculated for fish or drinking water consumption). EPA derived a non-cancer POD ($BMDL_5$ = 30 mg/kg-day from decreased offspring body weight) to support risk estimates for intermediate- and chronic-duration oral and inhalation exposures. No suitable inhalation studies were available to derive route-specific PODs. This noncancer POD was considered health-protective, including for cancer.

As such, these hazard conclusions inform the development of the conceptual exposure models. Acute exposures (any route or pathway) or dermal exposures are not a major focus. Instead, this assessment focuses on intermediate- and long-term oral and inhalation exposures, depending on the COU and population considered, as described in the next section.

1.7 Conceptual Exposure Overview

Exposure to HHCB may occur via inhalation (vapor, mist or dust), oral ingestion (water, human milk, fish, or soil containing HHCB), or dermal contact (neat chemical or in formulations or articles). The subsections below detail each exposure route; however, consistent with the Draft HHCB Human Health and Environmental Hazard Assessment (U.S. EPA, 2026h), and summarized within Section 1.6 of this draft TSD, only oral and inhalation exposures are calculated to align with the derived point of departures (PODs).

1.7.1 Inhalation

HHCB has a relatively low vapor pressure (see Section 1.2), indicating limited vapor-phase concentrations under typical conditions. Heating (*e.g.,* during transfer operations of highly concentrated material) increases vapor-phase potential. Indoor environments typically can have higher exposure potential than outdoor environments due to lower ventilation. This can be demonstrated in the vapor inhalation estimates as provided in Section 3.1.1.

HHCB is a viscous liquid predominantly used in liquid products, limiting dust inhalation. However, exposure via dust or mist can occur when handling materials that generate particulates or aerosols. Dust exposure may result from powder products containing HHCB (*e.g.,* carpet cleaners) and mist exposure from spray-applied or aerosol products (*e.g.,* air fresheners). HHCB may also sorb onto dust. Sections 3.1.2 and 3.2.1 detail occupational dust and consumer mist exposure estimates, respectively.

1.7.2 Oral

Direct oral exposure is not expected for workers or consumers. Worker oral exposure is not assessed because hand-to-mouth behaviors are not expected in occupational settings and COU-specific data indicating HHCB oral exposure were not identified. Direct oral consumer exposure is not expected based on typical product use patterns. Incidental ingestion could occur, but it is unlikely and was not further assessed.

Most HHCB in ambient surface water across the United States is from down-the-drain disposals, combined and released from POTWs (see Section 3.4 and 4.2.2 in the Draft HHCB Environmental Exposure Assessment TSD) (U.S. EPA, 2026e)). Wastewater treatment typically achieves substantial removal (method-dependent), reducing effluent and downstream concentrations, with residual HHCB primarily partitioning to biosolids (see Section 2.5 in the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e)). As such, oral exposures may occur through incidental ingestion during recreation downstream of effluent discharges or via drinking water sourced from contaminated surface water. Because incidental ingestion is expected to be lower than drinking water, this draft assessment focuses on drinking water as a health-protective scenario.

Biosolids containing HHCB may be incinerated, landfilled, or applied as soil amendments. Given its physical and chemical properties as well as environmental fate characteristics, HHCB is not expected to leach through the soil after land application or landfilling, limiting groundwater presence. Therefore, drinking water exposure via groundwater is not expected. Oral exposures from soil amendments may occur (*e.g.,* soil ingestion by children or individuals with pica) but is considered infrequent for the following reasons:

- Biosolids from POTWs/WWTPs may be applied in large volumes to agricultural sites; limited public access minimizes general-population exposure (see Section 4.2.3 of the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e)).
- Plant uptake of HHCB in biosolid amended soils is limited (see Section 2.4.7.2 of the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e)).
- Biosolids from POTWs/WWTPs may be sold for residential use; applications are typically small due to transport, packaging, and typical mix with soil (usually 1:2), limiting exposure.
- HHCB ingestion does not cause acute effects; soil ingestion would need to be recurrent to pose a hazard, which is unlikely for most individuals.

Accordingly, this draft human exposure assessment for HHCB does not consider drinking water exposure via groundwater or oral exposures from biosolids used as soil amendments.

HHCB has been detected in fish, likely from surface water exposure, sediment ingestion, and/or trophic transfer in the food chain. Levels are often higher in "non-edible" tissues (*e.g.,* viscera and gills), but whole-fish consumption by some individuals may increase exposure. This draft assessment considers HHCB exposure through fish ingestion.

HHCB has been detected in human milk (Reiner et al., 2007), indicating potential ingestion exposures for infants and children. This draft assessment includes exposures via human milk.

1.7.3 Dermal

Dermal exposure may occur via consumer products (*e.g.,* dishwashing detergents), occupational handling of formulations containing HHCB, or incidental contact with surface water containing HHCB. However, HHCB is not hazardous via the dermal route (see Section 2.3.2 in the Draft HHCB Human Health and Environmental Hazard Assessment (U.S. EPA, 2026h)). Therefore, dermal exposures are not further assessed; nevertheless, dermal exposure analysis for occupational and consumer routes are included within Appendix C for transparency.

1.7.4 Aggregate

Because inhalation and oral hazard values are based on same systemic endpoint—decreased offspring bodyweight in rats (Draft HHCB Human Health and Environmental Hazard Assessment TSD (U.S. EPA, 2026h))—aggregate exposures across routes, pathways, and sources was considered. Individuals may be exposed via multiple routes (*e.g.,* inhalation, oral), pathways (indoor air and drinking water), and sources (worker activities and use of consumer product). For example,

- **Workers:** Vapor inhalation during unloading and ingestion via drinking water.
- **Consumers:** Mist inhalation from continuous action air fresheners and ingestion via drinking water; additional exposures from daily use of other sources of HHCB (*e.g.,* lotions, shampoos, perfumes).
- **General population:** Drinking water exposure from multiple COUs and other sources of HHCB.

2 APPROACH AND METHODOLOGY

Table 2-1 provides a summary of exposure scenarios and corresponding COU that were estimated for workers (Section 2.1), consumers (Section 2.2), and general population (Section 2.3).

Table 2-1. Assessed Exposure Scenarios and COUs

Population Group	Exposure Route	Exposure Pathway	Evaluated Scenario	Corresponding COU
Occupational (Workers)	Inhalation	Vapor	Formulation of HHCB into fragrance oil occupational exposure scenario (OES)	Processing – Incorporation into formulation, mixture or reaction product – Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; Other: Fragrance mixtures and fragrance raw materials
Occupational (Workers)	Inhalation	Dust	Plastic compounding/ converting OES	Processing – Incorporation into articles – Odor agent in: Plastics material and resin manufacturing
Consumers	Inhalation	Mist (spray)	Metered Air Freshener in a Small Room	Commercial Use – Air care products – Continuous action air fresheners Consumer Use – Air care products – Continuous action air fresheners
General Population	Oral	Drinking water	Exposure from HHCB Released Down-the-Drain	**Aggregation of the following COUs:** Commercial Use – Cleaning and furnishing care products – All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain) Commercial Use – Laundry and dishwashing products – Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/ gel); Dishwashing detergent (unit dose/ granule); Dishwashing detergent liquid (hand-wash) Consumer Use – Cleaning and furnishing care products – All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain) Consumer Use – Laundry and dishwashing products – laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/gel); Dishwashing detergent (unit dose/ granule); Dishwashing detergent liquid (hand-wash)
General Population, including subsistence fishers and tribal populations	Oral	Fish ingestion		

Commercial and consumer product-specific searches were conducted to identify safety data sheets (SDSs) and ingredient disclosures for HHCB, which are documented in the HHCB Product Concentration Dataset (U.S. EPA, 2025b). All identified products were on the U.S. market as of April 2025. Table 2-2 summarizes HHCB weight-percent ranges for the product categories listed in the commercial and consumer use COUs. SDSs/disclosures were screened for current market status and other issues affecting the reliability of the concentration data (*e.g.,* recent reformulation removing HHCB). Excluding laboratory uses, air fresheners identified on the U.S. market typically had the highest HHCB concentrations; other product categories were less than 1% HHCB. Some cleaning products were registered under the FIFRA and thus outside TSCA; however, the product information was used to inform concentrations in TSCA-regulated products. For this draft assessment, HHCB (fragrance) content is assumed to be the same in non-pesticidal and pesticidal products. Although some commercial and consumer products were reported to be on the U.S. market (U.S. EPA (2020c) and U.S. EPA (2020a)), as summarized in U.S. EPA (2025b), at the time of this draft assessment, EPA could not verify their current availability or HHCB content. Therefore, some of these products were not further considered in the HHCB exposure assessment for workers or consumers.

Table 2-2. Product Concentration Information

Product Type	Specific Types of Products	Number of Commercial Products	Number of Consumer Products	Range of HHCB Weight Concentrations[a]
Air fresheners for motor vehicles	Vent clips, paper, hanging, jar, can or spray air fresheners	12	15	<1 to 12.5%
Continuous action air fresheners	Metered spray air fresheners, air freshener diffusers, plug-ins, wax melts, candles, plastic clips, toilet bowl deodorizer, floor mat, rim cages and urinal screens	26	10	<0.01 to 10%
Instant action air fresheners	Aerosol/spray air fresheners, odor eliminating discs, liquid or powder deodorizer, and autoclave deodorizer (discontinued)	21	16	<0.1 to 5%
All-purpose foam spray cleaner	Bathroom cleaner	1	1	NR
All-purpose liquid cleaner/polish	Bath/washroom cleaner, floor cleaner, carpet cleaner, floor polish, hard-surface cleaner, and glass cleaner	12	6	<0.1 to 0.3%
All-purpose liquid spray cleaner	Hard-surface cleaner, furniture cleaner, and bathroom cleaner	1	2	<0.1%
All-purpose waxes and polishes	Car polish, granite and stone polish, wood oil, and wood polish	1	3	NR

Product Type	Specific Types of Products	Number of Commercial Products	Number of Consumer Products	Range of HHCB Weight Concentrations[a]
Appliance cleaners	None found	0	0	NR
Drain and toilet cleaners (liquid) [b]	Bathroom cleaner	6 [b]	1	<0.1 to 0.3%[b]
Powder cleaners (floors)	None found	0	0	NR
Powder cleaners (porcelain)	None found	0	0	NR
Laundry detergent (liquid)	Laundry detergents, and scent boosters	0	20	≤0.1%
Laundry detergent (unit dose/granule)	Powder laundry detergents, laundry packs/packs/unit doses	1	11	0.01 to 0.9%
Fabric enhancers	Scent/odor boosters, fabric softeners, dryer sheets, clothing refresher mist, washing machine cleaner, and other laundry products	2	16	<0.1 to <1%
Stain removers	Stain remover (liquid and foam), gel stick, and pre-spotter	1	13	≥0.1 to <1%
Dishwashing detergent (liquid/gel)	None found	0	0	NR
Dishwashing detergent (unit dose/ granule)	None found	0	0	NR
Dishwashing detergent liquid (hand-wash)	Dish and hand soap	0	1	<0.1%
Laboratory chemicals	Laboratory chemical at varying concentrations	5	0	0.01 to ≤100%

NR = not reported
[a] Only weight concentrations included are products deemed to be "high" quality (*i.e.,* no issues identified) (U.S. EPA, 2025b)
[b] Some of the commercial all-purpose liquid cleaner/polish are also marketed as toilet cleaners.

This draft assessment focuses on screening level and in some cases more refined scenarios protective across TSCA COUs. Subsections describe the analysis plan by population. EPA does not consider HHCB to be acutely toxic; therefore, the focus is on long-term exposures. Because intermediate and chronic toxicity are identified for oral and inhalation routes, oral exposure is assessed for the general population and inhalation exposure for workers and consumers. HHCB is considered non-hazardous via dermal contact; therefore, dermal exposures are reported in Appendix C but not further considered in this draft human health exposure assessment of HHCB.

2.1 Occupational

Workers, including occupational non-users (ONUs[4]), experience inhalation exposures (vapor, mists, and dust) and dermal exposures from contact with solid or liquid HHCB. For this screening-level assessment, ONUs are not assessed separately. Their exposures are expected to be similar or lower than those of directly exposed workers; therefore, workers are used as a surrogate for ONUs.

When monitoring data were not available or not suitable for exposure assessment, occupational exposures are estimated using deterministic or probabilistic modeling. Probabilistic analyses use Monte Carlo simulations using the Lumivero @RISK software with parameter distributions as detailed in Appendix A, reporting the 50th and 95th percentiles. Deterministic analyses use the 50th percentile of monitoring data and the Occupational Safety and Health Administration (OSHA) regulatory limit for particulates not otherwise regulated (PNOR). Estimated air concentrations are then used to calculate intermediate and chronic average daily dose (intermediate average daily dose [IADD] and chronic average daily dose [CADD]) using exposure duration, exposure frequency, breathing rate, and body weight.

2.1.1 Inhalation Exposure via Vapor

Occupational inhalation monitoring data are limited to only two area monitoring studies, both reporting low concentration levels (<0.1 mg/m^3) (Upadhyay et al., 2011; ECB, 2008). ECB (2008) provides area monitoring data from plants that produce fragrance oils in 1988 and 1999 in the European Union (EU), but there is uncertainty on how these sites compared to current U.S. manufacturing as production details at the sampled sites were not provided. Upadhyay (2011) provides area sampling near wastewater aeration basins, which may not be reflective of the workers' exposure at the plant and is not a scenario where workers are expected to have the highest vapor exposure to HHCB. As a result of these limitations, in addition to fit the purpose of this screening assessment, worker inhalation exposures were modeled. The selected scenario—Workers formulating fragrance oils—is expected to yield the highest vapor inhalation exposure to HHCB that were used to screen across all scenarios and COUs, providing high-end estimates that are inclusive and protective of other population groups. Therefore, the resulting estimations are expected to be higher than exposure across all COUs in the draft risk evaluation.

In the above scenario, HHCB is received and blended with other fragrances to produce specific scent blends[5], corresponding to the COU Processing – Incorporation into formulation, mixture or reaction product – Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; other: Fragrance mixtures and fragrance raw materials, which is mapped to the "Formulation of HHCB into fragrance oils" OES. This scenario was selected as having the highest vapor-inhalation exposure potential for several reasons:

- **Elevated temperatures:** Increased vapor pressure and vapor-phase HHCB vs. room-temperature handling in other COUs
- **High concentration levels:** 90 to 100% HHCB vs. diluted levels in other COUs
- **Higher volumes:** Larger quantities handled than other COUs
- **Frequent exposure:** Workers have repeated handling events

Other scenarios were not further analyzed in this screening-level assessment due to lower vapor-

[4] ONUs are employed individuals who do not directly handle HHCB but may be indirectly exposed due to their proximity to the substance in their workspace.
[5] Scent blends are added to downstream commercial and consumer products such as detergents, cleaning products, air fresheners, and scented plastics (OECD, 2010).

inhalation exposure potential than the selected scenario.

2.1.1.1 Formulation of HHCB into Fragrance Oils OES

The exposure models, as provided in Appendix A.2.1. were used to estimate vapor generation and resulting HHCB exposure concentrations. A block diagram of the assessed scenarios is presented in Figure 2-1 and described below.

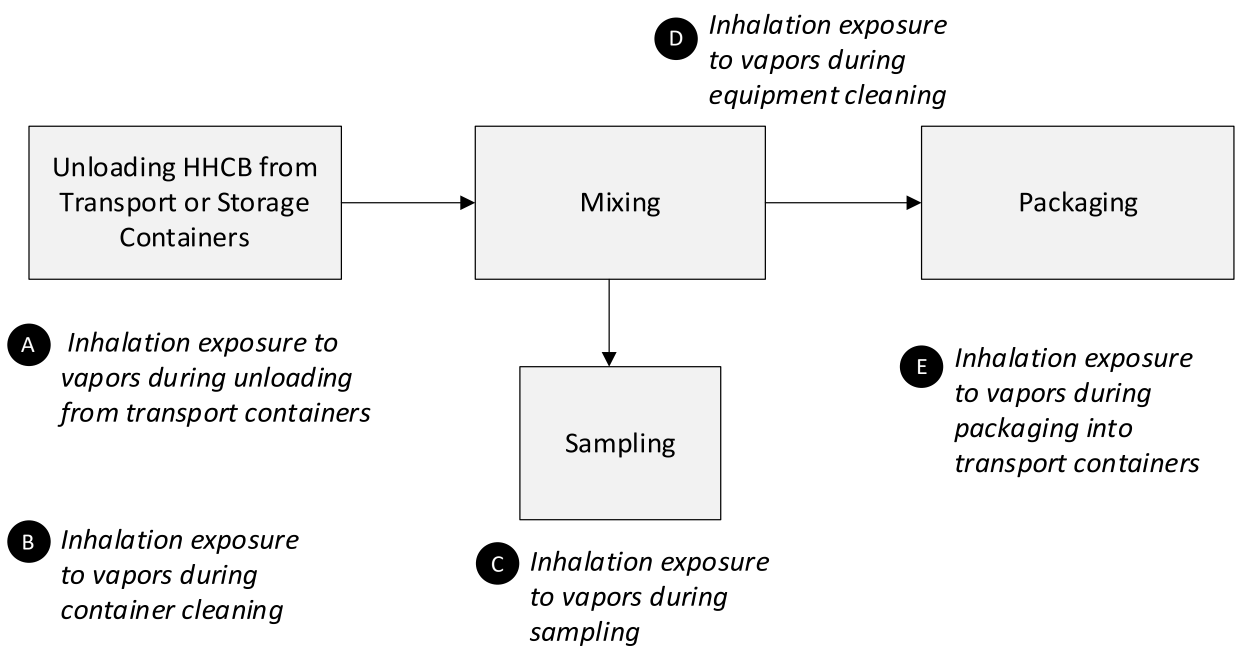


Figure 2-1. Block Diagram of the Formulation of Fragrance Oil OES

For modeling, HHCB transport is assumed via drums, totes, tanker trucks, or rail cars. Specific information on the transport containers used by U.S. fragrance oil producers is not available. The *European Union risk assessment report: 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta-γ-2-benzopyran (HHCB)* (ECB, 2008) indicates that deliveries arrived in tanker trucks or containers 50 or more gallons, consistent with these assumptions. Model input parameters are summarized below in Table 2-3.

Table 2-3. Key Parameters for Formulation of Fragrance Oils

Key Parameters	Value	Source
Total U.S. aggregate production volume	453,592–4,535,924 kg/yr for all sites	U.S. EPA (2020b)
Number of sites	12 sites	U.S. EPA (2024)
Production volume per site	37,799–377,994 kg/site-yr	Calculated from the total U.S. aggregate production volume and number of sites
HHCB concentration (raw materials)	90–100% (weight by weight [w/w])	U.S. EPA (2020b)
HHCB concentration (final product)	0.25–60% (w/w)	U.S. EPA (2025b)

Key Parameters	Value	Source
Operating days	239–271 days	FCA (2021)
Unloading temperature	75 °C	ECB (2008)
Non-unloading temperature	25 °C	Standard assumption
Container sizes	Varies (drums, totes, tank trucks, or rail cars)	Assumption

The starting material concentration was set at 90 to 100% HHCB per 2020 Chemical Data Reporting (CDR), which is comparable to preliminary 2024 CDR data (U.S. EPA, 2020b). Although some sites may use diluted 50 to 65% solutions, the highest range was chosen due to the current assessment's screening-level analysis.

Because highly concentrated HHCB is viscous, transfer operations often heat HHCB to between 25 to 75 °C (77–167 °F) (ECB, 2008). Therefore, a measured vapor pressure of 2.81×10^{-2} mmHg for HHCB at 77°C (171 °F) (Wootitunthipong and Chickos, 2019) was used to estimate inhalation exposure during unloading (see Activity A in Figure 2-1).

After unloading, HHCB may be stored in tanks or directly mixed with other fragrance chemicals. Mixing is not expected at elevated temperatures because many aroma chemicals are heat-sensitive (OECD, 2010). If the containers are cleaned, worker exposure during the cleaning process (see Activity B in Figure 2-1) is modeled at standard temperature. Some sites return the empty containers to suppliers or third-party cleaners (FCA, 2021); therefore, formulation site-workers may not be exposed during container cleaning as assumed in this assessment.

Batch size data for U.S. sites were unavailable; daily batch sizes were estimated to be approximately 139 to 1,582 kg/day-site, based on aggregate production (453,592–4,535,924 kg/year), 12 sites (2023 TRI), and 239 to 271 operating days/year.

After blending, final fragrance oil blends are packaged into drums with HHCB at 0.25 to 60%. Worker exposure may occur during sampling, equipment cleaning, and packaging (see Activities C through E in Figure 2-1).

For chronic exposures, activity-specific concentrations were combined to estimate an 8-hour time weighted average (TWA), assuming a worker completes all activities; this TWA was then used to calculate IADDs and CADDs. The 50th and 95th percentile are reported in Section 3.1.1 with modeling details provided in Appendix A.2.

2.1.2 Inhalation Exposure via Dust

For most COUs, workers' inhalation of HHCB-containing dust is not expected. Dust exposure may occur when handling HHCB-containing plastic pellets (caused by abrasion during handling and transport) or powder products. Given limited occupational monitoring data on HHCB in dust, dust inhalation during unloading and loading at plastic manufacturers was modeled, corresponding to the COU Processing – Incorporation into formulation, mixture or reaction product – Processing – Incorporation into articles – Odor agent in: Plastics material and resin manufacturing. This scenario was selected to serve as a screen because it is expected to have the highest dust-exposure than other scenarios due to the following:

- **Higher concentration levels:** HHCB weight fraction in plastic pellets exceeding levels found in

commercial and consumer powders; notably, only one powder product was identified (consumer stain remover) with less than or equal to 0.1% HHCB.
- **Higher volumes:** Handling large quantities increases dust generation and exposure potential.
- **Frequent exposure:** Workers having repeated handling events.

Other scenarios for this pathway were not analyzed because plastic compounding/converting is expected to yield the highest HHCB dust inhalation exposures across scenarios and COUs, providing the highest estimates for all dust inhalation scenarios, including other exposed populations.

2.1.2.1 Plastic Compounding/Converting

HHCB is compounded into plastic pellets, granules, or flakes, then sent to converting sites to produce final articles. Transport and handling can generate dust, exposing workers during unloading or storage transfers; additionally, exposures may occur during the converting and trimming activities.

The PNOR Central and High-End Exposure Model (PNOR Model) (U.S. EPA, 2021b) was used to estimate HHCB exposure concentrations, which relies on OSHA PNOR monitoring data categorized by North American Industry Classification System (NAICS) sectors. OSHA monitoring data typically lacks supplemental information on the worker activities being sampled; therefore, the model does not account for differences in tasks. Key inputs to the model were the industry sector (NAICS code) and the HHCB weight concentration in the dust. Because the hazard is systemic, only total PNOR was used (no respirable dust estimates). Dust generation was assumed to rise solely from HHCB-related activities and to be proportional to the HHCB concentration in the bulk plastic. The PNOR Model outputs 8-hour TWAs for total HHCB dust, based on the 50th percentile of PNOR data and the PNOR regulatory limit.

Based on the 2023 TRI data, the Chemical Manufacturing sector was selected as the relevant industry sector with the highest 50th percentile PNOR (regulatory limit: 15 mg/m^3; 50th percentile: 3.5 mg/m^3). HHCB weight fraction in the plastic pellets was unavailable; therefore, the maximum concentration in finished plastic was used (range: 0.1–5%).

