United States Environmental Protection Agency

March 2024
Office of Chemical Safety and Pollution Prevention

Draft Occupational Exposure Assessment for Formaldehyde

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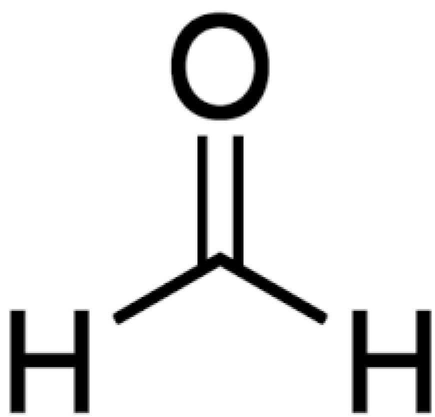

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EXECUTIVE SUMMARY

Key Points: Occupational Exposure Assessment for Formaldehyde

- EPA estimated occupational exposures to formaldehyde through air (inhalation) and skin contact (dermal) routes. EPA estimated both high-end and central tendency exposure estimates for occupational exposure scenarios (OESs) associated with each Toxic Substances Control Act (TSCA) condition of use (COU).
- Exposure for most OESs were estimated based on monitoring data. For OESs that lacked available monitoring data, EPA applied Monte Carlo statistical modeling approaches to estimate exposures.
- In general, air concentrations in workplaces are higher than ambient air (outdoor) concentrations.
- The full-shift inhalation exposure estimates for the OESs ranged from 0.006 to 0.6 ppm for central tendency exposures and 0.006 to 14 ppm for high-end exposures. The dermal exposure estimates ranged from 0.56 to 840 μg/m^3 for central tendency exposures and 0.84 to 3,090 μg/m^3 for high-end exposures.

EPA estimated inhalation exposures to workers and occupational non-users (ONUs) and dermal exposures for workers for the TSCA COUs specified in the 2020 *Final Scope of the Risk Evaluation for Formaldehyde*. These COUs cover formaldehyde as it is manufactured, processed, used, distributed, and