For full descriptions of this occupational modeling approach, see Appendix A.3.

2.1.3 Inhalation Exposure via Mist

Mist inhalation can occur from spray or aerosol products (common in cleaning, laundry, and air care products). Air care products generally have the highest levels of HHCB among sprays. The consumer assessment (see Section 2.2) includes a continuous-action air freshener scenario that provides an upper-bound for worker mist exposure; therefore, the exposure estimates for the consumer continuous-action air freshener scenario are used as a screening analysis for exposure of workers from mist inhalation of spray or aerosol products.

2.2 Consumer

Given its low vapor pressure, HHCB is not expected to be present at significant vapor-phase levels; therefore, exposure for commercial workers, consumers, and bystanders is expected to occur primarily via atomization or air freshener use.

2.2.1 Inhalation Exposure via Dust

HHCB has been measured in household dust up to 4.9 µg/ft^2 (Dodson et al., 2017) and exposure may occur for individuals crawling on residential floors or in crawl spaces (NRDC, 2016). Consumer dust exposure is not further assessed for reasons noted below; potential household dust exposures are provided in Appendix D.

- HHCB dust is not expected to result from consumer use (*e.g.,* air care, cleaning, laundry). No consumer plastic articles containing HHCB were identified.
  - Creation of HHCB-containing dust particles due to abrasion of plastic is not expected.
- Consumer oral exposure via dust is accidental and minimal compared to mists.
  - Given HHCB's semi-volatility and high log K_{OW} of 5.9 (see Table 1-2), HHCB has a strong affinity to dust particles.
  - When released as a vapor in air, HHCB is expected to bind to suspended and settled dust particles.
  - HHCB in dust likely originates, in part, from sorption following aerosol product use.
  - Bioavailability of HHCB requires desorption; based on physical-chemical properties (see Table 1-2), HHCB is expected remain largely bound to dust.
  - Measured dust concentrations are low (see Section 3.4.1) with COUs contributing only a fraction of total HHCB.
  - Incidental oral exposure may occur via dust inhalation and is encompassed in inhalation exposure estimates and available toxicity data (U.S. EPA, 2026h).
- Inhalation hazard values are derived via route-to-route extrapolation from oral studies (U.S. EPA, 2026h), ensuring oral exposure is considered; developmental effects observed in oral exposure studies are protective of children.

2.2.2 Inhalation Exposures via Mist

HHCB monitoring data for consumer products confirms the potential for exposure from multiple sources, including TSCA-regulated products (*e.g.,* cleaning products) and other sources of HHCB (*e.g.,* lotions, cosmetics, perfumes), occurring sometime after use. Monitoring data represents snapshots of exposure that vary by product combinations, amounts used, and sampling lag time, and likely do not represent the highest expected consumer exposures. Accordingly, as a screening-level analysis, inhalation exposure from continuous-action air freshener use in a small room (*e.g.,* bathrooms, dorm rooms) was modeled as a bounding scenario to generate upper-end mist exposure estimates protective across COUs and exposed populations. Scenario inputs are expected to yield the highest mist inhalation for the following reasons:

- **Highest weight fraction:** Up to 1% HHCB in aerosol continuous-action air fresheners (per SDSs (Chase Products, 2025)). Non-aerosol products may have higher HHCB but were not prioritized because vapor inhalation is minor; HHCB is semi-volatile and persists less in indoor air than when aerosolized.
- **Highest use duration/frequency:** Continuous-action air fresheners emit throughout the day, exceeding intermittent spray cleaning/laundry uses.
- **Small room volume:** Use in a small bathroom, bedroom, or office yields the highest air concentrations due to rapid saturation (per Consumer Exposure Model [CEM] v3.2).
- **Occupancy:** Assumes 24/7 (24 hours, 7 days a week) presence in the product room or 24/7 movement between rooms with product use for 1 year—a high-exposure, non-typical scenario.

Because the above scenario was used as a screening analysis intended to result in concentrations higher than other potential exposure scenarios, additional quantitative analyses for other scenarios were not conducted. See Appendix E.1 for key considerations and justifications for the screening-level quantitative and qualitative assessments of relevant consumer COUs. Screening estimates of consumer exposures to mists were used to also represent commercial exposures for workers (*i.e.,* front desk hotel workers, bathroom attendants) and bystanders (*i.e.,* hotel guests) who occupy a space with continuous action air fresheners. Commercial worker exposures are assumed to be as high as for consumers due to proximity and extended exposures to the product, while bystander exposures are expected to be lower due to distance and transient exposures to the product.

Consumer inhalation exposures due to atomization or air freshener use were estimated using the CEM v3.2, which uses consumer-use patterns and user-defined inputs to estimate daily average concentration (mg/m^3). For HHCB, the E1 (emissions from products applied to indoor surfaces) and P_INH1(inhalation TWAs from product use) models were applied. CEM v3.2 was used to convert air concentration to population-specific doses (mg/day) for infants, children, and adults. Both air concentration and doses are reported in Appendix B.3 and Section 3.2.1, respectively.

2.2.2.1 Continuous Action Air Fresheners

CEM v3.2 was used to evaluate inhalation exposures from continuous-action air fresheners. HHCB is assumed to be atomized in a small room (15 m^3; *e.g.,* bathrooms, dorm rooms), discharging every 15 minutes over 24 hours (Chase Products, 2025). Ventilation is 107 m^3/h with well-mixed air. Continuous dispensing plus ventilation yields a stable airborne HHCB concentration. CEM reports air concentrations and age-dependent doses. Model inputs are summarized in Table 2-4. Key parameter derivations are provided below, with full methods described in Appendix B.

Table 2-4. Summary of Key Parameters for Products Modeled in CEM v3.2

Product	Exposure Scenario Level [a]	Weight Fraction (%) [b]	Duration of Use (min) [c]	Product Mass Used per Day (g) [d]	Freq. of Use (day^{-1})	Use Environment Volume (m^3) [e]	Air Exchange Rate, Zone 1 & Zone 2 (h^{-1}) [f]	Interzone Ventilation Rate (m^3/h) [f]
Continuous action air fresheners	High Intensity	1	1,440	6.6	365	15	0.45	107

[a] EPA prioritized a high-intensity use scenario for a screening approach to the HHCB inhalation exposure assessment from continuous action air fresheners.
[b] Represents an average of 5 reported weight fractions from variations of the same product (Chase Products, 2025).
[c] To cover all possible exposure scenarios, for this screening approach, the extreme of exposure for 24 hours per day was assumed.
[c] To cover all possible exposure scenarios, for this screening approach, the extreme exposure duration of 24 hours per day was assumed.
[d] Based on product use descriptions, available on product label (Chase Products, 2025).
[e] Use environment was determined based on professional judgement.
[f] CEM default. For the screening assessment, EPA employed a well-mixed room instead of using the near-field modeling option given the small size. Only the user was assumed to be in the room of use.

A continuous-action air freshener (Chase Products, 2025) with 198 g (7 oz) per can is assumed to release 68.75 mg (0.06875 g) HHCB every 15 minutes for 30 days (2,880 dispenses). The can is intended to be replaced every 30 days. Continuous-action air fresheners are used in residential settings—bathrooms, bedrooms, nurseries, dorm rooms, recreational vehicles (RV), and campers—as well as commercial settings such as offices, small boutiques, and nursing home rooms.

A 15 m^3 room (approximately 10-foot long × 6.6-foot wide × 8-foot height) with an interzone ventilation rate of 107 m^3/h was simulated to represent use of a continuous action air fresher in a small residential room. In comparison,

- A typical U.S. bathroom is 5 to 6 feet wide and 7 to 9 feet long with 8-foot ceilings (NKBA, 2022), slightly smaller than the modeled room;
- By City of New York (2023) standards, a legal *bedroom* must be at least 80 square feet (8-foot

long × 10-foot wide × 8-foot height), slightly larger than the modeled room (19 m^3); and

- Dorm room sizes vary by campus, building, and occupancy with single rooms typically about 80 to 120 square feet (roughly 7–11 m^2), often 8-foot × 10-foot to 10-foot × 12-foot (Boston University, 2026; UCLA, 2026; University of Virginia, 2026; PSU, 2022).

Residential buildings should have a minimum ventilation rate of 0.35 air changes per hour (ACH), or greater than or equal to 15 ft^3/min (25.5 m^3/h) (U.S. EPA, 2025a). An ACH of 0.45 (median for U.S. residences) was used (U.S. EPA, 2011b); which means 45% of the air volume is replaced once per hour or the entire volume of air is replaced once every 2 hours and is independent of interzone ventilation used in the model. ACH, ventilation, and room size use CEM default inputs representative of typical residential spaces.

Exposure from use of a continuous-action air fresheners in vehicles (*e.g.*, plug-ins, hanging paper tree fresheners, diffusers) is expected to be captured by the 24/7 use of continuous-action air freshener in a small residential room (15 m^3) used in this screening-level assessment because HHCB air concentrations are expected to be lower because of the following:

- **Lower occupancy patterns**: Most people do not remain in vehicles continuously for a year. Long-haul commercial truck drivers are an exception; however, they routinely exit (*e.g.*, for refueling, meals, rest, bathroom breaks, deliveries, etc.) the vehicle into fresh air, limiting continuous exposure. Regulation (49 CFR part 395) limits drivers to approximately 310 to 315 working days per year.
- **Larger interior space:** Commercial cabin volumes where an individual may spend more time such as sleeper cabs are generally larger—often exceeding 17 m^3 (Peterbilt 579 UltraLoft, Volvo VNL 860, and, Kenworth W900L [accessed March 10, 2026]).
- **Higher ventilation rates:** Automobile ACH rates are higher at about 12.5 per hour (CEM 3.2; (U.S. EPA, 2023)).
- **Lower product usage:** SDSs and company websites (U.S. EPA, 2025b) indicate that based on HHCB amount used as well as duration of use, HHCB air concentration is expected to be lower.

The assessment assumes continuous occupancy of a small room (24 hours, 7 days a week), which may represent exposure for home-bound individuals in small rooms (*i.e.*, elderly, infants in small nurseries, college students in dorm rooms, and individuals with severe illness or disability in small bedrooms). This is atypical and conservative; most individuals are anticipated to move throughout a home and leave for daily activities.

2.3 General Population

General population exposure is assessed for oral ingestion from drinking water and fish downstream of releases. HHCB has been detected in U.S. surface waters, and many community drinking water systems draw from lakes, rivers, or reservoirs. HHCB is not regulated under the Safe Drinking Water Act and is not included on the EPA's Contaminant Candidate List (CCL) for future regulation (for the regulatory and assessment history of HHCB, see Appendix B in the *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026i)). Infants and children may also ingest HHCB via human milk. Detailed analysis plans for the assessed routes and pathways for general population exposure are provided in the subsections that follow.

Incidental oral exposure (*e.g.,* swimming) is expected to be lower than long-term drinking-water exposure and is not further evaluated. General population inhalation exposure is unlikely based on the physical-chemical proprieties (see Sections 2.4.1 and 2.5 in the Draft HHCB Environmental Exposure

Assessment TSD (U.S. EPA, 2026e)), and HHCB is not hazardous via the dermal route (see Section 2.3.2 in the Draft HHCB Human Health and Environmental Hazard Assessment (U.S. EPA, 2026h); these pathways are therefore not evaluated further. However, because this draft exposure assessment was developed concurrently with the human hazard assessment, dermal exposure estimates were developed before the determination that HHCB does not pose a dermal hazard, and, for transparency, are provided in the *Draft General Population Surface Water Risk Calculator for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026g).

2.3.1 Oral Exposure via Drinking Water

This draft assessment uses measured and modeled HHCB surface water concentrations (summarized in Section 1.5 and Table 1-4) to estimate HHCB concentrations in drinking water. The measured data represents surface water concentrations but not drinking water. The estimated concentrations are based on the harmonic-mean flow at the effluent release point and represent a high-end[6] drinking-water scenario without additional removal during drinking water treatment for this screening-level assessment, though typical drinking water treatment is expected to remove HHCB. Given its high K_{OC}, HHCB primarily partitions to suspended solids and organic carbon in water. Conventional drinking-water treatment—coagulation, flocculation, sedimentation, and filtration—removes sorbed HHCB. Wastewater studies focused on sludge separation report 50 to 95% removal due to sorption, indicating these methods are expected to be effective for HHCB removal in drinking water.

An average daily dose (ADD) from drinking water was calculated using 95th percentile ingestion rates across age groups per EPA's *Exposure Factors Handbook* (U.S. EPA, 2011b), with oral doses computed using the equations in Appendix D. Short-term exposure was not estimated due to the absence of an established acute HHCB hazard (Section 1.6).

2.3.2 Oral Exposure via Fish Ingestion

This assessment estimates human exposure from fish ingestion using measured and modeled fish concentrations (summarized in Section 1.5.2 and Table 1-5). Oral exposure to HHCB from shellfish consumption among the general population, subsistence fishers, and tribal communities is acknowledged within Section 5.3, Human Health Risk Characterization, in the *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026i). However, because a detailed shellfish consumption analysis was not conducted, fish consumption was used as a surrogate.

Measured fish tissue concentrations represent site-specific conditions, such as the local HHCB concentrations (impacted by the local hydrologic conditions, release magnitudes, and proximity of releases to biota collections) as well as the fish species present and their behaviors (range and feeding patterns). Modeled surface water concentrations reflect combined down-the-drain releases from consumer and commercial TSCA products and use harmonic-mean flow, representing average water column concentrations at the effluent outfall. The concentration at the effluent outfall likely overestimates concentrations experienced by fish, which do not remain at the outfall continuously. The extent of overestimation is uncertain due to species-specific movement ranges and spatial variability in HHCB concentrations due to site-specific conditions and the distance from the release.

[6] EPA considers this a high-end exposure estimate due to the use of the 95th percentile combined consumer plus commercial down-the-drain release scenarios, assuming no further removal from drinking water treatment and that there is no degradation or further dilution in the receiving water body (*i.e.,* applying the same concentration as modeled at the point of release from the POTW), and applying a 95th percentile ingestion rate. These protective factors are intentionally combined to develop an effective screening scenario, though their co-occurrence is unlikely.

Equations provided in Appendix D.3 derive fish tissue concentrations from surface water concentrations and the HHCB bioconcentration factor and apply age- (when available) and population-specific ingestion rates over time (Table 2-5). Ingestion rates are based on EPA's analysis of NHANES[7] survey data and other published literature, as discussed in the *Exposure Factors Handbook* (U.S. EPA, 2011b). General population rates represent the U.S. population, while tribal central tendency and high-end ingestion rates are drawn from surveys of specific tribal communities and reflect the range in the Handbook. Short-term (*e.g.,* 1-day) fish consumption is excluded because EPA identified no acute oral hazard from exposure to HHCB (Section 1.6).

Table 2-5. Fish Ingestion Rates

Population (Age Range)		Fish Ingestion Rate (g/kg-day) [a]
General population, 95th percentile	Young toddlers (1 to <2 years)	0.412
	Toddlers (2 to <3 years)	0.341
	Small children (3 to <6 years)	0.312
	Children (6 to <11 years)	0.242
	Teens (11 to <16 years)	0.146
	Adults (16 to <70 years)	0.278
Subsistence	Adults (16 to <70 years) [b]	1.78
Tribal	Adult (current, central tendency)	2.7
	Adult (current, high-end)	10.9

[a] Fish ingestion rates for general population are sources from the *Exposure Factors Handbook* (U.S. EPA, 2011b)
[b] Subsistence fisher ingestion rate represented with the 90th percentile general population ingestion rate.

Subsistence fishers are considered a potentially exposed or susceptible subpopulation (PESS) due to substantially higher fish ingestion rates (mean 1.78 g/kg-day vs. 0.28 g/kg-day at the 90th percentile for the general population (U.S. EPA, 2000)). These adult rates (ages 16 to <70 years) were used as an upper bound of potential exposure for all populations and for this screening-level analysis. Tribal populations are also a PESS given distinctive lifeways that can increase exposure; a high-end scenario applies the highest current 95th percentile ingestion rate—10.9 g/kg-day from a Shoshone–Bannock survey conducted from 2014 to 2015 (Polissar et al., 2016). Ingestion rates of shellfish reported in the *Exposure Factors Handbook* (U.S. EPA, 2011b) across tribal and general populations were generally near or notably less than fish ingestion rates for the same populations. Inputs and intermediate calculations are provided in the *Draft Fish Ingestion Risk Calculator for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026f).

2.3.3 Oral Exposure via Human Milk

Human biomonitoring data indicate that HHCB is present in human milk, consistent with its lipophilicity (log K_{OW} = 5.9) noted in the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e). Available monitoring data are limited but are considered for relevance to the U.S. population and to the COUs considered in this assessment in Section 3.3.1.

[7] National Health and Nutrition Examination Survey, a continuous, nationally representative survey run by the Centers for Disease Control and Prevention's (CDC) National Center for Health Statistics (NCHS).

2.4 Aggregate and Sentinel

Common, reasonably expected aggregate exposure scenarios were evaluated. Industrial releases are excluded from this aggregate analysis because releases to POTWs—which may subsequently discharge to the environment and contribute to human exposure via drinking water or fish consumption—are minimal (see Section 4.2.2 of the Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e)). Additionally, dermal exposures are excluded because they are not expected to be hazardous (Section 1.6), primarily due to HHCB's lipophilicity (Fontal et al., 2016; Ramirez et al., 2010), which promotes retention on or within the skin—consistent with its use as a fixative in fragrance products (Homem et al., 2015; Correia et al., 2013)—and results in minimal entry into systemic circulation (see detailed summary of dermal absorption literature in Appendix C). For the general population, aggregate exposure can occur when commercial and consumer waste go down-the-drain to the same POTW, which then discharges to water bodies used for drinking water or fish habitat. The aggregate down-the-drain approach is discussed earlier (Section 2.3) and not separately discussed in this section.

HHCB has been detected in monitoring data that are presented in Section 3.4.1 to characterize total residential HHCB exposures from multiple sources, including TSCA-regulated and others. However, because the monitoring data cannot be source-apportioned, aggregate exposures were also assessed using modeling data.

Three long-term aggregate scenarios were estimated by combining routinely expected exposure pathways as follows:

- **Aggregate Exposure Scenario 1 (Worker + Drinking Water + Fish Ingestion [Adults, 21+ Years]):** Workplace inhalation (HHCB dust during compounding/converting) combined with oral ingestion from HHCB in drinking water and fish (combined down-the-drain release scenario for subsistence fisher exposure; see Section 2.3).
- **Aggregate Exposure Scenario 2 (Consumer + Drinking Water + Fish Ingestion [Adults, 21+ Years]):** Consumer inhalation from continuous action air fresheners at home combined with oral ingestion from HHCB in drinking water and fish (combined down-the-drain release scenario for subsistence fisher exposure; see Section 2.3).
- **Aggregate Exposure Scenario 3 (Consumer [Infants, <1 Year] + Drinking Water):** Consumer (infants, <1 year) inhalation from continuous action air fresheners at home combined with oral ingestion from HHCB in drinking water.

For Aggregate Exposure Scenarios 1 and 2, exposure estimates were provided only for adults (21+ years) to align with typical worker ages. Scenario 3 focused exclusively on infants (<1 year) to address exposures in PESS. For fish ingestion in Scenarios 1 and 2, subsistence fisher intake rates were used to represent upper-bound exposures for the U.S. population. Because summing doses across pathways may not account for route-specific uncertainty factors or effect additivity, the draft HHCB risk evaluation (see Section 5.2.5.2 of draft RE) applied a total margin of exposure (total MOE) approach (U.S. EPA, 2026i), which is not presented here. Instead, the above assessment provides a qualitative description of selected aggregate scenarios assuming combined pathway exposures.

Sentinel exposures, which represent a plausible upper bound of exposure relative to all other exposures within a broad category of similar or related exposures, are captured throughout this draft assessment using screening-level or high-end exposure scenarios and high-end inputs and output estimates.

3 ANALYSIS RESULTS

3.1 Occupational

3.1.1 Inhalation Exposures via Vapor

Table 3-1 provides the 50th and 95th percentile HHCB modeled vapor concentrations and the annual average daily dose for occupational exposure during fragrance-oil formulation. This scenario represents the highest vapor exposure to act as screening for vapor exposure through other scenarios. The 8-hour TWA is driven primarily by unloading HHCB from transport containers at 167 °F, where vaporization is elevated.

Table 3-1. Occupational Vapor Inhalation Dose Estimates for HHCB

OES	Worker Type	8-Hour TWA (mg/m³) [c]		Intermediate Average Daily Dose (IADD; mg/kg-day)		Chronic Average Daily Dose (CADD; mg/kg-day)	
		P50	P95	P50	P95	P50	P95
Formulation of fragrance oils [a]	Adult	2.03E−03	1.84E−02	1.86E−04	1.69E−03	1.74E−04	1.58E−03
	Average woman of childbearing age			2.06E−04	1.87E−03	1.92E−04	1.74E−03
	Women of childbearing age 16 to <21 years[b]			2.26E−04	**2.05E−03**	2.11E−04	1.91E−03

OES = occupational exposure scenario; TWA = time-weighted average
[a] COU: Processing – Incorporation into formulation, mixture or reaction product – Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; Other: Fragrance mixtures and fragrance raw materials
[b] Different daily doses were calculated from the same 8-hour TWA due to different body weights. Women of childbearing ages between 16–21 years have the lowest body weight; therefore, they result in the highest doses.
[c] The 8-hour TWA was calculated from modeling the air concentrations for each worker activity as specified in Section 2.1.1.1. The model and other details including the activity-based exposure concentrations are provided in Appendix A.2.
Bolded font indicates the highest HHCB dose.

3.1.1.1 Weight of Scientific Evidence Conclusions for Occupational Exposures

Inhalation exposure estimates for fragrance-oil formulation are reflect a highest vapor generation scenario, driven by elevated unloading temperatures (167 °F), high HHCB weight fractions, and large batch sizes. Similar scenarios (*e.g.,* manufacturing or import-repackaging) likely share these same factors, but because U.S. data for these parameters are limited; the selected scenario aligns with worker activities for which parameter data are more available and increases confidence in the estimates.

Uncertainties include batch size, indoor vs. outdoor operations, and loading duration, which could lead to over- or underestimation. Monte Carlo simulations (100,000 iterations), as described in Appendix A, were used to address parameter variability and support the robustness of results. From the model simulations, the 50th percentile is used as the central tendency and the 95th percentile is used as the high-end estimates for the scenario.

In conclusion, there is moderate-to-robust confidence that the estimated vapor inhalation exposures represent upper-bound (sentinel) occupational exposures across all occupational COUs, and moderate confidence that the HHCB vapor estimates precisely reflect real-world exposures.

3.1.2 Inhalation Exposures via Dust

Table 3-2 reports the modeled 8-hour TWA concentrations and average daily doses for HHCB dust from occupational exposure during plastic compounding/converting of HHCB-containing pellets. This scenario serves to screen all other occupational exposure scenarios where there is potential for dust inhalation and conservatively assumes all HHCB is bioavailable upon inhalation.

Table 3-2. Occupational Modeled Dust Inhalation Dose Estimates for HHCB

OES	Worker Type[b]	TWA Exposures 8-Hour TWA (mg/m^3) [c d]		Intermediate Average Daily Dose (IADD; mg/kg-day)		Chronic Average Daily Dose (CADD; mg/kg-day)	
		P50	Reg. Limit	P50	P95	P50	P95
Plastic compounding/ converting[a]	Adult	1.75E−01	7.50E−01	1.65E−02	6.88E−02	1.54E−02	6.42E−02
	Average woman of childbearing age			1.82E−02	7.59E−02	1.70E−02	7.09E−02
	Women of childbearing age 16 to <21 years			2.00E−02	**8.35E−02**	1.87E−02	7.80E−02

OES = occupational exposure scenario; PNOR = particulates not otherwise regulated; TWA = time-weighted average
[a] COU: Processing – Incorporation into articles – Odor agent in: Plastics material and resin manufacturing
[b] Different daily doses were calculated from the same 8-hour due to different body weights. Women of childbearing ages between 16–21 years have the lowest body weight; they therefore result in the highest doses.
[c] As the 95th percentile of the PNOR data exceeds the regulatory limit, EPA calculated an estimate using the PNOR OSHA regulatory limit of 15 mg/m^3.
[d] All modeling details are included in Appendix A.3.
Bolded font indicates the highest HHCB dose.

3.1.2.1 Weight of Scientific Evidence Conclusions for Occupational Dust Exposures

Inhalation exposure estimates for HHCB dust during plastic compounding/converting are industry-specific and reflect a high dust generation scenario driven by high HHCB concentration. Dust exposure in these operations is expected to exceed that from handling powder cleaning/laundry products that contain lower amounts of HHCB. PNOR data provides a reliable range of worker dust concentrations, but workplace dust composition is uncertain. Estimates assume (1) all workplace dust originates from pellets containing HHCB, (2) HHCB in dust is bioavailable, and (3) pellet HHCB concentrations equal those in finished articles. These assumptions are likely to overestimate exposure because workplace dust is likely to contain multiple constituents and not all HHCB will be bioavailable. As this is a screening-level assessment, these limitations support that these estimates will be protective for workers exposed to HHCB dust through the various COUs.

In conclusion, there is moderate-to-robust confidence in the scientific evidence that the estimated dust inhalation exposures for HHCB serve as upper bound or sentinel estimate of exposure to HHCB in occupational settings across all COUs. There is moderate confidence in the scientific evidence that the estimated inhalation exposures for HHCB dust serve as precise estimate of real exposure.

3.2 Consumer

3.2.1 Inhalation Exposures via Mist

Table 3-3 presents HHCB mist concentrations from continuous-action air fresheners and associated exposure doses for adults, youth, children, and infants. These values are upper bounds, based on a conservative assumption of continuous (24/7) occupancy in a small room (*e.g.,* bathroom, dorm room, small room within a home) with product use, or continuous movement between such rooms with product use, sustained over one year. Infants (<1 year) have the highest estimated average daily dose (1.27×10^{-3} mg/kg/day) due to a higher inhalation rate per body weight.

Table 3-3. Consumer Mist Inhalation Dose Estimates for HHCB[a]

Scenario	Consumer Population	Annual Daily Average Concentration (mg/m^3)	Chronic Non-Cancer Exposure Time (hours/day)	Chronic Non-Cancer Exposure Frequency (days/year)	Annual Daily Average Dose (mg/kg/day) [c]
Continuous action air fresheners	Adults 21+ years	8.95E−04	24	365	1.99E−04
	Youths 16–20 years [b]				2.35E−04
	Youths 11–15 years				2.95E−04
	Children 6–10 years				4.46E−04
	Children 3–5 years				7.62E−04
	Infants 1–2 years				1.23E−03
	Infants <1 year				**1.27E−03**

[a] Continuous action air fresheners
[b] The body weight for this age group was adjusted from 71.6 kg (*Exposure Factors Handbook* (U.S. EPA, 2011b)) to 65.9 kg per latest EPA guidance on the consideration of body weights for the assessment of exposures and risks among females of reproductive age.
[c] Doses derived using CEM.
Bolded font indicates the highest HHCB dose.

3.2.1.1 Weight of Scientific Evidence Conclusions for Consumer Inhalation

Inhalation dose estimates for HHCB mist from continuous-action air fresheners are product-specific and represent upper bound rather than typical exposures (Section 2.2.2). Conservatism derived from assuming a small room, 24 hours/day occupancy, and the highest product weight fraction; more realistic assumptions (*e.g.,* movement to larger rooms or areas without fresheners) would reduce estimates. Overall, these high-end results exceed those expected for other consumer products.

In conclusion, based on the weight of evidence, there is moderate-to-robust confidence that the modeled inhalation exposures represent high-end (screening) consumer and commercial mist exposures to HHCB across all COUs. Confidence in the precision of these high-end estimates is low due to compounded conservative assumptions in input parameters.

3.3 General Population

3.3.1 Oral Exposure via Drinking Water

Table 3-4 provides estimated source water concentrations for drinking water and resulting HHCB doses for adults, infants, and toddlers. The P95 POTW scenario yields concentrations exceeding 95% of POTWs and includes 92% HHCB removal during wastewater treatment, which is representative of modern facilities. The protective case assumes no additional removal by drinking water treatment, likely overestimating exposure because typical treatment would further reduce HHCB. Infants have the highest dose due to greater water intake per body weight, representing a potentially exposed and susceptible subpopulation; combined with conservative scenario parameters, this serves as a sentinel exposure.

Table 3-4. General Population Drinking Water Doses

Scenario	Estimated Surface Water Concentrations Harmonic Mean Conc. (µg/L)	Adult (21+ years) ADD (mg/kg-day)	Infant (Birth to <1 year) ADD (mg/kg-day)	Toddler (1–5 years) ADD (mg/kg-day)
Combined *modeled* commercial plus consumer down-the-drain release with the P95 POTW scenario[a]	21.2	2.33E−04	5.95E−04	2.55E−04
Highest *measured* surface water[b]	25.5	2.80E−04	**7.16E−04**	3.07E−04

[a] Only this scenario was used in the general population screening assessment because it resulted in the highest surface water concentrations. A 92% removal efficiency was applied for the wastewater, and no further drinking water removal efficiency was applied.
[b] Water Quality Portal database reported the highest monitored surface water concentration from California as described further in the Draft HHCB Environmental Exposure Assessment TSD (U.S. EPA, 2026e). This single maximum value does not correspond to either the 30Q5 (*i.e.,* the lowest 30-day average flow that occurs [on average] once every 5 years or harmonic mean concentrations); nevertheless, it is included for reference alongside modeled exposure estimates. Note that monitored concentrations are source-agnostic and cannot be attributed to specific TSCA COUs.
Bolded font indicates the highest HHCB dose.

3.3.1.1 Weight of Scientific Evidence Conclusions for General Population Oral Exposure via Drinking Water

Oral dose estimates from drinking water downstream of combined POTW releases are high-end, reflecting conservative inputs and assumptions (*e.g.,* source water obtained adjacent to the outfall of P95 POTW). The assessment also incorporates site-specific data (population, weather, streamflow) to improve realism. While the conservative conditions may co-occur at some sites, these conditions are unlikely to represent nationwide concentrations.

In conclusion, based on the weight of evidence, there is moderate-to-robust confidence that the modeled concentrations provide a high-end concentration for the purposes of a screening-level assessment for general population exposure to via drinking water and capture all individual COUs. Confidence in the precision of the estimate is low due to compounded conservative assumptions in input parameters.

3.3.2 Oral Exposure via Fish Ingestion

Table 3-5 presents HHCB fish-tissue concentrations and adult ADDs, reflecting combined exposure from TSCA COUs and other sources for whole fish and filet. Most individuals consume the filet, though some populations consume whole fish. Because HHCB is highest in less commonly consumed tissues (*e.g.,* viscera, gills), whole-fish results likely overestimate exposure for most people. The highest modeled ADD (0.093 mg/kg-day) corresponds to the high-end tribal fish consumption rate and is roughly an order of magnitude above the 90th percentile general-population ADD. This high-end ingestion scenario incorporates multiple compounding conservative parameters and assumptions that bias the results toward higher estimates.

Table 3-5. Population-Specific Oral Fish Ingestion Dose Estimates

Scenario	Surface Water Concentration (SWC; µg/L)	Fish Tissue Concentration (mg/kg) [a]	ADD, Adults (mg/kg-day)			
			Gen Pop, 90th Percentile IR	Subsistence Fisher IR	Tribal, Current [c] Central Tendency IR	Tribal, Current High-End IR
Consumer Plus Commercial Combined DTD (KABAM) (*modeled*)	25.4 [b] (P95 POTW)	8.5 Whole fish	5.36E−04	1.51E−02	2.30E−02	**9.27E−02**
Highest *monitored* fish tissue (common carp, whole fish)	N/A	2.10 Whole fish	5.83E−04	3.74E−03	5.67E−03	2.29E−02

ADD = average daily dose; BCF = bioconcentration factor; DTD = down-the-drain; IR = (fish) ingestion rate; KABAM = K_{OW} (based) Aquatic BioAccumulation Model; SWC = surface water concentration
[a] $Fish\ Tissue\ Conc. = SWC \times BCF \times 0.001$ mg/µg
[b] A 92% removal efficiency for HHCB is applied to these modeled releases.
Bolded font indicates the highest HHCB dose.

Table 3-5 also presents the highest measured fish-tissue concentration from the literature and corresponding dose estimates to contextualize the modeling results. Both modeled and monitored results represent combined exposure from multiple sources. Monitoring data are sparse; while the maximum reflects a near-outfall scenario, limited sampling frequency and locations may miss high-end concentrations. Monitoring likely integrates over fish home ranges larger than the near-outfall area modeled in the PSC, with species-specific variability, yielding lower tissue concentrations. Nonetheless, the monitoring data confirms the presence and magnitude of HHCB in ambient surface water and fish tissues.

3.3.2.1 Weight of Scientific Evidence Conclusions for General Population Oral Exposure via Fish Ingestion

Oral doses from fish downstream of combined POTW releases are high-end, assuming sustained near-outfall exposure, long-term consumption, and application of a protective BCF across the relevant range. Under a P95 POTW scenario (based on contributing population and receiving-water harmonic mean flow; only approximately 5% of POTWs would be higher), modeled fish-tissue concentrations can exceed the highest monitoring detections due to conservative assumptions about proximity and uptake. The scenario combines multiple protective factors that result in higher modeled doses, including approximately 20 days of consistent exposure to high surface water concentration to reach steady state in fish, use of the highest present-day ingestion rate (*e.g.,* 95th percentile reported from the Shoshone-Bannock), and sourcing all fish consumed from water at the outfall. Achieving these doses would require consuming about 800 g/day of such fish (for an 80-kilogram adult) for months to years.

Confidence in high-end environmental surface-water concentrations and ingestion rates is moderate to high. Use of refined fish-tissue estimates using KABAM, the Agency has moderate confidence in high-end fish-tissue concentrations. The high-end monitored surface water concentration reflects conditions similar to the POTW point of release modeling, with a larger community POTW discharging to lower flow conditions, and repeated sampling on two different days yielding similar results increases confidence in monitored concentration.

In conclusion, based on the weight of evidence, there is moderate confidence that the modeled concentrations represent high-end concentrations for the purposes of a screening-level assessment for different populations' oral exposures to HHCB following fish consumption across all individual COUs.

3.3.1 Oral Exposure via Human Milk

As shown in Table 3-6, EPA identified one study reporting HHCB concentrations in milk in U.S. populations (Reiner et al., 2007). Several small studies (sample size <100) from Asian and European countries report HHCB concentrations in human milk. Although the study locations are not necessarily representative of U.S. exposures, these studies confirm this exposure pathway is plausible (see Table_Apx A-2 in OCSPP (2014)).

The available U.S. study (Reiner et al., 2007) measured HHCB in milk from 39 Massachusetts women. HHCB was detected in 97% of the samples at a mean concentration of 227 ng/g lipid weight (range <5 to 917 ng/g lipid weight), indicating widespread exposure via human milk within this study population. However, it is unknown to what extent this study is representative of the larger U.S. population as a whole. According to the study authors, variability was likely due to personal consumption habits and specific products used by the nursing mothers (not characterized in the study), while maternal age, parity, and breastfeeding duration had little statistical impact.

Table 3-6. U.S. HHCB Human Milk Biomonitoring Data

Population	Sampling Year	Mean (± SD) HHCB Concentration; Range; Detection Frequency	Reference; Data Quality
Milk samples from 39 Massachusetts women	2004; sample collection time not reported	227 ± 228 ng/g lipid weight (lw) Range: <5 to 917 ng/g lw; 3% of samples non-detects	(Reiner et al., 2007); High

Biomonitoring data from this U.S. study were used as direct estimates to characterize potential infant exposure via human milk. Infants (birth to <1 year) were selected as the appropriate age group for screening due to high milk intake relative to body weight.

Notably, there are limitations associated with using the available biomonitoring data to characterize infant exposure to HHCB via human milk. These include (1) a small, single-state sample limiting generalizability to the U.S. population; and (2) inability to apportion maternal exposure routes (oral, dermal, inhalation) or sources. Thus, while reflecting total HHCB in milk from all sources of HHCB (*i.e.,* aggregate), the data cannot attribute contributions from specific COUs or other sources. Therefore, human milk exposures are not further assessed. However, potential HHCB ADDs associated with this study were estimated for infants (<1 year) and are presented in Appendix D.2 for transparency.

3.3.1.1 Weight of Scientific Evidence Conclusions for General Population Oral Exposure via Human Milk

Based on the weight of evidence, EPA has slight-to-moderate confidence that the monitoring exposure estimates reflect real-world infant exposures to HHCB via human milk in the general U.S. population. This is because the 1 available study conducted in the United States analyzed milk from a small sample (39 women) from the same state.

3.4 Aggregate Exposure

3.4.1 Monitoring

For home users, indoor air monitoring data for HHCB reflect total concentrations from multiple sources, including TSCA COUs and other sources. Common indoor sources of HHCB include personal care products (*e.g.,* lotions, fragrances, tampons, lipsticks), air care, and cleaning products (Api et al., 2023; Fontal et al., 2016). Shed skin cells previously exposed to HHCB-containing cosmetics can also indirectly contribute to HHCB in household dust.

A study of low-income housing in Boston, Massachusetts, found HHCB on indoor dust surfaces increased from 0.018 to 0.12 μg/ft^2 pre-renovation to 0.11 to 4.9 μg/ft^2 post-renovation, and indoor air concentrations increased from 6.4 to 14 ng/m^3 to 39 to 390 ng/m^3 (Dodson et al., 2017). According to Dodson et al. (2017), this increase may be attributed to lower air exchange rates for samples collected during the heating season.

Another study measured HHCB in the indoor air of renovated and non-renovated low-income units (n = 16), campus dormitories (n = 15), single-family homes (n = 5), and an office (n = 1) in greater Boston, reporting 35 to 430 ng/m^3 (Dodson et al., 2019). These values likely reflect average concentrations from multiple sources and/or sampling occurring sometime after product use. Aggregate exposures from multiple TSCA consumer products were not estimated, preventing direct comparison of measured indoor air to modeled aggregates.

3.4.2 Modeling

The first aggregate exposure scenario represents female of reproductive ages between 16 and 21 workplace inhalation (HHCB dust during compounding/converting) combined with oral ingestion from HHCB in drinking water and fish (combined down-the-drain release scenario for general population exposure; see Section 2.3). ADD for Aggregate Exposure Scenario 1 is presented in Table 3-7. Upper-bound estimates were used to construct aggregate exposure scenarios to protect most individuals. Although these scenarios may not reflect the most likely or common HHCB exposures, they provide examples of possible aggregate exposure pathways.

Table 3-7. Aggregate (Adult Worker + Drinking Water + Fish Ingestion) Exposure Scenario 1 Dose Estimates (Female Workers Aged 16–21 Years)

Exposed Population	Exposure Pathway and Source	ADD (mg/kg-day)
Occupational	Inhaling HHCB dust during plastic compounding or converting	7.80E−02
General population	Consuming drinking water containing HHCB from combined down-the-drain commercial and consumer down-the-drain releases to surface water (95th percentile [P95] POTW receiving water concentration scenario with 92% removal efficiency at POTW – assuming no further removal from drinking water treatment)	2.87E−03
Subsistence fisher	Ingesting fish containing HHCB (Combined consumer and commercial down-the-drain releases for the P95 POTW scenario, fish tissue concentrations derived from KABAM, and subsistence fishing ingestion rate)	1.51E−02
ADD = average daily dose; KABAM = K_{OW} (based) Aquatic BioAccumulation Model; POTW = publicly owned treatment works		

The second aggregate exposure scenario represents adult (21+ years) residential inhalation (HHCB mist from a continuous action air freshener) combined with oral ingestion from HHCB in drinking water and fish (combined down-the-drain release scenario for general population exposure; see Section 2.3). Results for Aggregate Exposure Scenario 2 are presented below in Table 3-8.

Table 3-8. Aggregate (Adult Consumer [21+ Years] + Drinking Water + Mist Inhalation) Exposure Scenario 2 Dose Estimates

Exposed Population	Exposure Pathway and Source	ADD (mg/kg-day)
Consumer	Inhaling HHCB mist from a continuous action air freshener	1.99E−04
General population	Consuming drinking water containing HHCB from combined commercial and consumer down-the-drain releases to surface water (P95 POTW receiving water concentration scenario with 92% removal efficiency at POTW – assuming no further removal from drinking water treatment)	2.87E−03
Subsistence fisher	Ingesting fish containing HHCB (Combined consumer and commercial down-the-drain releases from the P95 POTW scenario, fish tissue concentrations derived from KABAM, and subsistence fishing ingestion rate)	1.51E−02

ADD = average daily dose; KABAM = KOW (based) Aquatic BioAccumulation Model; POTW = publicly owned treatment works

The third aggregate exposure scenario represents infant (<1 year) residential inhalation (HHCB mist from a continuous action air freshener) combined with oral ingestion from HHCB in drinking water (combined down-the-drain release scenario for general population exposure; see Section 2.3). Upper-bound estimates were used to construct the aggregate exposure scenario to be protective of most infants (<1 year). Results for Aggregate Exposure Scenario 3 are presented in Table 3-9.

Table 3-9. Aggregate (Infant Consumer [<1 Year] + Drinking Water + Mist Inhalation) Exposure Scenario 3 Dose Estimates

Exposed Population	Exposure Pathway and Source	ADD (mg/kg-day)
Consumer	Inhaling HHCB mist from a continuous action air freshener	1.27E−03
General population	Consuming drinking water containing HHCB from combined commercial and consumer down-the-drain releases to surface water (P95 POTW receiving water concentration scenario with 92% removal efficiency at POTW – assuming no further removal from drinking water treatment)	5.95E−04

ADD = average daily dose; KABAM = K_{OW} (based) Aquatic BioAccumulation Model; POTW = publicly owned treatment works

3.4.2.1 Weight of Scientific Evidence Conclusions for Aggregate Exposure

As noted in Section 2.4, industrial releases are excluded from this aggregate analysis because discharges to POTWs are negligible; therefore, any downstream discharge—and associated human exposure via drinking water or fish—would be minimal. Dermal exposure is also excluded because it is not expected to be hazardous (See Section 1.6). HHCB's lipophilicity (Fontal et al., 2016; Ramirez et al., 2010) promotes retention on or within the skin, consistent with its role as a fragrance fixative (Homem et al., 2015; Correia et al., 2013), resulting in minimal systemic absorption (see detailed summary of dermal absorption literature provided in Appendix C).

For aggregate scenarios 1 and 2, we used the subsistence fish ingestion rate—rather than the higher tribal rate or the lower general-population 90th percentile rate—to better represent potential aggregate exposures for most people in the United States. Based on the weight of evidence, there is moderate-to-robust confidence that the modeled aggregate exposures represent high-end (screening) inhalation and oral exposures to HHCB across multiple COUs. The aggregate exposure scenarios are based on upper-bound assumptions (*e.g.,* highest inhalation exposure source, P95 POTW scenario, highest drinking water and fish ingestion estimates) in the approach that may result in an overestimation of most common aggregate exposures to TSCA sources, which leads EPA to this conclusion.

4 CONCLUSIONS

This draft assessment employs a tiered approach, combining screening-level methods with more refined analyses, selected based on the evaluated population and the relevant exposure routes and pathways. Tiered approaches enable timely assessments and conserve resources by focusing efforts on chemicals, uses, locations, populations, or exposure pathways and routes with the highest potential risk. As a result, high-end exposure scenarios were evaluated for workers, consumers, and the general population for HHCB. The analysis captures PESS and sentinel exposures.

Occupational Exposure

Workers may be exposed to HHCB via vapor, dust, or mist. Vapor exposures are highest at facilities blending fragrance oils due to unloading of concentrated HHCB at elevated temperatures; estimated ADDs are up to 2.26×10^{-4} mg/kg-day (50th percentile) and 2.05×10^{-3} mg/kg-day (95th percentile). Dust exposures can occur during tasks that generate airborne dust (*e.g.,* unloading HHCB-containing plastic pellets), with ADDs up to 8.35×10^{-2} mg/kg-day based on the PNOR regulatory limit and 2.00×10^{-2} mg/kg-day using the 50th percentile of PNOR data. Uncertainties include the HHCB fraction in workplace dust and pellets and the potential for incomplete bioavailability of HHCB in dust. Mist exposure is addressed using consumer estimates considered protective for workers.

Overall, these estimates can serve to screen for occupational risks from other occupational exposures scenarios. Confidence is moderate to robust for bounding exposure and moderate for precision relative to real-world conditions.

Consumer Exposure

Consumers are primarily exposed to HHCB via inhalation of mist. EPA conducted a screening analysis (Section 2.2.2.1) assuming continuous-action air freshener use with 24/7 occupancy of a small room (15 m^3) to represent an upper-bound inhalation scenario where an individual may be home-bound. Inputs reflected the highest identified product concentration, continuous emissions, small room size, and continuous presence to support the screening analysis approach. The high-end ADD was up to 1.27×10^{-3} mg/kg/day for infants (<1 year), driven by higher intake per body weight. Screening estimates of consumer exposures to mists were used to also represent commercial exposures for workers (*i.e.,* front desk hotel workers or bathroom attendants) and bystanders (*i.e.,* hotel guests) who occupy a space with continuous action air fresheners. This is because commercial worker exposures are assumed to be as high as consumer exposures due to proximity and extended exposures to the product, while bystanders' exposures are expected to be lower due to distance and transient exposures to the product. EPA has moderate-to-robust confidence that these estimates represent high-end consumer and commercial exposures, but only slight confidence in their precision due to conservative input assumptions. Overall, the estimated concentrations represent upper-bound consumer exposures to inhaled mists and are derived from the high-end assumptions described in Section 2.2.2. These estimates are intended to be an upper bound of HHCB exposure due to the screening analysis approach implemented rather than to represent typical individual exposures.

General Population Exposure

General population exposure to HHCB occurs primarily via ingestion of drinking water influenced by upstream wastewater and consumption of fish from waters containing HHCB. Highest concentrations are driven by combined consumer and commercial down-the-drain releases, with treated POTW effluent discharged to surface waters that is later sourced as drinking water and treated again. Although POTW releases are widespread, influent loading and receiving water characteristics vary, producing a wide range of potential concentrations. The highest ADD resulting from drinking water was 7.16×10^{-4}

mg/kg-day for infants; the highest dose resulting from fish ingestion was 9.27×10^{-2} mg/kg-day for tribal populations.

Overall, there is moderate-to-robust confidence that the estimated oral exposures represent high-end drinking water and fish ingestion exposures, and slight-to-moderate confidence in their precision due to compounded conservative assumptions.

Aggregate and Sentinel Exposure

The aggregate assessment considered total exposures (*i.e.,* TSCA, other sources) from residential monitoring data and modeled TSCA-specific aggregate scenarios based on upper bound estimated occupational, consumer, and dietary exposure estimates. Because inhalation and oral hazard values are based on same systemic endpoint, decreased offspring bodyweight in rats, EPA used a total MOE approach rather than summing doses, which may not account for differing uncertainty factors or ensure cross-route additivity. As such, results are presented in Section 5.3.7 of the draft HHCB risk evaluation (U.S. EPA, 2026i).

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APPENDICES

Appendix A OCCUPATIONAL INHALATION EXPOSURE MODELING APPROACH

This appendix presents the modeling approach and equations used in estimating occupational exposures for each of the applicable occupational scenarios. The models were developed through review of the literature and consideration of existing EPA/OPPT models, emission scenario documents (ESDs), and/or generic scenarios (GSs). An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on reasonably available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation used the Latin Hypercube sampling method in @Risk Industrial Edition, Version 8.0 (Palisade, 2022), which generates a sample of possible values from a multi-dimensional distribution and is considered a stratified method. This means that the generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture a broad range of possible input values, including values with low probability of occurrence.

EPA used both the 95th and 50th percentile Monte Carlo simulation model result values for this assessment—the 95th percentile value represents the high-end exposure level whereas the 50th represents the central tendency exposure level. The following appendix subsections detail the model design equations and parameters for each of the OESs.

A.1 EPA/OPPT Standard Models

This section discusses the standard models used by EPA to estimate occupational inhalation exposures. All the models presented in Appendix were previously developed by the Agency and are not the result of any new model development for this draft risk evaluation. Therefore, this appendix does not provide the details of the derivation of the model equations that have been provided in other documents such as the *ChemSTEER User Guide* (U.S. EPA, 2015b), Chemical Engineering Branch Manual for the Preparation of Engineering Assessments, Volume 1 (CEB, 1991), *Evaporation of Pure Liquids from Open Surfaces* (Arnold and Engel, 2001), E*valuation of the Mass Balance Model Used by the References Environmental Protection Agency for Estimating Inhalation Exposure to New Chemical Substances* (Fehrenbacher and Hummel, 1996), and Releases During Cleaning of Equipment (PEI Associates, 1988). The models include loss fraction models as well for estimating chemical vapor generation rates used in subsequent model equations to estimate the volatile releases to air and occupational inhalation exposure concentrations. The parameters in these equations are specific to calculating environmental releases and occupational inhalation exposures to HHCB.

The EPA/OPPT Penetration Model estimates releases to air from evaporation of a chemical from an open, exposed liquid surface (U.S. EPA, 2015b). This model is appropriate for determining volatile releases from activities that are performed indoors or when air velocities are expected to be less than or equal to 100 feet per minute. The EPA/OPPT Penetration Model calculates the average vapor generation rate of the chemical from the exposed liquid surface using the following equation:

Equation_Apx A-1.

$$G_{activity} = \frac{(8.24 \times 10^{-8}) * (MW_{HHCB}^{0.835}) * F_{correction\_factor} * VP * \sqrt{Rate_{air\_speed}} * (0.25\pi D_{opening}^{2}) \sqrt[4]{\frac{1}{29} + \frac{1}{MW_{HHCB}}}}{T^{0.05} * \sqrt{D_{opening}} * \sqrt{P}}$$

Where:

$G_{activity}$	=	Vapor generation rate for activity (g/s)
MW_{HHCB}	=	HHCB molecular weight (g/mol)
$F_{correction\_factor}$	=	Vapor pressure correction factor (unitless)
VP	=	HHCB vapor pressure (torr)
$Rate_{air\_speed}$	=	Air speed (cm/s)
$D_{opening}$	=	Diameter of opening (cm)
T	=	Temperature (K)
P	=	Pressure (torr)

The EPA/OPPT Mass Transfer Coefficient Model estimates releases to air from the evaporation of a chemical from an open, exposed liquid surface (U.S. EPA, 2015b). This model is appropriate for determining this type of volatile release from activities that are performed outdoors or when air velocities are expected to be greater than 100 feet per minute (ft/min). The EPA/OPPT Mass Transfer Coefficient Model calculates the average vapor generation rate of the chemical from the exposed liquid surface using the following equation:

Equation_Apx A-2.

$$G_{activity} = \frac{(1.93 \times 10^{-7}) * \left(MW_{HHCB}{}^{0.78}\right) * F_{correction\_factor} * VP * Rate_{air\_speed}^{0.78} * (0.25\pi D_{opening}^{2}) \sqrt[3]{\frac{1}{29} + \frac{1}{MW_{HHCB}}}}{T^{0.4} D_{opening}^{0.11} (\sqrt{T} - 5.87)^{2/3}}$$

Where:

$G_{activity}$	=	Vapor generation rate for activity (g/s)
MW_{HHCB}	=	HHCB molecular weight (g/mol)
$F_{correction\_factor}$	=	Vapor pressure correction factor (unitless)
VP	=	HHCB vapor pressure (torr)
$Rate_{air\_speed}$	=	Air speed (cm/s)
$D_{opening}$	=	Diameter of opening (cm)
T	=	Temperature (K)

The EPA's Office of Air Quality Planning and Standards (OAQPS) AP-42 Loading Model estimates releases to air from the displacement of air containing chemical vapor as a container/vessel is filled with a liquid (U.S. EPA, 2015b). This model assumes that the rate of evaporation is negligible compared to the vapor loss from the displacement and is used as the default for estimating volatile air releases during both loading activities and unloading activities. It is used for unloading activities because it assumes that while one vessel is being unloaded another is to be loaded. The EPA/OAQPS AP-42 Loading Model calculates the average vapor generation rate from loading or unloading using the following equation:

Equation_Apx A-3.

$$G_{activity} = \frac{F_{saturation\_factor} * MW_{HHCB} * V_{container} * 3785.4\frac{cm^3}{gal} * F_{correction\_factor} * VP * \frac{RATE_{fill}}{3600\frac{s}{hr}}}{R * T}$$

Where:

$G_{activity}$	=	Vapor generation rate for activity (g/s)
$F_{saturation\_factor}$	=	Saturation factor (unitless)
MW_{HHCB}	=	HHCB molecular weight (g/mol)
$V_{container}$	=	Volume of container (gal/container)
$F_{correction\_factor}$	=	Vapor pressure correction factor (unitless)
VP	=	HHCB vapor pressure (torr)
$RATE_{fill}$	=	Fill rate of container (containers/h)
R	=	Universal gas constant (L*torr/mol-K)
T	=	Temperature (K)

For large scale operations, EPA expects the majority of industrial facilities to use a vapor balance system to minimize fugitive emissions when loading and unloading tank trucks and railcars. As such, vapor losses from displacement of air are likely mitigated by the use of such systems. Actual fugitive emissions are likely limited to any saturated vapor that remain in the hose, loading arm, or related equipment after being disconnected from the truck or railcar. EPA uses EPA/OAQPS AP-42 Loading Model but estimates the emissions from the saturated air containing the chemical of interest that remains in transfer equipment from transfer hoses and/or loading arms when they are disconnected from tank trucks and rail cars (Equation_Apx A-4). In addition, EPA also estimates the emissions from leaks using equations from EPA's Chapter 5: Petroleum Industry of AP-42 (U.S. EPA, 2015a) and EPA's Protocol for Equipment Leak Emission Estimates (U.S. EPA, 1995), shown below in Equation_Apx A-5. The vapor generation rate, G, or the total emission rate over time, can be calculated by aggregating emissions from all sources (see Equation_Apx A-6). The dimensions of the transfer system and emission factors are provided in *Supplemental Information on Occupational Exposure Modeling for HHCB*.

Equation_Apx A-4.

$$E_T = \frac{F_{saturation\_factor} \times MW_{HHCB} \times 3{,}786.4 \times V_h \times F_{correction\ factor} \times VP}{t_{disconnect} \times T \times R \times 3{,}600 \times 760}$$

Equation_Apx A-5.

$$E_L = \sum (F_A \times WF_{TOC} \times N) \times \frac{1{,}000}{3{,}600}$$

Equation_Apx A-6.

$$G = E_T + E_L$$

Where:

G	=	Vapor generation rate for activity (g/s)
E_T	=	Emission rate of chemical from transfer/loading system (g/s)
$F_{saturation\_factor}$	=	Saturation factor (unitless)
MW_{HHCB}	=	HHCB molecular weight (g/mol)
V_h	=	Volume of transfer hose (gal/container)

$F_{correction\ factor}$	=	Vapor pressure correction factor (unitless)
VP	=	HHCB vapor pressure (torr)
$t_{disconnect}$	=	Time to disconnect hose/couplers (escape of saturated vapor from disconnected hose or transfer arm into air (h)
R	=	Universal gas constant (L*torr/mol-K)
T	=	Temperature (K)
E_L	=	Emission rate of chemical from equipment leaks (g/s)
F_A	=	Applicable average emission factor for the equipment type (kg/h-source)
WF_{TOC}	=	Average weight fraction of chemical in the stream (unitless)
N	=	Number of pieces of equipment of the applicable equipment type in the stream

For each of the vapor generation rate models, the vapor pressure correction factor ($F_{correction\_factor}$) can be estimated using Raoult's Law and the mole fraction of HHCB in the liquid of interest. However, in most cases, EPA did not have data on the molecular weights of other components in the liquid formulations; therefore, the Agency approximated the mole fraction using the mass fraction of HHCB in the liquid of interest. Using the mass fraction of HHCB to estimate mole fraction does create uncertainty in the vapor generation rate model. If other components in the liquid of interest have similar molecular weights as HHCB, then mass fraction is a reasonable approximation of mole fraction. However, if other components in the liquid of interest have much lower molecular weights than HHCB, the mass fraction of HHCB will be an overestimate of the mole fraction. If other components in the liquid of interest have much higher molecular weights than HHCB, the mass fraction of HHCB will underestimate the mole fraction.

The EPA/OPPT Mass Balance Inhalation Model estimates a worker inhalation exposure to an estimated concentration of chemical vapors within the worker's breathing zone using a one box model. The model estimates the amount of a chemical inhaled by a worker during an activity in which the chemical has volatilized and the airborne concentration of the chemical vapor is estimated as a function of the source vapor generation rate or the saturation level of the chemical in air. First, the applicable vapor generation rate model is used to calculate the vapor generation rate for the given activity. Using this vapor generation rate, the EPA/OPPT Mass Balance Inhalation Model calculates the volumetric concentration of HHCB using the equation below:

Equation_Apx A-7.

$$Cv_{activity} = Minimum\ between \left(\frac{170{,}000 * T * Gactivity}{MW * Q * k} \middle| \frac{1{,}000{,}000ppm * VP}{P} \right)$$

Where:

$G_{activity}$	=	Vapor generation rate for activity (g/s)
Q	=	Ventilation rate (ft^3/min)
k	=	Mixing Factor (unitless)
MW_{HHCB}	=	HHCB molecular weight (g/mol)
VP	=	HHCB vapor pressure (torr)
R	=	Universal gas constant (L*torr/mol-K)
T	=	Temperature (K)
P	=	Pressure (torr)

Mass concentration can be estimated by multiplying the volumetric concentration by the molecular weight of HHCB and dividing by molar volume at standard temperature and pressure. The mass concentrations for each exposure activity of a given OES can be summed to calculate the 8-hour TWA for a given worker using Equation_Apx A-8:

Equation_Apx A-8.

$$TWA_{8hr} = \frac{\sum_{i=0}^{n} Cm_i \times h_i}{8\ hours}$$

A.2 Formulation of Fragrance Oil Model Approaches and Parameters

This appendix section presents the modeling approach and equations used to estimate occupational exposure for HHCB during the Formulation of fragrance oil OES. This approach utilizes CDR data (U.S. EPA, 2020a) combined with Monte Carlo simulation (a type of stochastic simulation).

EPA identified the following potential exposure sources from formulation of fragrance oil operations:

- Exposure Source 1: Exposure to HHCB During Unloading
- Exposure Source 2: Exposure to HHCB During Container Cleaning
- Exposure Source 3: Exposure to HHCB During Product Sampling
- Exposure Source 4: Exposure to HHCB During Equipment Cleaning
- Exposure Source 5: Exposure to HHCB During Packaging into Transport Containers

Inhalation exposure for HHCB during formulation of fragrance oils is a function of HHCB's physical properties, container size, mass fractions, and other model parameters. Although physical properties are fixed, some model parameters are expected to vary. EPA used a Monte Carlo simulation to capture variability in the following model input parameters: HHCB concentration, production volume, air speed, diameter of openings, saturation factor, container size, and loss fractions.

A.2.1 Model Equations

Table_Apx A-1 provides the models and associated variables used to calculate inhalation exposure for each exposure source within each iteration of the Monte Carlo simulation. The values for these variables are provided in Appendix A.2.2.

Table_Apx A-1. Model Used for Formulation of Fragrance Oils

Exposure Source	Model(s) Applied	Variables Used
Exposure to HHCB during unloading	EPA/OAQPS AP-42 Loading Model or Chemical Loading Exposure Model (Tank Truck and Rail Car)	F_{HHCB_import}; $VP_{unloading}$; f_{sat}; MW; Vm; $Vcont$; EF; k; Q; R; T; $RATE_{fill\_drum}$; $RATE_{fill\_tote}$; E_{factor_RC}; E_{factor_TT}; $F_{correction\ factor}$; $RATE_{fill\_tank\_truck}$; $RATE_{fill\_rail\_car}$;
Exposure to HHCB during container cleaning	EPA/OPPT Penetration Model or EPA/OPPT Mass Transfer Coefficient Model, based on air speed	F_{HHCB_import}; $VP_{non-unloading}$; MW; Vm; EF; k; Q; $Ptorr$; T; $RATE_{air\_speed}$; $RATE_{air\_speed\_outdoor}$; $F_{correction\ factor}$; $RATE_{unload}$; $D_{container\ 1}$; $D_{container\ 2}$;
Exposure to HHCB during product sampling	EPA/OPPT Penetration Model or EPA/OPPT Mass Transfer Coefficient Model, based on air speed	F_{HHCB_prod}; $VP_{non-unloading}$; MW; Vm; EF; k; Q; $Ptorr$; T; $RATE_{air\_speed}$; $F_{correction\ factor}$; $D_{sampling}$; h_c;

Exposure Source	Model(s) Applied	Variables Used
Exposure to HHCB during equipment cleaning	EPA/OPPT Penetration Model or EPA/OPPT Mass Transfer Coefficient Model, based on air speed	F_{HHCB_prod}; $VP_{non-unloading}$; MW; Vm; EF; k; Q; $Ptorr$; T; $RATE_{air\_speed}$; $F_{correction\ factor}$; $D_{equipment}$; h_D;
Exposure to HHCB during packaging into transport containers	EPA/OAQPS AP-42 Loading Model	F_{HHCB_prod}; $VP_{non-unloading}$; f_{sat}; MW; $Vcont$; EF; k; Q R; T; $RATE_{fill\_drum}$; $F_{correction\ factor}$;

A.2.2 Model Input Parameters

Table_Apx A-2 summarizes the model parameters and their values for the Formulation of fragrance oils Monte Carlo simulation. Additional explanations of EPA's selection of the distributions for each parameter are provided after this table.

Table_Apx A-2. Summary of Parameter Values and Distributions Used in the Manufacturing Models

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Production Volume	PV	kg/yr	2,494,758	Mean	453,592	4,535,924	–	Uniform	See Appendix A.2.3
Exposure Frequency	EF	days/yr	250	Mode	239	271	250	Triangular	See Appendix A.2.4
HHCB Concentration	F_{HHCB_import}	kg HHCB / kg imported	0.9	Default	0.9	1.0	–	Uniform	See Appendix A.2.5
Post-Formulation HHCB Concentration	F_{HHCB_prod}	kg HHCB / kg product	0.0500	Mode	0.0025	0.6000	0.05	Triangular	See Appendix A.2.6
Drum Volume for Imported Containers	V_{drum}	gal/container	55	Mode	20	100	55	Triangular	See Appendix A.2.7
Tote Volume for Imported Containers	V_{tote}	gal/container	550	Mode	100	1,000	550	Triangular	See Appendix A.2.7
Tank Truck Volume for Imported Containers	V_{tank_truck}	gal/container	5,000	Mode	1,000	10,000	5,000	Triangular	See Appendix A.2.7
Rail Car Volume for Imported Containers	V_{rail_car}	gal/container	20,000	Mode	10,000	20,000	20,000	Triangular	See Appendix A.2.7
Saturation Factor	F_{sat}	Dimensionless	0.5	Mode	0.5	1.45	0.5	Triangular	See Appendix A.2.14
Indoor Air Speed	$RATE_{air\_speed}$	cm/s	10	50th Percentile	1.3	202.2	–	Lognormal	See Appendix A.2.12
		ft/min	19.7	50th Percentile	2.56	398	–	Lognormal	
Sampling Diameter Opening	$D_{sampling}$	cm	2.5	Default	2.5	10	2.5	Triangular	See Appendix A.2.13
Indoor Ventilation Rate	Q	ft^3/min	3,000	Default	500	10,000	3,000	Triangular	See Appendix A.2.16
Outdoor Ventilation Rate	$Q_{outdoor}$	ft^3/min	184,500	Midpoint	132,000	237,000	–	Uniform	See Appendix A.2.16
Working Years	WY	Years	36	Typical	10.4	44	36	Triangular	See Appendix A.4.6
Mixing Factor	k	Dimensionless	0.5	Mode	0.5	1	0.5	Triangular	See Appendix A.2.17

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Mixing Factor (TT and RC)	k	dimensionless	0.5	Default	–	–	–	–	See Appendix A.2.17
Drum Container Fill Rate	$RATE_{drum}$	containers/h	20	Default	–	–	–	–	See Appendix A.2.15
Tote Container Fill Rate	$RATE_{tote}$	containers/h	20	Default	–	–	–	–	See Appendix A.2.15
Tank Truck Container Fill Rate	$RATE_{tank\_truck}$	containers/h	2	Default	–	–	–	–	See Appendix A.2.15
Rail Car Container Fill Rate	$RATE_{rail\_car}$	containers/h	1	Default	–	–	–	–	See Appendix A.2.15
Container Opening Diameter (<5,000 gal container)	$D_{container\ 1}$	cm	5.08	Default	–	–	–	–	See Appendix A.2.13
Container Opening Diameter (>5,000 gal container)	$D_{container\ 2}$	cm	7.6	Default	–	–	–	–	See Appendix A.2.13
Operating Hours for Sampling	h_c	h/site-day	1	Default	–	–	–	–	See Appendix A.2.11
Operating Hours for Equipment Cleaning	h_d	h/site-day	4	Default	–	–	–	–	See Appendix A.2.11
Molar Volume	Vm	L/mol	24.45	Default	–	–	–	–	Molar volume at STP
Exposure Duration	ED	h/day	8	Default	–	–	–	–	Assuming a full 8-hour shift
Number of Sites	N_{sites}	Sites	12	Estimated	–	–	–	–	See Appendix A.2.3
Non-Unloading Ambient Temperature	$T_{non\text{-}unloading}$	K	298	Default	–	–	–	–	Standard temperature
Unloading Temperature	$T_{unloading}$	K	348	Maximum	–	–	–	–	See Appendix A.2.7
HHCB Molecular Weight	MW	g/mol	258.41	Default	–	–	–	–	Physical-chemical property of HHCB

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Non-Unloading Vapor Pressure	$VP_{non\text{-}unloading}$	mmHg	5.45E−04	Default	–	–	–	–	See Appendix A.2.7
Unloading Vapor Pressure	$VP_{unloading}$	mmHg	2.81E−02	Maximum	–	–	–	–	See Appendix A.2.7
HHCB Density	ρ_{HHCB}	kg/m^3	1005.4	Default	–	–	–	–	Physical-chemical property of HHCB
Ambient Pressure	Ptorr	torr	760	Default	–	–	–	–	Standard pressure

A.2.3 Production Volume, Number of Sites, and Throughput

Nearly all produced and imported HHCB is expected to be used in fragrance oils. Therefore, HHCB either arrives at processing plants at neat concentration to be blended with other fragrances or it arrives already incorporated into the fragrance oil. According to the 2020 CDR submissions, three of the eight submitters reported a concentration of 90% or higher by weight, while one submitter reported lower concentrations (<30%). The other two submitters reported less than 1%, which suggests import of final formulated products. The concentration reported by the last submitter cannot be disclosed (see Table_Apx A-3).

Table_Apx A-3. 2020 HHCB CDR Reporters and Production Volumes

Manufacturer or Importer (2020 CDR)	Maximum Concentration	Production Volume (lb/year)
Alen USA	Confidential business information (CBI)	36,313–46,743
CBI	90%+	63,453–166,016
Firmenich Inc	90%+	CBI
Givaudan Fragrances Corp.	<1%	CBI
International Flavors & Fragrances Inc.	90%+	CBI
Phoenix Aromas & Essential Oils	Not known or reasonably ascertainable	79,884–189,751
Proctor & Gamble Co.	1–30%	CBI
Ungerer and Company	<1%	CBI

To determine the throughput required for calculating container sizes, EPA uses the full non-CBI aggregate production volume of 1 to 10 million lb. This converts to a production volume of 453,592 to 4,535,924 kg/yr. The higher end of this range may be an overestimate as some portion of the production volume is for imported fragrance oils or final end-use products.

Based on 2023 TRI data and public information on the reported companies, 12 sites are expected to formulate HHCB into fragrance oils (see facilities listed in Table_Apx A-4 below).

Table_Apx A-4. 2023 TRI Facilities for Formulation of Fragrance Oils

Facility Name	Facility Location
Robertet Inc.	Budd Lake, NJ
International Flavors & Fragrances Inc[a]	Monmouth, NJ
Mane USA	Wayne, NJ
Arylessence Inc.	Marietta, GA
Symrise Inc	Somerset, NJ
Flavorchem Corp	Dupage, IL
Belle Aire Creations	Round Lake, IL
Andrea Aromatics Inc	Trenton, NJ
Cosmo International Corp	Deerfield Beach, FL
Intarome Fragrance Corp	Bergen, NJ
Flavor & Fragrance Specialties	Essex, MD

Facility Name	Facility Location
Firmenich Inc[a]	Plainsboro, NJ
[a] Site listed as importer in the 2020 CDR.	

Monte Carlo simulations are used to calculate the throughput. EPA used a uniform distribution for the total production volume, then averaged over 12 sites per equation below:

Equation_Apx A-9.

$$Q_{HHCB\_yr} = \frac{PV}{Nsites}$$

Where:

Q_{HHCB_yr} = Facility daily throughput of HHCB (kg/site-year)
PV = Annual production volume (kg/site-year)
N_{sites} = Number of sites

The reported throughput ranged from 37,799 to 377,994 kg/site-yr (83,333–833,334 lb/site-yr).

A.2.4 Exposure Frequency

A 2021 survey of fragrance compounders (*i.e.,* companies that formulate fragrance oils) reported operating days ranging from 240 to 270 days per year, with a mode of 250 days per year (FCA, 2021). The Agency used a triangular distribution between 239 to 271 days per year with a mode of 250 days per year.

A.2.5 Import HHCB Concentration

EPA used the highest concentration range reported by manufacturers and importers in the 2020 CDR, 90% or higher. The other reported concentrations were less than 1% and ranged from 1 to 30% HHCB. The Agency assumes the lower concentrations may be fragrance oils or downstream products. A uniform distribution of 90 to 100% HHCB was used.

A.2.6 Post-Formulation HHCB Concentration

For the final concentration of HHCB in fragrance oils, the Agency identified a total of 17 fragrance oils products with a wide range of HHCB concentration (see Table_Apx A-5). These were used to determine an upper-bound weight fraction of HHCB of 0.60 and a lower-bound of 0.0025 with a mode of 0.05. A triangular distribution was used for the exposures during product sampling, equipment cleaning, and packaging of the fragrance oils.

Table_Apx A-5. HHCB Concentrations in Fragrance Oils

Product Name	Manufacturer	HHCB Weight Fraction	
		Low-End	High-End
Vanilla Sugar	Candles and Supplies.com	0.02	0.05
Pumpkin Chai	Lone Star Candle Supply, Inc.	0.02	0.05
Downtown Bourbon	Candlewic	0.02	0.05
Love Spell Victoria's Secret Type	Candlewic	0.02	0.05
Black Lily Mod AF	CPL Aromas	0.025	0.10
P-1 Rose	Antari Lighting and Effects Ltd (Taiwan)	0.0025	0.01

Product Name	Manufacturer	HHCB Weight Fraction	
		Low-End	High-End
Blue Wave	Belle Aire Creations	0.01	0.01
Escentscia 4Bonbon	Gentil Sayre Limited (UK)	0.055	0.075
Escentscia 4Good Girl	Gentil Sayre Limited (UK)	0.0362	0.0562
Nepalva 0912	IFF Inc.	0.30	0.60
Egyptian Musk	Wellington Fragrance	0.40	0.50
Freesia	Wellington Fragrance	0.01	0.02
Sea Glass	Cierra Candles and Soap Supplies	0.02	0.05
Lilikoi Fragrance Oil	Majestic Mountain Sage	0.10	0.20
Honey Bunny Fragrance Oil	Natures Garden Fragrances	0.30	0.40
Cherry Vanilla	Cierra Candles and Soap Supplies	0.05	0.1
Mangosteen	Making Cosmetics	0.01	0.1

A.2.7 Vapor Pressure

EPA used vapor pressure as reported in a study published in 2019 (Wootitunthipong and Chickos, 2019). See Table_Apx A-6 for the vapor pressures of HHCB from 25 to 77 °C.

Table_Apx A-6. Vapor Pressures of HHCB

Temperature (°C)	Pressure (mmHg)
25.15	1.88E−04
37	7.20E−04
47	1.99E−03
57	5.21E−03
67	1.24E−02
77	***2.81E−02***
Bolded and italicized cells indicate vapor pressures used in this draft assessment.	

A.2.8 Container Size

Based on the PV range assessed, EPA assumed that HHCB may arrive in drums, totes, tank trucks, or rail cars. According to the ChemSTEER User Guide, drums are defined as containing between 20 and 100 gallons of liquid, with a default of 55 gallons; totes are defined as containing between 100 and 1,000 gallons, with a default of 550 gallons; tank trucks are defined as containing between 1,000 and 10,000 gallons, with a default of 5,000 gallons; and rail cars are defined as containing between 10,000 and 20,000 gallons, with a default of 20,000 gallons (U.S. EPA, 2015b). Therefore, EPA modeled packaged container size using a triangular distribution with lower and upper bounds with the default size as the mode based on the container type selected based on the daily use rate.

A.2.9 Number of Containers Unloaded Per Year

The number of transport containers unloaded was calculated by the following equation:

Equation_Apx A-10.

$$N_{cont\_unload\_site-year} = \frac{Q_{HHCB\_site\_yr}}{F_{HHCB\_import} * V_{cont} * \rho_{HHCB} * 0.00378541\ m^3/gal}$$

Where:

$N_{cont\_unload\_site-year}$	=	Annual number of transport containers (container/site-year)
$Q_{HHCB\_site\_yr}$	=	Annual production volume (see Appendix A.2.3) (kg/site-year)
F_{HHCB_import}	=	Imported HHCB concentration (see Appendix A.2.5) (kg/kg)
V_{cont}	=	Transport container volume (see Appendix A.2.8) (gal/container)
ρ_{HHCB}	=	Density of HHCB (kg/m^3)

A.2.10 Number of Containers Loaded Per Year

EPA assumes that fragrance oils will be packaged into drums. Most of the products identified in Appendix A.2.6 were packaged into small bottles (<5 gallon); however, this data may be skewed to smaller containers as these were the sizes available for general public purchase. EPA assumed industrial users are likely to receive fragrance oils in drums as suggested in the Organisation for Economic Co-operation and Development (OECD) Emission Scenario Document on the Blending of Fragrance Oils into Commercial and Consumer Products (OECD, 2010). The number of packaging containers loaded are calculated based on the following equation:

Equation_Apx A-11.

$$N_{cont\_load\_site-year} = \frac{Q_{HHCB\_site\_yr}}{F_{HHCB\_prod} * V_{cont} * \rho_{HHCB} * 0.00378541\ m^3/gal}$$

Where:

$N_{cont\_load\_site-year}$	=	Annual number of packaging containers (container/site-year)
$Q_{HHCB\_site\_yr}$	=	Annual production volume (see Appendix A.2.3) (kg/site-year)
F_{HHCB_import}	=	Product HHCB concentration (see Appendix A.2.5) (kg/kg)
V_{cont}	=	Transport container volume (see Appendix A.2.8) (gal/container)
ρ_{HHCB}	=	Density of HHCB (kg/m^3)

A.2.11 Operating Hours

EPA estimated operating hours or hours of duration for the applicable activities using data provided from the ChemSTEER User Guide (U.S. EPA, 2015b) and/or through calculation from other parameters. Exposure activities with operating hours provided from the ChemSTEER User Guide include an estimate of 1 hour for sampling (exposure activity 3) and 4 hours for equipment cleaning (exposure activity 4).

The operating hours for loading HHCB into transport containers (exposure activity 1, 2, and 5) were calculated based on the number of product containers filled at the site and the fill rate using the following equation:

Equation_Apx A-12.

$$Time_{EP} = \frac{N_{cont\_(un)load\_year}}{RATE_{fill\_} * OD}$$

Where:

$Time_{EP}$	=	Operating time for container related activities (hours/site-day)
$N_{cont\_load\_year}$	=	Annual number of containers either unloaded (EA #1 and #2) and Loaded (EA# 5) (containers/site-year)
$RATE_{fill\_drum}$	=	Fill rate of container (containers/h)
OD	=	Operating days (days/site-year)

A.2.12 Air Speed

Baldwin and Maynard measured indoor air speeds across a variety of occupational settings in the United Kingdom (Baldwin and Maynard, 1998). A total of 55 work areas were surveyed across a variety of workplaces. EPA analyzed the air speed data from Baldwin and Maynard and categorized the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. The Agency fit separate distributions for these industrial and commercial settings and used the industrial distribution for this OES.

EPA fit a lognormal distribution for the data set as consistent with the authors' observations that the air speed measurements within a surveyed location were lognormally distributed and the population of the mean air speeds among all surveys were lognormally distributed (Baldwin and Maynard, 1998). Because lognormal distributions are bound by zero and positive infinity, EPA truncated the distribution at the largest observed value among all of the survey mean air speeds.

EPA fit the air speed surveys representative of industrial facilities to a lognormal distribution with the following parameter values: mean of 22.414 cm/s and standard deviation of 19.958 cm/s. In the model, the lognormal distribution is truncated at a minimum allowed value of 1.3 cm/s and a maximum allowed value of 202.2 cm/s (largest surveyed mean air speed observed in Baldwin and Maynard) to prevent the model from sampling values that approach infinity or are otherwise unrealistically small or large (Baldwin and Maynard, 1998).

Baldwin and Maynard only presented the mean air speed of each survey. The authors did not present the individual measurements within each survey. Therefore, these distributions represent a distribution of mean air speeds and not a distribution of spatially variable air speeds within a single workplace setting. However, a mean air speed (averaged over a work area) is the required input for the model. EPA converted the units to ft/min prior to use within the model equations.

A.2.13 Diameters of Opening

The ChemSTEER User Guide indicates diameters for the openings for various vessels that may hold liquids in order to calculate vapor generation rates during different activities (U.S. EPA, 2015b). For product sampling operations (exposure point C), the ChemSTEER User Guide indicates a range of 2.5 to 10 cm with a default of 2.5 cm. As the distribution is unknown, EPA used a triangular distribution. For equipment cleaning operations (exposure point D), the ChemSTEER User Guide indicates a single default value of 92 cm (U.S. EPA, 2015b).

A.2.14 Saturation Factor

The *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments, Volume 1* (CEB Manual) indicates that during splash filling, the saturation concentration was reached or exceeded by misting with a maximum saturation factor of 1.45 (CEB, 1991). The CEB Manual indicates that saturation concentration for bottom filling was expected to be about 0.5 (CEB, 1991). The underlying distribution of this parameter is not known; therefore, EPA assigned a triangular distribution based on the lower bound, upper bound, and mode of the parameter. Because a mode was not provided for this parameter, the Agency assigned a mode of 0.5 for bottom filling as bottom filling minimizes volatilization (CEB, 1991). This value also corresponds to the typical value provided in the ChemSTEER User Guide for the EPA/OAQPS AP-42 Loading Model (U.S. EPA, 2015b).

A.2.15 Container Fill Rates

The ChemSTEER User Guide (U.S. EPA, 2015b) provides a typical fill rate of 20 containers per hour for drums and totes; and 1 to 2 containers per hour for rail cars and tank trucks, respectively.

A.2.16 Ventilation Rates

EPA did not identify chemical-specific information for this parameter from systematic review; therefore, the Agency used generic data from the CEB Manual (CEB, 1991). For indoor operations it indicates general ventilation rates in industry range from 500 to 10,000 ft^3/min, with a typical value of 3,000 ft^3/min. The underlying distribution of this parameter is not known; therefore, EPA assigned a triangular distribution based on an estimated lower bound, upper bound, and mode of the parameter. The Agency assumed the lower and upper bound using the industry range of 500 to 10,000 ft^3/min and the mode using the 3,000 ft^3/min typical value (CEB, 1991).

For general outdoor operations, ventilation rates in industry range from 132,000 to 237,600 ft^3/min in outdoor conditions. The underlying distribution of this parameter is not known; therefore, EPA assigned a uniform distribution, because a uniform distribution is completely defined by range of a parameter.

A.2.17 Mixing Factor

The CEB Manual (CEB, 1991) indicates mixing factors may range from 0.1 to 1, with 1 representing ideal mixing. The CEB Manual references the 1988 *ACGIH Ventilation Handbook*, which suggests the following factors and descriptions: 0.67 to 1 for best mixing; 0.5 to 0.67 for good mixing; 0.2 to 0.5 for fair mixing; and 0.1 to 0.2 for poor mixing (CEB, 1991). The underlying distribution of this parameter is not known; therefore, EPA assigned a triangular distribution based on the defined lower and upper bound and estimated mode of the parameter. The mode for this distribution was not provided; therefore, the Agency assigned a mode value of 0.5 based on the typical value provided in the *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b).

A.2.18 Exposure Results by Activity

Table_Apx A-7 presents the air concentrations calculated from the modeling for each exposure activity along with their respective duration.

Table_Apx A-7. Formulation of Fragrance Oils Exposure Concentration and Durations by Activity

Exposure Activity	Exposure Concentration (mg/m³)		Exposure Duration (hours)	
	P50	P95	P50	P95
Unloading from transport containers	7.06E−02	4.50E00	2.28E−02	3.08E−01
Container cleaning	7.22E−06	1.26E−04	2.28E−02	3.08E−01
Product sampling	8.95E−06	5.23E−05	1.00E00	1.00E00
Equipment cleaning	8.59E−04	3.85E−03	4.00E00	4.00E00
Packaging into transport containers	9.97E−04	4.62E−03	9.37E−01	2.95E00

A.3 Plastic Compounding/Converting

The Particulate, Not Otherwise Regulated (PNOR) Central and High-End Exposure Model (PNOR Model) (U.S. EPA, 2021b) provides central tendency and high-end estimates of worker inhalation exposure to total and respirable PNOR. This model utilizes inhalation monitoring data from OSHA, which are generally industry-specific (data include NAICS and SIC codes) but do not include worker activities. Thus, the PNOR Model provides estimates for each major industry code that are not activity-specific.

For the COUs of HHCB, the Agency expects that workers may be exposed to dust from the handling of plastic pellets or powder cleaning, laundry, or dishwashing products. Based on the industries reporting in 2023 TRI data (U.S. EPA, 2026j), the sites most likely to conduct these activities reported their primary industry group as either 325 – Chemical Manufacturing, or 339 – Miscellaneous Manufacturing. EPA also considered the Plastics and Rubber Manufacturing (326) as though it may not be the primary industry for sites using HHCB, the dust generating processes may be more similar to this industry group. In addition, downstream users such as professional cleaning or laundry staff who will use the powder products may be captured in the OSHA data under 62 – Health Care and Social Assistance, 71-72 – Arts, Entertainment, and Recreation, Accommodation and Food Services, 81 – Other Services (except Public Administration). Table_Apx A-8 shows the value for total PNOR across relevant industry groups.

Table_Apx A-8. Total PNOR for Relevant Industry Groups

Industry Group	No. of Samples	Percentile of OSHA PNOR PEL (Percentile)	Total PNOR Default – Central Tendency (50th Percentile; mg/m³)	Total PNOR Default – High-End (95th Percentile or PEL; mg/m³)
325 – Chemical Manufacturing	366	80%	**3.5**	**15**
326 – Plastics and Rubber Products Manufacturing	340	86%	**1.9**	**15**
339 – Miscellaneous Manufacturing	163	92%	**0.87**	**15**
62 – Health Care and Social Assistance	21	PEL does not fall in the range	**1.2**	**9.7**

Industry Group	No. of Samples	Percentile of OSHA PNOR PEL (Percentile)	Total PNOR Default – Central Tendency (50th Percentile; mg/m^3)	Total PNOR Default – High-End (95th Percentile or PEL; mg/m^3)
71-72 – Arts, Entertainment, and Recreation, Accommodation and Food Services	10	PEL does not fall in the range	**0.253**	**6.6**
81 – Other Services (except Public Administration)	149	92%	**1.4**	**15**
OSHA = Occupational Safety and Health Administration; PEL = permissible exposure limit; PNOR = particulates not otherwise regulated				

Using the default concentrations ($C_{particulate}$) listed in Table_Apx A-8, in conjunction with the expected concentration of the chemical of interest within the solid/powdered formulation being handled (F_{chem}), the following equation may be used to estimate worker inhalation exposure to total and respirable particulate from of a chemical of interest within a solid/powdered mixture:

Equation_Apx A-13.

$$EXP_{inhalation} = C_{particulate} \times F_{chem}$$

Where:

$EXP_{inhalation}$	=	Inhalation exposure to chemical per day (mg chemical/m^3)
$C_{particulate}$	=	Concentration of particulate in the worker breathing zone (from Table_Apx A-8)
F_{chem}	=	Mass fraction of chemical of interest in the solid/powdered mixture (kg chemical/kg mixture)

Note that the exposure duration that can be used with this model is 8 hours/day, which is assumed to be a full-shift for a worker. This exposure duration is consistent with the sample durations for the data used to determine the default central tendency and high-end PNOR concentrations.

Table_Apx A-9. Air Fresheners Identified

Product Name	Manufacturer	Type of Product	Physical Form	Fchem[a]
Areon Fresh Wave Black Crystal	Balev Corporation (Bulgaria)	Air fresheners for motor vehicles	Plastic Article	0.01
Areon Smile No Smoking	Balev Corporation (Bulgaria)	Air fresheners for motor vehicles	Plastic Article	0.025
Airlift Ultra Fragrant Commode Clips	Spartan Chemical Company	Continuous action air fresheners	Plastic Article	0.05
Breeze Mat Mango	Kando Service GmbH	Continuous action air fresheners	Plastic Article	0.02
PRISTINE Fresh 30-Day Urinal Screen Fresh Linen	Prime Source	Continuous action air fresheners	Plastic Article	0.0025
NABC Urinal Screen with Deodorizing Block & Blue Dye Indicator	Spartan Chemical Company	Continuous action air fresheners	Plastic Article	0.0010
Urigard C Disposable Floor Mat	Spartan Chemical Company	Continuous action air	Plastic	0.0010

Product Name	Manufacturer	Type of Product	Physical Form	Fchem[a]
		fresheners	Article	
Urigard U Disposable Floor Mat	Spartan Chemical Company	Continuous action air fresheners	Plastic Article	0.0010
Airlift Ultra Fragrant Commode Clips NABC Fresh Scent	Spartan Chemical Company, Inc.	Continuous action air fresheners	Plastic Article	0.05
Airlift Ultra Fragrant Urinal Screen NABC Fresh Scent	Spartan Chemical Company, Inc.	Continuous action air fresheners	Plastic Article	0.05
NABC Deodorizing Rim Cages	Spartan Chemical Company, Inc.	Continuous action air fresheners	Plastic Article	0.0010
Bowl Clip (Spiced Apple)	Waypoint Corporation, manufactured for (UK)	Continuous action air fresheners	Plastic Article	0.03
Odor Eliminating Disc SDS	BISSELL Homecare, Inc	Continuous action air fresheners	Plastic Article	0.05

[a] Mass fraction of chemical of interest in the solid/powdered mixture (kg chemical/kg mixture)

The concentration of HHCB in the plastic pellets is unknown; however, the highest concentration of HHCB in the plastic articles is 5% (see Table_Apx A-9). EPA assumed that the concentration was the same in the plastic pellets; therefore, a calculation of a central tendency and high-end exposure estimate were completed as shown in the equations below:

Equation_Apx A-14. Central Tendency

$$EXP_{inhalation} = 3.5\frac{mg}{m^3} \times 0.05$$

$$EXP_{inhalation} = 0.175\ mg/m^3$$

Equation_Apx A-15. High-End

$$EXP_{inhalation} = 15\frac{mg}{m^3} \times 0.05$$

$$EXP_{inhalation} = 0.75\ mg/m^3$$

A.4 Equations for Calculating Intermediate and Chronic (Non-Cancer) Inhalation

This section presents the equations used to calculate IADDs for intermediate, non-cancer risks as well as CADDs for chronic, non-cancer risks. IADDs are used to estimate workplace exposures for intermediate risks and are estimated as follows:

Equation_Apx A-16.

$$IADD = \frac{C \times ED \times EF_{Int} \times IR}{AT_{Int} \times BW}$$

Where:

$IADC$ = Intermediate average daily concentration
C = Contaminant concentration in air (TWA)

ED = Exposure duration (h/day)
IR = Breathing rate (m^3/h)
EF_{Int} = Intermediate exposure frequency
BW = Body Weight (kg)
AT_{Int} = Averaging time (h) for intermediate exposure

CADD is used to estimate workplace exposures for non-cancer. These exposures are estimated as follows:

Equation_Apx A-17.

$$CADD = \frac{C \times ED \times EF \times WY \times IR}{AT \times BW}$$

Equation_Apx A-18.

$$AT = WY \times 365 \frac{day}{yr}$$

Where:
$CADD$ = Average daily concentration used for chronic non-cancer risk calculations
C = Contaminant concentration in air (TWA)
ED = Exposure duration (h/day)
EF = Exposure frequency (day/yr)
WY = Working years per lifetime (yr)
IR = Breathing rate (m^3/h)
BW = Body weight (kg)
AT = Averaging time (h) for chronic, non-cancer risk

The input parameter values in Table_Apx A-10 are used to calculate each of the above intermediate and chronic exposure estimates. Where exposure is calculated using probabilistic modeling, the calculations are integrated into the Monte Carlo simulation. Where multiple values are provided for ED, it indicates that EPA may have used different values for different COUs. The EF and EF_{Int} used for each OES can differ, and the values used are described in the appropriate sections of this draft TSD. The maximum values used in the equations as well as a general summary for these differences are described below.

Table_Apx A-10. Parameter Values for Calculating Inhalation Exposure Estimates

Parameter	Symbol	Value	Unit
Exposure duration	ED	8	h/day
Breathing rate	BR	1.25	m^3/h
Exposure frequency	EF	Generally calculated through probabilistic modeling with a maximum of 250	days/yr
Exposure frequency, intermediate	EF_{Int}	Generally calculated through probabilistic modeling with a maximum of 22	days
Days for intermediate duration	ID	30	days
Working years	WY	31 (50th percentile) 40 (95th percentile)	years
Lifetime years, cancer	LT	78	years

Parameter	Symbol	Value	Unit
Averaging time, intermediate	AT_{Int}	720	hours
Averaging time, non-cancer	AT	271,560 (central tendency) [a] 350,400 (high-end) [b]	hours
Body weight	BW	80 (average adult worker) 72.4 (female of reproductive age) [c]	Kg

[a] Calculated using 50th percentile value for working years (WY)
[b] Calculated using 95th percentile value for WY
[c] Not used in calculations due to being less protective value

A.4.1 Exposure Duration (ED)

EPA generally uses an exposure duration of 8 hours per day for averaging full-shift exposures. The calculated TWA from each iteration of the Monte Carlo analysis was then used to calculate corresponding intermediate and chronic exposure values.

A.4.2 Breathing Rate (IR)

The typical worker breathes about 10 m^3 of air in 8 hours, or 1.25 m^3/h (CEB, 1991).

A.4.3 Exposure Frequency (EF)

EPA uses an EF of 250 days per year for this assessment.

EF is expressed as the number of days per year a worker is exposed to the chemical being assessed. In some cases, it may be reasonable to assume a worker is exposed to the chemical on each working day. In other cases, it may be more appropriate to estimate a worker's exposure to the chemical that occurs during a subset of the worker's annual working days (AWD). The relationship between exposure frequency and AWD can be described mathematically using Equation_Apx A-19 below.

A.4.4 Intermediate Exposure Frequency (EF_{Int})

Set at 30 days, EPA estimated the maximum number of working days within the ID, using the equation below and assuming 5 working days per week:

Equation_Apx A-19.

$$EF_{Int}(max) = 5\frac{working\ days}{wk} \times \frac{30\ total\ days}{7\frac{total\ days}{wk}} = 21.4\ days, rounded\ up\ to\ 22\ days$$

However, EPA used probabilistic modeling to estimate exposures and their associated intermediate exposure frequencies, often resulting in intermediate exposure frequencies below 22 days. The estimation of the intermediate exposure frequency and associated distributions for each OES are described in the relevant section of this report. In general, the EF_{Int} estimated for each iteration of the model is then used to calculate the corresponding intermediate exposure values.

A.4.5 Intermediate Duration (ID)

EPA assessed an intermediate duration of 30 days based on the available health data.

A.4.6 Working Years (WY)

EPA has developed a triangular distribution for working years and defined the parameters of this distribution as follows:

- **Minimum value:** BLS CPS tenure data with current employer as a low-end estimate of the number of lifetime working years: 10.4 years;
- **Mode value:** The 50th percentile tenure data with all employers from Survey of Income and Program Participation (SIPP) as a mode value for the number of lifetime working years: 36 years; and
- **Maximum value:** The maximum average tenure data with all employers from SIPP as a high-end estimate on the number of lifetime working years: 44 years.

This triangular distribution has a 50th percentile value of 31 years and a 95th percentile value of 40 years. EPA uses these values for central tendency and high-end average daily concentration (ADC) and lifetime average daily concentration (LADC) calculations, respectively.

The U.S. BLS (2014) provides information on employee tenure with *current employer* obtained from the Current Population Survey (CPS). CPS is a monthly sample survey of about 60,000 households that provides information on the labor force status of the civilian non-institutional population age 16 years and older. CPS data are released every 2 years and are available by demographics and generic industry sectors, but not by NAICS codes.

The U.S. Census Bureau (2019) SIPP provides information on *lifetime tenure with all employers*. SIPP is a household survey that collects data on income, labor force participation, social program participation and eligibility, and general demographic characteristics through a continuous series of national panel surveys of between 14,000 and 52,000 households (U.S. Census Bureau, 2019). EPA analyzed the 2008 SIPP Panel Wave 1, a panel that began in 2008 and covers the interview months of September 2008 through December 2008 (U.S. Census Bureau, 2019). For that panel, lifetime tenure data are available by Census Industry Codes, which can be crosswalked with NAICS codes.

SIPP data include fields for the industry in which each surveyed, employed individual works (TJBIND1), worker age (TAGE), and years of work experience *with all employers* over the surveyed individual's lifetime.[8] Census household surveys use different industry codes than the NAICS codes used in its firm surveys, so these were converted to NAICS using a published crosswalk (U.S. Census Bureau, 2012). EPA calculated the average tenure for the following age groups: (1) workers aged 50 and older, (2) workers 60 and older, and (3) workers of all ages employed at time of survey. The Agency used tenure data for age group "50 and older" to determine the high-end lifetime working years because the sample size in this age group is often substantially higher than the sample size for age group "60 and older." For some industries, the number of workers surveyed, or the *sample size*, was too small to provide a reliable representation of the worker tenure in that industry. Therefore, data where the sample size was less than five was excluded from the analysis.

Table_Apx A-11 summarizes the average tenure for workers aged 50 years and older from SIPP data. Although the tenure may differ for any given industry sector, there is no significant variability between the 50th and 95th percentile values of average tenure across manufacturing and non-manufacturing sectors.

[8] To calculate the number of years of work experience EPA took the difference between the year first worked (TMAKMNYR) and the current data year (*i.e.,* 2008). The Agency then subtracted any intervening months when not working (ETIMEOFF).

Table_Apx A-11. Overview of Average Worker Tenure from U.S. Census SIPP (Age Group 50+ Years)

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
All industry sectors relevant to the (first) 10 chemicals undergoing risk evaluation	35.9	36	39	44
Manufacturing sectors (NAICS 31–33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42–81)	36.1	36	39	44
Note: Industries where sample size is <5 are excluded from this analysis Source: U.S. BLS (2016)				

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx A-12 presents CPS data for all demographics (men and women) by age group from 2008 to 2012. To estimate the low-end value on number of working years, EPA uses the most recent (2014) CPS data for workers aged 55 to 64 years, which indicates a median tenure of 10.4 years with their current employer. The use of this low-end value represents a scenario where workers are only exposed to the chemical of interest for a portion of their lifetime working years, as they may change jobs or move from one industry to another throughout their career.

Table_Apx A-12. Median Years of Tenure with Current Employer by Age Group

Age (years)	January 2008	January 2010	January 2012	January 2014
16+	4.1	4.4	4.6	4.6
16–17	0.7	0.7	0.7	0.7
18–19	0.8	1.0	0.8	0.8
20–24	1.3	1.5	1.3	1.3
25+	5.1	5.2	5.4	5.5
25–34	2.7	3.1	3.2	3.0
35–44	4.9	5.1	5.3	5.2
45–54	7.6	7.8	7.8	7.9
55–64	9.9	10.0	10.3	10.4
65+	10.2	9.9	10.3	10.3
Source: U.S. BLS (2014)				

A.4.7 Body Weight (BW)

EPA assumes a BW of 80 kg for average adult workers and a BW of 72.4 kg for females of reproductive age per Chapter 8 of the EPA's *Exposure Factors Handbook* (U.S. EPA, 2011b).

A.5 Example Calculation for Calculating Chronic (Non-Cancer) Inhalation Exposures

An example calculation for the plastic converting to estimate the average daily dose is provided below.

Chronic Average Daily Dose Equation

Equation_Apx A-20.

$$EXP_{inhalation} = \frac{EXP_{inhalation}}{BW \times AT} \times \frac{1.25\,m^3}{h} \times 8\,h \times 0.05$$

Where:

BW	=	Body weight, 80 kg (Average adult)
EF	=	Exposure frequency, 250 days/year
WY_{CT}	=	Working years (central tendency), 31 years
WY_{HE}	=	Working years (high-end), 40 years
AT	=	Averaging time, 365 days × $WY_{CT\ OR\ HE}$

Example Calculations

$$CADD_{dust\_inhalation} = 1.75\frac{mg}{day} \times \frac{250\,days}{365\,days} \times \frac{31\,yrs}{31\,yrs} \div 80\,kg = 0.015\,mg/kg-day$$

HE-CADD:

$$CADD_{dust\_inhalation} = 7.5\frac{mg}{day} \times \frac{250\,days}{365\,days} \times \frac{40\,yrs}{40\,yrs} \div 80\,kg = 0.064\,mg/kg-day$$

Appendix B CONSUMER INHALATION EXPOSURE MODELING APPROACH

The main steps in performing the consumer inhalation exposure assessment for HHCB include the following:

1. Identification and mapping of product examples according to COU.
2. Compilation of products according to manufacturer's use instructions to determine patterns of use.
3. Selection of exposure exposed populations according to product use descriptions.
4. Identification of data gaps and further search to fill gaps with studies, chemical surrogates or product proxies, or professional judgment.
5. Selection of appropriate modeling tools based on available information and chemical properties.
6. Gathering of input parameters per exposure scenario.
7. Parameterization of selected modeling tools and generation of exposure estimates for the relevant scenarios and routes.

B.1 Content of HHCB in Products

The preferred data sources for HHCB content in U.S. consumer goods were SDSs for specific products with reported HHCB content, peer-reviewed literature providing measurements of HHCB in consumer goods purchased in the United States, and U.S. government reports with manufacturer-reported concentrations. When data from preferred sources were not available, HHCB contents in specific products provided in peer-reviewed literature and government reports were considered. HHCB weight fractions reported in the CDR database (U.S. EPA, 2020b) were not considered for the inhalation exposure assessment for HHCB because it was unclear whether the data pertained to HHCB as an intermediate or in finished goods.

EPA further evaluated the products identified to ensure that data represented items currently available to U.S. consumers. Where possible, SDSs were cross-checked with company websites to ensure that each product could reasonably be purchased by consumers. In instances where a product could not be purchased by a consumer, EPA did not consider evaluating the item in a do-it-yourself (DIY) or application scenario but did determine whether consumers might reasonably be exposed to the specific item as part of a purchased good, including homes and automobiles.

In addition to HHCB weight fractions, EPA obtained additional information about physical characteristics and potential uses of specific products and articles from technical specifications, manufacturer websites, and vendor websites. These data were used in the assessment to define exposure scenarios.

HHCB vapor from consumer non-spray products were not assessed for inhalation exposure due to emissions to air being unlikely to occur (low vapor pressure [5.45×10^{-04} mmHg] at 25 °C (MacGillivray, 1996)) or short application uses, and/or products being used in outdoor conditions where air exchange rates are high and product application is not expected to generate aerosols. The occupational assessment of vapor during loading and unloading activities where HHCB in liquid form is heated is expected to be the most conservative exposure scenario based on TSCA COUs (see Section 1.1).

B.1.1 Continuous Action Air Fresheners

One continuous action air freshener with at least five variations reported HHCB concentrations in formulation (Champion Spray on Spray Scents® Metered Air Freshener/Deodorizer (Chase Products, 2025)) was identified for a screening assessment of inhalation exposure. EPA used the highest concentration of 1% HHCB across the identified aerosolized continuous action air fresheners (Table_Apx B-1). Non-aerosolized products were reported to have the highest HHCB concentrations among all continuous action air fresheners (Table 2-2). However, non-aerosolized products were not prioritized in the screening exposure assessment because inhalation of HHCB vapor is not expected to be a significant consumer pathway of exposure because HHCB is semi-volatile and is not expected to linger in indoor air for as long as when it is aerosolized. While the manufacturer for the identified products primarily markets to janitorial supply companies, these products could be readily purchased via online retailers. Thus, this product is expected to have both commercial and consumer applications. In addition to their potential uses in homes, they were formulated for use in hotels, hospitals, offices, motels, nursing homes, restaurants, schools, and public buildings.

Table_Apx B-1. Continuous Action Air Freshener Weight Fractions Reported and Used in Modeling

CDR Category/ Subcategory	Product Name	Company	SDS Publication Year	SDS Reported Concentration (Weight %)	Assumed Concentration (Weight %) [a]
Continuous action air fresheners	CHAMPION SPRAYON SPRAY SCENTS® METERED AIR FRESHENER/ DEODORIZER CUCUMBER MELON	Chase Products	2025	<1	1
	CHAMPION SPRAYON SPRAY SCENTS® METERED AIR FRESHENER/ DEODORIZER EXOTIC GARDEN			<1	1
	CHAMPION SPRAYON SPRAY SCENTS® METERED AIR FRESHENER/ DEODORIZER HAWAIIAN ISLAND			<0.1	0.1
	CHAMPION SPRAYON SPRAY SCENTS® METERED AIR FRESHENER/ DEODORIZER ODOR NEUTRALIZER			<0.01	0.01
	CHAMPION SPRAYON SPRAY SCENTS® METERED AIR FRESHENER/ DEODORIZER WARM HARVEST			<0.1	0.1

[a] Safety data sheets (SDSs) often report HHCB weight fractions up to a percentage in formulation. This makes it difficult to determine the actual HHCB concentration in formulation. Therefore, in such cases EPA assumes that the bounding value is representative of actual chemical concentrations in the consumer product formulation.

B.2 Inhalation Modeling Approach

The CEM v3.2 (U.S. EPA, 2023) was selected for the consumer exposure screening model of continuous action air freshener uses as the most appropriate model based on the type of input data available for HHCB. The advantages of using CEM to assess exposures to consumers are as follows:

- CEM has been peer reviewed (ERG, 2016).
- CEM accommodates the distinct inputs available for the products containing HHCB, such as weight fractions, product density, room of use, frequency and duration of use (see Table 2-4 for specific product scenario inputs).
- CEM uses the same calculation engine to compute indoor air concentrations as the higher-tier Multi-Chamber Concentration and Exposure Model (MCCEM) but does not require measured chamber emission values (which have not been identified for HHCB).
- CEM allows for calculation of inhalation exposure for product users in close proximity to products.

Although CEM v3.2 can be used to estimate acute exposures, since EPA only identified long-term hazard effects, EPA only used the model to estimate 1-year chronic TWA rates for inhalation exposures. The Agency considered exposures to all age groups to identify age groups with the highest potential exposures from the screening analysis. Exposure inputs for adults are provided in the EPA's CEM v3.2 Appendices (U.S. EPA, 2023).

CEM's estimated emission rates are used in a deterministic mass balance model to calculate indoor air concentrations. CEM employs different models depending on the product and associated use behavior (*e.g.,* washing dishes vs. washing hands). For products, CEM v3.2 uses a two-zone representation of the building of use when predicting indoor air concentrations. Zone 1 represents the room where the consumer product is used. Zone 2 represents the remainder of the building. Each zone is considered well-mixed. The model allows for further division of Zone 1 into a near-field and far-field component to accommodate situations where a higher concentration of product is expected very near the product user during the period of use. Zone 1 near-field represents the breathing zone of the user at the location of the product use, while Zone 1 far-field represents the remainder of the Zone 1 room. The modeled concentrations in both zones are a function of the time-varying emission rate in Zone 1, the volumes of Zones 1 and 2, the air flows between each zone and outdoor air, as well as the air flows between the two zones.

Following product use, the user and bystander may follow one of three predefined activity patterns: full-time worker, part-time worker, and stay-at-home. The activity-use pattern determines which zone is relevant for the user and bystander and the duration of the exposures. Users and bystanders inhale airborne concentrations within these zones, which can vary over time, resulting in the overall estimated exposure for each individual. EPA assumes that direct users of consumer products are generally expected to receive higher relative exposures in comparison to bystanders who are located away from the immediate space where the product is being used. Therefore, while EPA acknowledges that some HHCB exposures to bystanders are possible, the Agency prioritized the quantification of consumer exposures to users given their higher expected exposures. The stay-at-home activity pattern was selected for this assessment for all scenarios as the most conservative behavior pattern. By default, the pre-defined CEM stay-at-home activity pattern assumes that occupants are inside the home for a total of 21 hours per day, in an automobile 1 hour per day, and outside 2 hours per day. Of the hours spent in the home, 10 hours are spent in the bedroom, 7 hours in the living room, 2 hours in the kitchen, and 1 hour in both the utility room and bathroom. However, the default stay-at-home activity pattern was overridden for this assessment. Instead of the above assumptions, the occupant was assumed to remain in Zone 1, the room where the product is used, for the full duration of product use.

CEM default air exchange rates for the building are from the *Exposure Factors Handbook* (U.S. EPA, 2011b). The default interzonal air flows are a function of the overall air exchange and volume of the building as well as the openness of the room, which is characterized in a regression approach for closed rooms and open rooms (U.S. EPA, 2023). See Table 2-4 for product scenario specific selection of environment (*i.e.,* small room) and the associated air exchange rate. Kitchens, living rooms, and the garage area are considered more open, with an interzonal ventilation rate of 109 m^3/hour. Bedrooms, bathrooms, laundry rooms, and utility rooms are considered less open, and an interzonal ventilation rate of 107 m^3/hour was applied. Therefore, for the purposes of this screening analysis, a bathroom was selected as the room of use. However, this room may represent a bathroom, dorm room, or an office bathroom, as previously described in Section 2.2.2.1. In instances where an entire house is selected as the room of use, the entire building is considered Zone 1, and the interzonal ventilation rate is therefore equal to the negligible value of 1×10^{-30} m^3/hour.

B.2.1 CEM Modeling Inputs and Parameterization

The COU evaluated for HHCB was continuous action air fresheners. The embedded models within CEM v3.2 that were used for HHCB are listed below in Table_Apx B-2. As dermal exposure was modeled separately, only inhalation routes were evaluated in CEM.

Table_Apx B-2. CEM Version 3.2 Model Codes and Descriptions

Model Code	Description
E1	Emission from product applied to a surface indoors incremental source model
P_INH1	Calculation of inhalation TWA from product usage

Table_Apx B-3 presents a crosswalk between the COU subcategories with either a predefined or generic scenario. Models were generated to reflect specific use conditions as well as physical and chemical properties of identified products. Table_Apx B-3 also summarizes the emissions model and exposure pathways modeled for the screening exposure scenario. Emissions models were selected based upon physical and chemical properties of the product and application use method for products. Specifically, E1 was selected which assumes a constant application rate over the specified duration of use; each instantaneously applied segment has an emission rate that declines exponentially over time, at a rate that depends on the chemical's molecular weight and vapor pressure. This model is dependent solely on the mass of chemical, rather than the amount of product used. Therefore, dilution is not calculated in this model. Exposure pathways were selected to reflect the anticipated use of each product. Relevant consumer behavioral pattern data (*i.e.,* use patterns) and product-specific characteristics were applied to the CEM screening scenario and are summarized in Section B.2.2.

Table_Apx B-3. Crosswalk of COU Subcategories, CEM Version 3.2 Scenarios, and Relevant CEM Models Used for Consumer Modeling

Consumer COU	Subcategory COU	Product	Emission Model and Exposure Pathway(s)	CEM Saved Analysis
Air care products	Continuous action air fresheners	CHAMPION SPRAYON SPRAY SCENTS® METERED AIR FRESHENER/ DEODORIZER	Continuous action air fresheners (inhalation)	E1, P_INH1 (Users)

B.2.2 Key Parameters for Spray Products Modeled in CEM

CEM was used to evaluate inhalation exposures of air fresheners with continuous aerosol spray applications. High concentrations of HHCB in air increases inhalation exposure. This may occur due to product formulation or use patterns that allow for higher emissions of HHCB to air and/or environment specific characteristics such as smaller room volume and lower ventilation rates. Key parameters that control HHCB emission rates from products in CEM v3.2 models are weight fraction of HHCB in the formulation, duration of product use, mass of product used, and frequency of use. Any increase in these parameters results in higher chemical exposure from product use.

CEM default values for key parameters including product mass used, duration of use, and frequency of use are product specific. As such, values for these parameters were based on manufacturer use instructions for product mass and professional judgment for duration of use and frequency (U.S. EPA, 2025b). This information was synthesized to better understand how consumers use these products and professional judgment was applied to develop specific values expected to capture a realistic range of values for each parameter, with the exception of duration of use which was assumed to be continuous over one year. Product densities were taken from product specific technical specifications and associated SDS sheets. A detailed description of derivations of key parameter values used in CEM v3.2 models for liquid products is provided below, and a summary of values be found in Table 2-4.

Amount of Product Used

EPA utilized the continuous action (Champion Spray on Spray Scents® Metered Air Freshener/ Deodorizer (Chase Products, 2025)) use instructions noted on the product label which was 198 grams (7 oz) as the total amount available for use. EPA incorporated this value in its screening exposure inhalation exposure assessment. This product can deodorize up to a 6,000 ft^2 area. It is meant to be inserted into an aerosolization dispenser, which releases a small amount of the air freshener every 15 to minutes for a total of 30 days. EPA assumed continuous use of the product with replacement rate of once per 30 days. The Agency calculated a standard of 2,880 times it dispenses, which would be 68.75 mg of the air freshener dispensed (0.6875 mg of HHCB).

Duration and Frequency of Use

EPA assumed continuous use of the product, 24 hours per day, for 365 days. Normally, the activity pattern with CEM would assume the individual would move throughout the home. Although this assumption was overridden to estimate a worst-case scenario. EPA recognizes that this is a conservative estimate of exposure duration for continuous action air fresheners but determined these assumptions are appropriate for a screening assessment.

Environmental Parameters

Default values are provided in CEM for use environment and ventilation rates in each room, but these may be modified by the user. EPA sought to identify the highest potential concentration that could be estimated in the model over the period of a year. Selecting a small room volume where the product may be most likely used in the model facilitates this goal. Therefore, EPA assumed that the product user was in a small room (15 m^3) constantly within a residence or office. See Section 2.2.2 and Table 2-4 for a summary of key parameters used for this screening assessment.

B.2.3 Inhalation Dose Calculation

EPA estimated chronic average daily dose rates for inhalation exposures to HHCB via metered continuous action air fresheners in a small room using the following formula:

Equation_Apx B-1. Chronic Average Daily Dose Rate for Inhalation of Product Used in an Environment

$$CADD = \frac{C_{air} \times Inh \times FQ \times D_{cr} \times ED}{BW \times AT \times CF_1 \times CF_2}$$

Where:

$CADD$	=	Chronic average daily dose (mg/kg-day)
C_{air}	=	Concentration of chemical in air (mg/m^3)
Inh	=	Inhalation rate (m^3/h)
FQ	=	Frequency of use (events/year)
D_{cr}	=	Duration of use (min/event), chronic
ED	=	Exposure duration (years of product usage)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF_1	=	Conversion factor (365 days/year)
CF_2	=	Conversion factor (60 min/h)

CEM uses two defaults inhalation rates that trace back to the *Exposure Factors Handbook* (U.S. EPA, 2011b) (see Table_Apx B-4 notes)—one when the person is using the product and the other after the use has ended. Table_Apx B-4 also shows the inhalation rates by receptor age category for during and after product use.

Table_Apx B-4. Inhalation Rates Used in CEM Product Models

Age Group (years)	Inhalation Rate During Use (m^3/h) [a]	Inhalation Rate After Use (m^3/h) [b]
Adults (21+)	0.74	0.61
Youths (16–20)	0.72	0.68
Youths (11–15)	0.78	0.63
Children (6–10)	0.66	0.50
Small Children (3–5)	0.66	0.42
Infants (1–2)	0.72	0.35
Infants (<1)	0.46	0.23

[a] Table 6-2, light intensity values (U.S. EPA, 2011a)
[b] Table 6-1 (U.S. EPA, 2011a)

The inhalation dose is calculated iteratively at a 30-second interval during the first 24 hours and every subsequent hour for 60 days—taking into consideration the chemical emission rate over time, the volume of the house and each zone, the air exchange rate and interzonal airflow rate, and the exposed individual's locations and inhalation rates during and after product use.

B.3 Results

Table_Apx B-5 below presents a summary of the estimated inhalation exposures in doses (mg/kg/day) from the use of continuous action air fresheners over one year. Through a screening approach, EPA estimated 1-year average daily doses resulting from an individual's exposure to HHCB 24 hours per day, every day in a room that is 15 m^3. In the model, EPA assumed that the room is a residential bathroom, but it also represents other small spaces such as a dorm room or office (see Section 2.2.2.1). The estimated HHCB dose for this scenario is 9.71×10^{-5} mg/kg/day.

Table_Apx B-5. Estimated Chronic Average Daily Doses of HHCB via Inhalation Exposures to Continuous Action Air Fresheners

Scenario	Consumer Population (years)	CEM Calculated Chronic Average Daily Concentration (mg/m³)	Chronic Non-Cancer Exposure Time (hours/day)	Chronic Non-Cancer Exposure Frequency (days/yr)	CEM Estimated Chronic Average Daily Dose (mg/kg/day)
Continuous action air fresheners	Adults (21+)	8.95E−04	24	365	1.99E−04
	Youths (16–20)	8.95E−04	24	365	2.16E−04
	Youths (11–15)	8.95E−04	24	365	2.95E−04
	Children (6–10)	8.95E−04	24	365	4.46E−04
	Small Children (3–5)	8.95E−04	24	365	7.62E−04
	Infants (1–2)	8.95E−04	24	365	1.23E−03
	Infants (<1)	8.95E−04	24	365	1.27E−03

B.4 Weight of Scientific Evidence

EPA evaluated over 50 exposure studies with potential relevance to the draft risk evaluation for HHCB per systematic review exposure evaluation metrics (U.S. EPA, 2021a). The data were used as contextual information for the consumer exposure assessment of HHCB via the inhalation route. However, this exposure literature does not differentiate between TSCA COUs and other sources. This data also did not provide consumer exposure scenario specific information such as amount, frequency, duration of use, and so on. Instead, this data provides strong evidence that there are many potential sources of inhalation exposures to HHCB, primarily through sources no addressed by TSCA COUs (U.S. EPA, 2025b; Api et al., 2023).

For the HHCB consumer inhalation exposure assessment, CEM modeling was parameterized based on weight fractions acquired from product-specific SDSs, activity, and product use pattern data from the *Exposure Factors Handbook* (U.S. EPA, 2011b) as well as the 1987 Westat survey (Westat, 1987). This is the best available data to define the exposure scenario/consumer activities. Collectively, data and information from such sources in addition to the data and information presented in the *Draft Physical Chemistry, Fate and Transport, Environmental Release, and Environmental Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026e) and CEM v3.2 modeling methodology (U.S. EPA, 2023) provide a moderate overall confidence in the consumer inhalation exposure assessment of HHCB under the appropriate exposure scenarios.

EPA's moderate confidence is primarily driven by assumption of a 24-hour duration of exposure since, in most cases, an individual would be expected to move in and out of the room of use. Nevertheless, the assessed scenario may be considered reflective of individuals who experience 24/7 HHCB exposure in a small room (15 m^3) as an upper-bound consumer inhalation exposure to aerosolized continuous action air fresheners, which are replaced every 30 days and used for at least 1 year.

Appendix C DERMAL EXPOSURE ANALYSES

This appendix summarizes the available dermal absorption data related to HHCB, the interpretation of the dermal absorption data, and dermal absorption modeling efforts. Although the inhalation pathway was modeled within CEM (see Appendix B), dermal modeling for liquid and solid products was performed using the approach described below. For liquid products, EPA applied empirical dermal flux data in its estimation of dermal exposures to HHCB using a spreadsheet and therefore bypassed the need for certain inputs required by CEM, like weight fractions and migration rates. Dermal exposures to vapors are not expected to be significant based on HHCB's volatility (Henry's Law constant is 1.06×10^{-4} atm·m^3/mole at 25 °C) (U.S. EPA, 2012)); therefore, they are not included in the dermal exposure assessment of HHCB.

During direct dermal contact with liquid products, HHCB can migrate to the aqueous phase available in the skin surface. As a hydrophobic compound, HHCB has an affinity for the stratum corneum, which is lipophilic. HHCB has an affinity for this layer, potentially leading to its retention on the skin surface or within the upper layers—even if the systemic absorption into the bloodstream may be low. HHCB is formulated into a variety of water-based products (*e.g.,* liquid detergents) where it can be present in the aqueous fraction through emulsification or solubilization. When these products are applied to the skin, even if the HHCB does not readily dissolve in water, its contact with the skin surface combined with its hydrophobic nature can facilitate its transfer from the formulation to the skin. In addition, use of CEM for dermal absorption estimation, which relies on total concentration rather than aqueous saturation concentration, would greatly overestimate exposure to HHCB in liquid chemicals.

There was no empirical data available for solid products (*e.g.,* powdered detergents). Therefore, EPA assumed that the identified empirical data from liquids was applicable to solids.

C.1 Flux-Based Dermal Absorption Data

EPA identified three studies directly related to the dermal absorption of HHCB via liquids (Zhang et al., 2017; An-eX, 2001; Ford et al., 1999). These studies are discussed in further detail in the Draft HHCB Human Health and Environmental Hazard Assessment (U.S. EPA, 2026h). EPA did not identify empirical dermal absorption data for solids. In general, the following are key considerations for prioritizing dermal absorption data when EPA uses a flux-based approach for dermal exposure assessments, which are applied when comparing the suitability of the three available studies:

- Time-course data are required to calculate dermal flux.
- Recent studies were preferred that used modern dermal testing techniques and guidelines for *in vivo* and *in vitro* dermal absorption studies (*i.e.,* OECD Guideline 427 (OECD, 2004b) and Guideline 428 (OECD, 2004c)).
- Studies using human skin were preferred over animal models.

Based on the criteria above, as well as on additional strengths and uncertainties associated with the candidate studies (discussed in the Draft HHCB Human Health and Environmental Hazard Assessment (U.S. EPA, 2026h)), EPA selected the *in vitro* dermal absorption study conducted in human epidermal membranes as the most suitable for use in the dermal exposure assessment (An-eX, 2001). In this study, which pre-dated but was conducted in general compliance with OECD guideline 428, HHCB was applied to epidermal membranes as a single dose of 20 µL/cm^2 (1% in ethanol solution) using non-occlusive simulated conditions of exposure. The amount of applied HHCB that permeated past the membranes into the receptor phase was measured at 1, 2, 6, 12, and 24 hours (Table_Apx C-1). At 24 hours, membranes were tape-striped 10 times, after which radio-labeled content of the strips and remaining epidermis were also measured. Evaporative loss of HHCB was also measured and determined to be minimal (2.4% applied HHCB over 24 hours). The investigators reported that HHCB skin permeation was low. Following 24 hours exposure, the average total absorbed dose was 17.69 $\mu g/cm^2$, or 8.85% of the applied dose. This total absorbed dose included levels of radioactivity found in tape strips 2 through 10, any remaining skin after tape stripping, filter paper, and receptor fluid.

Table_Apx C-1. Amounts of HHCB Detected in Various Compartments in the Dermal Absorption Study by An-eX (2001) [a]

Time (hours)	Receptor Phase ($\mu g/cm^2$)	Receptor Phase (% Applied Dose)	Remaining Skin + Tape Strips 2–10 + Filter Paper ($\mu g/cm^2$)	Remaining Skin + Tape Strips 2–10 + Filter Paper (% Applied Dose)
1	0.006	0.003		
2	0.024	0.012		
6	0.079	0.039		
12	0.242	0.121		
24	0.795	0.397	16.89	8.45

[a] Numbers expressed in this table reflect the mean amount of HHCB detected across n = 12 epidermal membranes. Amounts of HHCB in compartments other than the receptor phase were only measured at 24 hours in this study.

C.2 Dermal Absorption Data Interpretation

With respect to interpretation of the HHCB dermal absorption data reported by An-eX (2001), it is important to consider the relationship between the applied dermal load and the rate of dermal absorption. Specifically, the work of Kissel (2011) suggests the dimensionless term N_{derm} to assist with interpretation of dermal absorption data. The term N_{derm} represents the ratio of the experimental load (*i.e.,* application dose) to the absorptive flux for a given experimental duration as shown in the following equation.

Equation_Apx C-1. Relationship Between Applied Dermal Load and Rate of Dermal Absorption

$$N_{derm} = \frac{experimental\ load\ (\frac{mass}{area})}{flux\ \left(\frac{mass}{area * time}\right) \times experimental\ duration\ (time)}$$

Kissel (2011) indicates that high values of N_{derm} (>>1) suggest that supply of the material is in excess, and that the dermal absorption is considered "flux-limited," whereas lower values of N_{derm} indicate that absorption is limited by the experimental load and would be considered "delivery-limited." Furthermore, Kissel (2011) indicates that values of percent absorption for flux-limited scenarios are highly dependent on the dermal load and should not be assumed transferable to conditions outside of the experimental conditions. Rather, the steady-state absorptive flux should be utilized for estimating dermal absorption of flux-limited scenarios.

HHCB's molecular weight, relatively large size, and low solubility in water likely impede its ability to cross the dermal barrier, limiting the rate of flux independent of the concentration on the skin. Furthermore, for flux-limited scenarios, a dermal flux is primarily governed by the chemical's ability to permeate the skin rather than the total applied dose (*i.e.,* dermal loading). Although the dermal surface concentration does influence flux to some extent, for HHCB its impact is expected to be relatively small compared to the fundamental transport limitations imposed by the skin barrier. Therefore, the steady-state flux value derived from experimental data should be reasonable for estimating absorption across commercial and consumer products and articles, despite variability in formulation concentration. If sufficient surface concentration is present to sustain diffusion, differences in loading should not meaningfully impact the absorption rate.

Based on the application of HHCB from an aqueous solution to human skin *in vitro*, An-eX (2001) reported a flux of 2.02×10^{-5} mg/cm^2/h at 12 hours, which corresponds to the expected duration of an upper bound commercial work shift and 6.00×10^{-6} mg/cm^2/h at 1 hour, which corresponds to the expected duration of most product consumer uses. According to the study, the applied dose per skin specimen was 0.2 mg/cm^2. The experimental fluxes, time points, and applied dose were used to calculate N_{derm}, as shown below.

Equation_Apx C-2. N_{derm} Calculated According to Flux at 12 Hours

$$N_{derm} = \frac{0.2\ mg/cm^2}{0.00002\ \ mg/cm^2/hr\ \times 12\ hr} = 833.33$$

Equation_Apx C-3. N_{derm} Calculated According to Flux at 1 Hour

$$N_{derm} = \frac{0.2\ mg/cm^2}{0.000006\ \ mg/cm^2/hr\ \times 1\ hr} = 33333.33$$

Because $N_{derm} >> 1$ for the experimental conditions in An-eX (2001), it is shown that the absorption of HHCB is considered flux-limited, even at finite doses (*i.e.,* <10 µL/cm^2 (OECD, 2004c)).

C.3 Modeling Inputs and Parameterization

C.3.1 Occupational

Occupational dermal exposures to HHCB were characterized using a flux-based approach to dermal exposure. To ensure that the flux approach does not exceed the amount of loading on the skin, EPA used the lesser of Equation_Apx C-4 and Equation_Apx C-5 to estimate the acute potential dose rate (APDR). The APDR is then used to calculate intermediate (IADD) and average daily dose (ADD).

Equation_Apx C-4.

$$APDR = J\ \times S \times t_{abs}$$

Where:

J = Average absorptive flux through and into skin (mg/cm^2/h)
S = Surface area of skin in contact with the chemical formulation (cm^2)
t_{abs} = Duration of absorption (h/day)

Equation_Apx C-5.

$$APDR = \ Q \times Y_{derm} \times S$$

Where:

Q = Dermal loading of liquid or solid (mg/cm^2)
S = Surface area of skin in contact with the chemical formulation (cm^2)
Y_{derm} = Weight fraction of HHCB in the liquid or solid formulation (unitless)

Equation_Apx C-6.

$$ADD = \frac{APDR \times ED \times EY \times WY}{BW \times AT}$$

Where:

$APDR$ = Acute potential dose rate (mg/day)
ED = Exposure duration (hours/day)
EY = Exposure frequency (days)
BW = Body weight (kg)
AT = Averaging time (hours)

Table_Apx C-2. Input Parameters for Occupational Dermal Exposure Estimates

Input Parameter	Symbol	Value	Unit
Absorptive Flux	J	2.02E−05	$mg/cm^2/h$
Surface Area	S	Workers: 535 (central tendency) 1,070 (high-end)	cm^2
Absorption Time	t_{abs}	8	hours
Dermal Loading	Q	Liquid contact: 1.4 (central tendency) 2.1 (high-end) Liquid immersion: 3.8 (central tendency) 10.3 (high-end) Solids contact[a] : 900 (central tendency) 3,100 (high-end) Solid contact with container surfaces/ solders/pastes: 450 (central tendency) 1,100 (high-end)	mg/cm^2 (liquids) mg/day (solids)
HHCB Weight Fraction	Y_{derm}	1 (highest)	unitless
Exposure Duration	ED	8	hours/day
Exposure Frequency	EY	250	days
Working Years	WY	31 years (central tendency) 40 years (high-end)	years
Body Weight	BW	80	kg
Averaging Time	AT	271,560 (central tendency) 350,400 (high-end)	hours

C.3.2 Consumer

Consumer dermal exposures to HHCB are characterized using a flux-based approach to dermal exposure. The equation used to estimate the dermal dose of DEHP associated with routine use of consumer liquid products is as follows:

Equation_Apx C-7. Dermal Dose Per Exposure Event for Liquid and Solid Products

$$Dose\ per\ Event = Flux\ \times Duration\ of\ Use\ \times \frac{SA}{BW}$$

Where:

$Dose\ per\ Event$	=	Amount of chemical absorbed (mg/kg by body weight)
$Flux$	=	Steady-state absorptive flux (mg/cm^2-h)
$Duration\ of\ use$	=	Extent of time specific product/article is in use (hours)
SA	=	Surface area of body parts in direct contact with product/article (cm^2)
BW	=	Body weight by lifestage (kg)

The chronic dose rate for direct dermal contact with a product was calculated as follows:

Equation_Apx C-8. Chronic Average Daily Dose Rate for Dermal

$$CADD_{Dermal} = Dose\ per\ Event \times Chronic\ Frequency$$

Where:

$CADD_{Dermal}$	=	Chronic dermal rate for dermal contact (mg/kg-day by body weight)
$Dose\ per\ Event$	=	Amount of chemical absorbed per use (mg/kg by body weight)
$Chronic\ Frequency$	=	Chronic frequency of use, day^{-1} (see Table_Apx C-3 for input parameters)

Table_Apx C-3 provides a summary of key parameters incorporated in the flux-based dermal exposures assessment of liquid detergents. As noted in Section 2.2, only liquid products were assessed for consumer dermal exposures. Exposure estimates to liquid products are generally assumed to be higher compared to powdered products as such products are expected to adhere less to the skin.

Table_Apx C-3. Key Parameters Used in Dermal Consumer Exposure Models

Product	Scenario	Duration of Contact (min)	Frequency of Contact (year^{-1})	Frequency of Contact (day^{-1})	Dermal Flux (mg/cm^2/h)	Contact Area[a]
Hand dishwashing soap/liquid detergent[b]	High	60	365	1	6.00E−06	Inside of 2 hands (palms, fingers)
	Med	30	300		6.00E−06	Inside of 1 hand (palms, fingers)
	Low	5	185		6.00E−06	10% of both hands (some fingers)

[a] See appendix Table B-3 of U.S. EPA (2023).
[b] SDS confirming HHCB in liquid dish washing detergent formulation (INEOS Hygienics Limited, 2023).

Duration of Use/Contact Time/Lifestages

For all products, it was assumed that contact with the product occurs at the beginning of the period of use and the product is not washed off until use is complete. As such, the duration of dermal contact for these products is equal to the duration of use applied in CEM modeling for products. EPA consulted Appendix Table B-4 of U.S. EPA (2023) for suggested durations and durations of use according to product. However, the Agency determined that the summarized durations of hand dishwashing were likely underestimating common use patterns. Therefore, EPA used professional judgement when assuming durations of exposure based on reasonable product uses to represent a low, central tendency and upper bound scenario. Since the expected duration of use for liquid and dishwashing products was an hour or less, the Agency applied the empirical dermal flux at 1 hour to best match the exposure scenario.

For example, a quick wash of a few utensils (*i.e.,* 1 plate, spoon, fork, and knife) may only take 5 minutes; while typical dish washing may take 30 minutes if an individual washes dishes and utensils for a small family after dinner. It may take a full hour for that individual to wash a sink full of dishes after a dinner party. In this example, this individual is expected to use the inside of two hands (including palms and fingers) to wash the dishes (U.S. EPA, 2023) and is not expected to be wearing gloves.

EPA assumes this individual may be anyone above the age of 11; that is, old enough to handle common household chores including dishwashing. EPA also assumes that associated use scenarios for infants and toddlers are a misuse because such individuals are not reasonably mature enough to handle such chores. The Agency acknowledges that some children under 11 years may be involved in washing dishes but assumes that scenario to be less common. Therefore, the selection of 11 years and above is an arbitrary lifestage cutoff that is meant to represent most individuals who may be washing dishes and reduces the likelihood of misrepresentation. EPA has a robust confidence that the selection of durations, contact time and user lifestages accurately represent expected use scenarios.

Frequency of Use

For liquid dishwashing detergents modeled in CEM, frequency of contact was assumed to be equal to the frequency of use (per year and per day) that was applied in CEM modeling. EPA consulted Appendix Table B-4 of U.S. EPA (2023) for suggested frequencies of use. For an upper-bound estimate, EPA assumed an individual who is likely from a large family washes a sink filled with dishes every day.

C.4 Occupational and Consumer Dermal Exposure Results

C.4.1 Occupational

Table_Apx C-4 present a summary of the estimated dermal exposure in doses (mg/kg/day) from occupational exposures using the flux-based approach. EPA expects workers to experience routine exposures across the different industrial and commercial COUs. As the absorption studies demonstrated, a relatively large proportion of the HHCB that crossed through the skin barrier remain in the epidermis. Although the maximum duration that EPA expects the loading to remain on the skin is 8 hours, HHCB will likely continue to pass through the epidermis membranes after skin is rinsed. For this screening-level analysis, EPA applied the flux measured at 12 hours for a continuous period of 24 hours and 365 days as a comparison for a worst-case estimate protective of the absorption potentially occurring after rinsing the skin.

Table_Apx C-4. Estimated Chronic Average Daily Doses of HHCB via Occupational Dermal Exposures

	Tabs (hours)	J (mg/cm^2/h)	S (cm^2)	APDR (mg/day)	ADD (mg/kg-day)
Full-shift	8	2.02E−05	1,070	1.73E−01	4.93E−04
All day	24	2.02E−05	1,070	5.19E−01	6.48E−03

C.4.2 Consumer

Table_Apx C-5 below presents a summary of the estimated dermal exposures in doses (mg/kg/day) from the use of liquid dishwashing detergents over 1 year. EPA estimated 1-year average doses resulting from routine uses of liquid dishwashing detergents which contain HHCB (INEOS Hygienics Limited, 2023). Only users aged 11 years or more were assessed. Bystanders were not assessed. Of the users, the highest estimated chronic average daily exposures were for youths aged 11 to 15 years, followed by adults aged over 20 years and youths aged 16 to 20 years. As expected, an increase in the duration and frequency of liquid dishwashing detergents assessed led to higher average daily doses of HHCB via dermal contact. Thus, daily uses of such products for an hour resulted in the highest estimated doses of HHCB via the dermal route.

Table_Apx C-5. Estimated Chronic Average Daily Doses of HHCB via Dermal Exposures to Liquid Dishwashing Detergents

Product/ Article Name	Exposure Level	User(s) [a]		Input Parameters						Chronic Dose (mg/kg bw year)		
		Adults	Youths	Event Time (min)	Frequency (Chronic)	Frequency (Acute)	Flux ($mg/cm^2/h$)	Dermal Absorption per Scenario (mg/cm^2)	Contact Area	Adults (21+ years)	Youths (16–20 years)	Youths (11 to <15 years)
Liquid dishwashing detergent	High	1	1	60	365	1	6.00E−06	6.00E−06	Inside of 2 hands (palms, fingers)	1.36E−02	1.27E−02	1.39E−02
	Medium	1	1	30	300	1	6.00E−06	3.00E−06	Inside of 2 hands (palms, fingers)	5.57E−03	5.22E−03	5.70E−03
	Low	1	1	5	185	1	6.00E−06	5.00E−07	Inside of 2 hands (palms, fingers)	5.73E−04	5.36E−04	5.86E−04

[a] A 0 would have indicated that the population was not assessed for dermal exposure.

C.4.3 Weight of Scientific Evidence

EPA identified three available studies on the dermal absorption of HHCB and determined that an *in vitro* study of HHCB absorption through human skin by An-eX (2001) was the most suitable for use in a flux-based approach for assessing dermal exposure to HHCB. This study pre-dates OECD 428, but was conducted in general compliance with the guideline and received a rating of "acceptable, non-guideline" in the attached data evaluation record (U.S. EPA, 2026a). The other available studies, which were non-guideline, assessed dermal absorption in animals and/or had greater uncertainty regarding the amount actually absorbed. The strengths and uncertainties of the available dermal absorption studies for HHCB are discussed in more detail in the Draft HHCB Human Health and Environmental Hazard Assessment (U.S. EPA, 2026h).

HHCB's molecular weight, relatively large size, and low solubility in water likely impeded its ability to cross the dermal barrier, limiting the rate of flux independent of the concentration on the skin. As a result, EPA relied exclusively on its flux-based dermal modeling approach for assessing occupational and consumer exposure which has been peer reviewed by the Science Advisory Committee on Chemicals (SACC) and have been used in previous risk evaluations. Although the flux of HHCB into the bloodstream was low, the rate of absorption through the skin layer is notably higher based on the accumulation of HHCB within the skin layers. At the end of the absorption study, only 0.397 percent was found in the receptor fluid while 8.45 percent of the applied dose was in the skin and tape strippings. With an *in vitro* study, the absorption rate does not account for microcirculation that occurs *in vivo* which potentially increases the absorption rate into the bloodstream (OECD, 2004a). This limitation may lead to an underestimation of the flux and the calculated dermal exposure. Additionally, the HHCB present in the skin will continue to be absorbed post-rinsing, but the degree of that absorption is unknown. EPA relied on continuous exposure throughout the year (*i.e.,* 24 hours, 365 days per year) for occupational workers to address this uncertainty.

EPA evaluated reasonably available literature with potential relevance to the risk evaluation for HHCB per systematic review exposure evaluation metrics (U.S. EPA, 2021a). The data were used as contextual information for the occupational and consumer dermal exposure assessment of HHCB. However, this exposure literature does not differentiate between TSCA COUs and other sources. The data also did not provide exposure scenario-specific information such as amount, frequency, duration of use, and so on. Instead, this data provides strong evidence that there are many potential sources of dermal exposures to HHCB, primarily through sources other than TSCA COUs (Api et al., 2023).

One key strength of the occupational and consumer exposure assessments is that they relied upon reasonable assumptions of product use patterns which may represent common exposures. For these reasons, EPA has a moderate confidence in the dermal approach used to assess occupational and consumer exposures.

C.5 General Population Dermal Exposure Assessment

The general population may swim in surface waters (*e.g.,* streams, lakes) that could be affected by HHCB contamination. Modeled surface water concentrations estimated in Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e) were used to estimate acute dose rates (ADR) and average daily doses (ADD) from dermal exposure while swimming. The following equations were used to calculate incidental dermal (swimming) doses for adults, youths, and children:

Equation_Apx C-9. Acute Incidental Dermal Calculation

$$ADR = \frac{(SWC \times K_p \times SA \times ET \times CF1 \times CF2)}{BW}$$

Where:

ADR	=	Acute dose rate (mg/kg-day)
SWC	=	Surface water concentration (ppb or µg/L)
K_p	=	Permeability coefficient (cm/h)
SA	=	Skin surface area exposed (cm^2)
ET	=	Exposure time (h/day)
$CF1$	=	Conversion factor (1.0×10^{-3} mg/µg)
$CF2$	=	Conversion factor (1.0×10^{-3} L/cm^3)
BW	=	Body weight (kg)

Equation_Apx C-10. Average Daily Incidental Dermal Calculation

$$ADD = \frac{(SWC \times K_p \times SA \times ET \times RD \times ET \times CF1 \times CF2)}{(BW \times AT \times CF3)}$$

Where:

ADD	=	Average daily dose (mg/kg-day)
SWC	=	Chemical concentration in water (µg/L)
K_p	=	Permeability coefficient (cm/h)
SA	=	Skin surface area exposed (cm^2)
ET	=	Exposure time (h/day)
RD	=	Release days (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
$CF1$	=	Conversion factor (1.0×10^{-3} mg/µg)
$CF2$	=	Conversion factor (1.0×10^{-3} L/cm^3)
$CF3$	=	Conversion factor (365 days/year)

EPA used the dermal permeability coefficient (K_p) of 0.0209 cm/h, derived from ten Berge (2009) to estimate the steady-state exposure to a constant concentration in a water body.

Table_Apx C-6 shows a summary of the estimates of ADRs and ADDs due to dermal exposure while swimming for adults, youth, and children. Dermal doses were calculated from Equation_Apx C-10 using the highest surface water concentration from the combined commercial and consumer down-the-drain scenario at the P95 POTW, with a 50% removal efficiency, as a screening analysis. Dermal doses were also calculated using the highest values from ambient surface water monitoring concentration. Doses calculated using the surface water monitoring data are up to two orders of magnitude lower than corresponding doses modeled using the high-end Plastic compounding OES.

Table_Apx C-6. Dermal (Swimming) Doses Across Lifestages[9]

Scenario	Water Column Concentrations		Adults (21+ years)		Youths (11–15 years)		Children (6–10 years)	
	30Q5 Conc. (µg/L)	Harmonic Mean Conc. (µg/L)	ADR (mg/kg-day)	ADD (mg/kg-day)	ADR (mg/kg-day)	ADD (mg/kg-day)	ADR (mg/kg-day)	ADD (mg/kg-day)
Combined commercial plus consumer down-the-drain scenario at the P95 POTW, 50% removal efficiency	25.4	21.2	3.88E−04	3.24E−04	2.97−004	2.48−004	1.80E−04	1.50E−04
High from monitored surface water[a]	25.5	25.5	3.90E−04	3.90E−04	2.98E−04	2.98E−04	1.81E−04	1.81E−04

ADD = average daily dose; ADR = acute dose rates 30Q5 = lowest 30-day average flow that occurs (on average) once every 5 years 30 consecutive days of lowest flow over a 5-year period.
[a] Water Quality Portal database reported the highest monitored surface water concentration from California, the only U.S. study, as described further in Draft HHCB Environmental Exposure Assessment (U.S. EPA, 2026e). This is a single maximum value from the study and does not correspond to either the 30Q5 or harmonic mean concentrations. However, it was used in both instances to compare exposure estimates based on modeled and monitored surface water concentrations. It is important to note that monitored HHCB concentrations do not distinguish between sources and cannot be correlated to any TSCA COUs.

C.5.1 Weight of Scientific Evidence

The approach taken for general population exposure from contact with a water body of constant concentration applies a different approach than the flux-based approach detailed for the occupational and consumer exposure assessments. This is consistent with existing TSCA risk evaluations and allows an estimation of exposure from this swimming scenario. Dermal exposures from the occupational and consumer assessments exceed those of the general population scenario and are protective of this endpoint.

[9] Doses calculated using Equation_Apx C-9 and Equation_Apx C-10.

Appendix D ORAL EXPOSURE ANALYSES

D.1 Residential Dust Ingestion

Based on wipe samples of household dust covering an area of 1ft^2, Dodson et al. (2017) reported HHCB concentration in dust as high as 4.9 ug/ft^2 after home renovations occurred in low-income housing units in Boston, Massachusetts. To determine the potential dust ingestion for an infant exhibiting crawling and hand-to-mouth behavior (NRDC, 2016) or anyone who may accidently ingest HHCB via dust after touching 1 ft^2 area of a home, the reported peak concentration was first converted to ug/g. For this conversion, the following steps were taken:

1. Finding the density of the material: Determining the density of dust in most homes in g/ft^3. Based on a study by Fayad-Martinez et al. (2025), the average density of household dust is about 44,740.62 g/ft^3 (1.58 g/cm^3).
2. Determining the depth of the sample: Estimating the approximate depth of the household dust in ft. Assuming that a film thickness accumulated on the infant's hands as a layer of dust is equivalent to the depth of the household dust, EPA utilized Table B-3 of the CEM 3.2 User Guide Appendix U.S. EPA (2023) from which a film thickness of 8.33×10^{-6} ft (0.000253833 cm) was selected for the use of powder based coatings, pastels, and craft products, as a surrogate for household dust depth.
3. Calculating the volume occupied by 1 gram: Dividing 1 g by the density to find the volume 1 gram occupies in cubic feet:
   a. $1 \text{ g} \div (44{,}740.62 \text{ g/ft}^3) = 2.24\times10^{-5} \text{ ft}^3$
4. Calculating the area occupied by 1 gram: Taking the volume calculated in step 3 and dividing it by the sample's estimated depth:
   a. $(2.24\times10^{-5} \text{ ft}^3) \div (8.33\times10^{-6} \text{ ft}) = 2.69 \text{ ft}^2$
5. Converting μg/ft^2 to μg/g: Multiplying the monitoring concentration in μg/ ft^2 by 2.69 ft^2/1 g since 1 g of dust is estimated to occupy 2.69 ft^2.
   a. $(4.9 \text{ μg/ ft}^2 \times 2.69 \text{ ft}^2/1\text{g}) = 13.181$ μg/g (HHCB per g of dust)

Next, EPA estimated the average daily dose of HHCB ingested from household dust by multiplying the 95th percentile dust ingestion rate (mg/day) (U.S. EPA, 2011b) by the HHCB concentration in dust (μg/g) as noted above, divided by bodyweight (kg) (U.S. EPA, 2011b), divided by 1000,000 for an estimated dose in mg/kg/day. Table_Apx D-1 summarizes these key inputs and Table_Apx D-2 summarizes the worst case average daily dose HHCB ingested based on a maximum HHCB concentration in indoor dust monitoring.

Overall, infants (<1 year old) had the highest estimated ingested dose of HHCB from household dusts following renovations in low-income housing units in Boston, Massachusetts. Due to the assumptions made in the conversion of HHCB dust concentration from μg/ ft^2 to μg/g and an inability to source-apportion the measured concentrations, EPA has a slight to moderate confidence in the assessment of HHCB oral exposures via household dust.

Table_Apx D-1. Key Inputs for the HHCB Dust Ingestion Calculator

Age	Dust Ingestion (mg/day)		Body Weight (kg)	HHCB Dust Concentration (µg/g) Maximum Measured
	Geometric Mean	95th Percentile		
0–1 months	19	103	4.8	13.1810
1– 3 months	21	116	5.9	
3–6 months	23	112	7.4	
6 months to 1 year	26	133	9.2	
1–2 years	23	119	11.4	
2–3 years	14	83	13.8	
3–6 years	15	94	18.6	
6–11 years	13	87	31.8	
11–16 years	8.8	78	56.8	
16–21 years	3.5	46	71.6	
21–30 years	3.5	46	78.4	
30–40 years	3.5	46	80.8	
40–50 years	3.5	46	83.6	
50–60 years	3.5	46	83.4	
60–70 years	3.5	46	82.6	
70–80 years	3.5	46	76.4	
80+ years	3.5	46	68.5	

Table_Apx D-2. Estimated Average Daily Dose of HHCB Ingested from Household Dust After Renovations in Low-Income Homes in Boston, Massachusetts

Average Daily Dose (mg of HHCB/kg body weight/day)		
Population	Age Range (years)	Worst Case (95% Dust Ingestion, Max [HHCB]) per Age Group
Infants	<1	2.33E−04
Toddlers	1–2	1.38E−04
Preschoolers	2–5	7.29E−05
Middle Childhood	6–10	3.61E−05
Young Teens	11–15	1.81E−05
Teenagers and Young Adults	16– 21	8.47E−06
Adults	21+	7.70E−06

D.2 Human Milk Ingestion

Based on human milk samples from 39 Massachusetts women, HHCB was measured as high as 917 ng/g (Reiner et al., 2007) (See Table_Apx D-3). To estimate the daily HHCB dose (mg/kg/day) ingested from human milk by exclusively breastfed infants (<1 year), the reported peak concentration was first converted to 0.917 µg/g. Of infants aged less than 1 year, doses could only be calculated for 3- and 6-month-old infants specifically because EPA could only identify birth weights for these breastfeeding infants based on the *Exposure Factors Handbook* (U.S. EPA, 2011b). To estimate their ingested dose, the following steps were taken:

1. Identifying volume of milk (mL) consumed per day for 3- and 6-month-old breast-fed infants.
2. Converting volume of milk consumed to amount or mass (mg) using an average milk density of about 1,030 mg/mL (U.S. EPA, 2011b), where mass (g) = volume of milk consumed per day (mL) ÷ average density of milk (mg/mL). The amount of human milk consumed (mg/day) by completely breast-fed infants are presented in Table_Apx D-4.
3. Calculating ingested dose of HHCB by 3- and 6-month-old infants in mg/kg/day. The reported body weights of 3- and 6-month-old infants were averaged across genders as presented in Table_Apx D-4. EPA used the following formula to calculate the ingested dose: (mean and maximum amount of human milk consumer per day [mL/day]) × (maximum measured HHCB concentration in human milk ÷ infant weight [kg]) ÷ 1,000,000 for unit conversion. See Table_Apx D-5 for a summary of the estimated HHCB exposures resulting from human milk ingestion among 3- and 6-month-old infants.

Overall, 3-month-old infants had the highest estimated ingested HHCB dose from human milk compared with 6-month-old infants. Because these estimates require converting milk volume (mL/day) to amount consumed (mg/day) for human milk and an inability to source-apportion the measured concentrations—EPA has a slight-to-moderate confidence in the resulting oral exposure estimates.

Table_Apx D-3. Summary of Human Milk Exposures Among Massachusetts Women

Study	Source	Levels	Reported HHCB Concentration (ng/g)	Conversion HHCB Concentration (µg/g)
Reiner et al. (2007)	Milk samples from 39 Massachusetts women	Low	5	0.005
		Mean	227	0.227
		High	917	0.917

Table_Apx D-4. Key Inputs for the HHCB Dust Ingestion Calculator

Age	Volume of Human Milk Ingestion (mL/day) by Completely Breast-Fed Infants			Amount of Human Milk Consumed (mg/day) by Completely Breast-Fed Infants			Body Weight (kg) of Breast-Fed Infants (Combined Average for Males and Females)	HHCB Concentration (µg/g) in Human Milk
	Min	Mean	Max	Min	Mean	Max		Max Measured
3 months	645	833	1,000	664,350	857,990	1,030,000	6.2	0.917
6 months	616	682	786	634,480	702,460	809,580	7.8	

Table_Apx D-5. Estimated Average Daily Dose of HHCB Ingested from Human Milk

Infant Age	Dose According to Mean Milk Ingestions and Maximum HHCB Concentration	Dose According to Maximum Milk Ingestions and Maximum HHCB Concentration
3 months	1.27E−01	1.52E−01
6 months	8.26E−02	9.52E−02

D.3 General Population Oral Exposure

Equation_Apx D-1. Average Daily Drinking Water Ingestion Calculation

$$ADD_{POT} = \frac{\left(SWC \times \left(1 - \frac{DWT}{100}\right) \times IR_{dw} \times ED \times RD \times CF1\right)}{(BW \times AT \times CF2)}$$

Where:

ADD_{POT}	=	Potential average daily dose (mg/kg/day)
SWC	=	Surface water concentration (ppb or µg/L; 30Q5 conc. for ADR, harmonic mean for ADD, LADD, LADC)
DWT	=	Removal during drinking water treatment (assume 0% for screening)
IR_{dw}	=	Drinking water intake rate (L/day)
ED	=	Exposure duration (years for ADD, LADD, and LADC; 1 day for ADR)
RD	=	Release days (days/yr for ADD, LADD, and LADC; 1 day for ADR)
BW	=	Body weight (kg)
AT	=	Exposure duration (years for ADD, LADD, and LADC; 1 day for ADR)
$CF1$	=	Conversion factor (1.0×10^{-3} mg/µg)
$CF2$	=	Conversion factor (365 days/year)

Fish tissue concentrations were estimated from modeled and monitored water column concentrations by applying equation:

Equation_Apx D-2. Fish Tissue Concentration

$$Fish\ Tissue\ Conc.\left(\frac{mg}{kg}\right) = SWC \times BCF \times CF1$$

Where:

SWC	=	Surface water (dissolved) concentration (µg/L)
BCF	=	Bioconcentration factor (L/kg wet weight)
$CF1$	=	Conversion factor for mg/µg (1.0×10^{-3} mg/µg)

These terms are also incorporated into the estimation of HHCB exposure from fish ingestion, estimated with the following equation:

Equation_Apx D-3. Fish Ingestion Calculation

$$ADR\ or\ ADD = \frac{(SWC \times BCF \times IR \times CF1 \times CF2 \times ED)}{AT}$$

Where:

ADR	=	Acute dose rate (mg/kg-day)
ADD	=	Average daily dose (mg/kg-day)
SWC	=	Surface water (dissolved) concentration (µg/L)
BCF	=	Bioconcentration factor (L/kg wet weight)
IR	=	Fish ingestion rate (g/kg-day)
$CF1$	=	Conversion factor for mg/µg (1.0×10^{-3} mg/µg)
$CF2$	=	Conversion factor for kg/g (1.0×10^{-3} kg/g)
D	=	Exposure duration (year)
AT	=	Averaging time (year)

Appendix E QUALITATIVE ANALYSES OF EXPOSURE POTENTIAL

E.1 Occupational

To select the scenario with the highest exposure, a review of the COUs were completed as shown in Table_Apx E-1. Each COU was considered for its potential for exposure to each physical form of HHCB that workers could be exposed to vapor, dust, and mist. For all forms, the potential of exposure can be correlated with the volume of the chemical handled, concentration of the chemical in material being handled, and environment where the exposure occurs. For example, higher concentrations or volumes handled results in higher potential for exposure to the chemical. For exposure through vapor, the potential for volatilization can be measured by the vapor pressure. The lower the vapor pressure of a chemical indicates a lower potential for the chemical to exist in the vapor phrase during worker activities. Temperature of the chemical during exposure activity is also important because the vapor pressure rises with temperature.

Table_Apx E-1. Inhalation Exposure Potentials for COUs Not Quantified

<table>
<tr><th>COU</th><th>Inhalation Exposure Potential</th></tr>
<tr><td>Manufacturing – Domestic manufacturing</td><td rowspan="3">Via vapor
• Handling of HHCB will likely occur at elevated temperature, high concentrations (maximum: 100%), and high volumes. Exposures are expected to be similar to the assessed scenario; however, it was not selected due to uncertainties on these activities and throughput at for these scenarios in the United States.
Via dust
• Dust generation is possible if repackaging involves pellets or powder materials, but there is not current information indicating repackaging of these types of materials.
Via mist
• Mist generation not expected (i.e., no spray applications)</td></tr>
<tr><td>Manufacturing – Importing</td></tr>
<tr><td>Processing – Repackaging – Odor agent in all other chemical product and preparation manufacturing</td></tr>
<tr><td>Processing – Recycling</td><td>Via vapor
• Presumably recycling would occur only via plastics recycling, where HHCB is at low concentrations (maximum: <5%) and entrained. Volatilization would be low.
Via dust
• Dust generation may occur, but uncertainties on concentration of HHCB.
Via mist
• Mist generation not expected (i.e., no spray application)</td></tr>
<tr><td>Distribution in commerce</td><td>Distribution in commerce is expected to occur with HHCB or products containing HHCB to be in sealed containers, therefore no potential for inhalation exposure</td></tr>
<tr><td>Commercial Use – Air care products – Air fresheners for motor vehicles</td><td rowspan="4">Via vapor
• Products may be heated but at low HHCB concentrations (maximum: <12%), and at low volumes, potential for vapor inhalation is lower than assessed scenario
Via dust
• Products may generate dust, but at low HHCB concentrations, potential for dust exposure is lower than assessed scenario
Via mist
• Products may generate mist when spray applied; however, assessed scenario for continuous action air fresheners are expected to be higher due to the longer exposure duration and frequency than use of instant action air fresheners</td></tr>
<tr><td>Commercial Use – Air care products – Instant action air fresheners</td></tr>
<tr><td>Commercial Use – Cleaning and furnishing care products – All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)</td></tr>
<tr><td>Commercial Use – Laundry and dishwashing products – Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dry cleaning and associated products; Dishwashing detergent (liquid/ gel); Dishwashing detergent (unit dose/granule); Dishwashing detergent liquid (hand-wash)</td></tr>
</table>

COU	Inhalation Exposure Potential
Commercial Use – Plastic and rubber articles not covered elsewhere – Plastic and rubber articles	Via vapor • Products are solid polymeric articles, where HHCB is entrained in the polymeric matrix, volatilization would be slow. Potential for vapor inhalation is lower than assessed scenario Via dust • Use of finished plastic and rubber articles (*i.e.,* hard plastics) are not expected to generate dust Via mist • Use of finished plastic and rubber articles are not expected to generate mist
Commercial Use – Other use laboratory chemicals – Laboratory chemicals	Via vapor • Products may be heated but at very low volumes, potential for vapor inhalation is lower than assessed scenario Via dust • No products identified for laboratory use would generate dust (*i.e.,* all liquid products) Via mist • Products may generate mist when spray applied, however, volumes handled are low. In addition, most uses such as for analytical needs would not generate mist.
Disposal	Via vapor • Handling of waste may require heating for transfer but heighted uncertainties on the concentration and volumes handled as compared to assessed scenario. Via dust • Certain waste may generate dust, however, higher level of uncertainties on the concentration and volumes handled as compared to assessed scenario Via mist • Mist generation not expected (*i.e.,* no spray application)

E.2 Consumer

Consumer exposures were considered for uses of products that fit within TSCA COUs as identified in CDR and summarized in the HHCB Scope (U.S. EPA, 2020c). These include COUs listed in Table_Apx E-2, which also provide a simplified description of associated exposure scenarios that were considered. Although HHCB is expected to be more prevalent in cosmetic products, such products in addition to pesticides are beyond TSCA jurisdiction and were not assessed.

This assessment did not attempt to quantify accidental exposures or exposures to HHCB from unreasonable use patterns per the aforementioned sources. It also did not attempt to predict exposures from products for which it has no or insufficient information; therefore, slight confidence regarding consumer uses. This includes CDR submitted uses such as Chemical Substances in Treatment Products – Ion Exchangers; Liquid Water Treatment Products; Solid Powder Water Treatment Products. Moreover, this draft assessment focused on the quantification of exposures from long-term exposures given that the identified human health hazard effect (*i.e.,* reduction of offspring birthweight following mother's exposure to HHCB during pregnancy) is associated with intermediate or long-term durations. Consequently, only long-term scenarios were used to quantify HHCB exposure across all age groups.

Based on a review of the draft physical, chemical, and fate properties of HHCB (primarily vapor pressure), exposures to HHCB via inhalation are likely to result from aerosolized HHCB (*i.e.,* via continuous action air freshener sprays), and heated solutions containing HHCB due to HHCB's vapor pressure is not expected to emit significantly from products on its own at room temperature. Although potential dermal consumer exposures were acknowledged, dermal consumer risks were not estimated for any of the TCSA consumer COUs given no dermal hazard was identified for HHCB. Regarding oral exposures, though monitoring data supports the assessment of HHCB in dust, the mechanisms through which HHCB gets to household dust, the proportion of HHCB released from products to air then dust, and whether those measured HHCB concentrations are from TSCA or other sources, all remain unknown. Thus, as with the dermal route, and though EPA acknowledged potential oral exposures to HHCB via TSCA COUs, the Agency did not calculate oral consumer risks to HHCB resulting from any of the TSCA consumer COUs because such exposures are expected to be minimal and not predictable with at least a moderate level of confidence. Instead, EPA relied exclusively on the monitoring data for a qualitative assessment of oral consumer exposures to HHCB. While the monitoring data cannot be source-apportioned according to TSCA vs. other sources, generally, HHCB exposures from inhalation and dermal routes are expected to be higher compared to oral ingestion.

EPA used a screening approach to assess potential consumer exposures from TSCA COUs by targeting the highest potential exposures with a consideration of the product with the most frequent long-term uses, longest duration of use possible, weight fraction per product type, the most amount used, and the smallest room of use in a home that was identified as a standard bathroom within CEM with a volume of 15 m^3. Notably, in CEM there is no difference in the way exposures are modeled in a bathroom or a bedroom. Therefore, this small room is assumed to also be representative of a small bedroom in a home. Using these considerations, EPA identified continuous action air fresheners as consumer product for which exposures were quantified. For consumers, short-term and intermediate exposures were assessed qualitatively. While it should be noted that due to the continuous nature of the exposures assessed, the estimated long-term doses for consumer users of continuous action air fresheners are applicable to intermediate timeframes of exposure as well.

If risks were to be identified beyond the established benchmark, this analysis would be refined using less conservative input parameters that could lead to an improved representation of more common consumer exposures to HHCB; and/or the consumer exposure analysis would be expanded to other products and COUs, as appropriate. Given the level of conservatism associated with the aforementioned assumptions, the consumer HHCB exposure assessment was assumed to be protective of potential commercial exposures—especially since ventilations in residential spaces are typically less than commercial environments and because room sizes are typically larger than residential environments. These factors can generally lead to lower concentrations in commercial environments relative to residential environments. See Table_Apx E-2 for a summary of consumer TSCA COUs that were assessed for HHCB, including products identified, assessment types, scenario description, and rationale for conducting a quantitative or qualitative consumer exposure assessment for the associated TSCA COUs.

Table_Apx E-2. Simplified Preliminary Consumer Exposure Scenarios According to TSCA Consumer COUs

COU Category	Product Type Identified	Exposure Assessment Type (Quantitative or Qualitative) / Route[a]	Representative Exposure Scenario[b]	Rationale
Plastic	No consumer plastic products identified	Not applicable	Not applicable	No assessment could be generated for this COU with at least a moderate level of confidence.
Air Care	Continuous action air freshener, instant action air fresheners	Quantitative (inhalation)/qualitative (dermal, oral)	Individual is located in a small room 15m^3 where a plug-in continuous action air freshener releases aerosolized HHCB-based fragrance continuously every day	Continuous action air fresheners were selected as representative products based on a consideration of product concentration, duration of use, frequency of use (persistence), amount and mass of product. The focus of the assessment was on inhalation exposures via aerosolization instead of the vapor phase based on HHCB's semi-volatility. Based on manufacturer's use directions, any oral exposures would be a misuse, and any dermal exposures are expected to be accidental which could occur during installation.
	Paper tree	Qualitative (inhalation, dermal, oral)	Driver installs paper tree as car air freshener and drives a few hours per day	During installation, dermal exposures are expected to be minimal if any as there may be residual fragrance oils containing HHCB from the paper tree air fresheners. An oral exposure is not an intended use of this articles. Inhalation exposures though possible are expected to be minimal due to ventilation from car's AC/heating or natural air if window is down, and relatively low concentration of HHCB, relatively low mass of product, duration, frequency of exposure compared to continuous action air fresheners.
Cleaning and furnishing care	No consumer plastic products identified	Not applicable	Not applicable	No assessment could be generated for this COU with at least a moderate level of confidence.
Laundry and dishwashing	Liquid, solid laundry products, liquid dish detergents	Quantitative (dermal)/qualitative (inhalation, oral)	Consumer uses dish detergent to washing dishes by hand for 30–45 minutes, every day	Dishwashing products were identified are the representative product for this COU primarily based on the expected relatively higher mass of product, duration of and frequency of contact in comparison to other products in this COU category. The dermal route of exposure is expected to be the primary route of exposure given HHCB's dermal fixative properties. Therefore, EPA quantified exposures given that such exposures are reasonably expected. However, because EPA did not identify dermal hazards for HHCB, risks were not calculated for this use. Inhalation

COU Category	Product Type Identified	Exposure Assessment Type (Quantitative or Qualitative) / Route[a]	Representative Exposure Scenario[b]	Rationale
				exposure is possible but expected to be minimal while in comparison to dermal exposures while oral exposures are expected to come from residual amounts ingested from kitchenware after dishwashing, accidental exposures or a misuse.
Chemical substances in treatment products	Products reported in CDR on: ion exchangers; liquid water treatment products; solid powder water treatment products	Qualitative (inhalation, dermal, oral)	Unknown	Products reported in CDR. However, no actual consumer products or their SDSs could be identified. Therefore, no assessment could be generated for this COU with at least a moderate level of confidence.

[a] Oral consumer exposures are not expected based on expected and reasonable consumer product use patterns. A qualitative assessment was conducted across products presented exclusively in Appendix D.

[b] The quantification of exposures focused on long-term exposures given that the hazard endpoint identified is for long-term durations. Therefore, where appropriate only long-term scenarios were quantified. Short term or intermediate exposures for consumers are acknowledged to occur but are not further assessed.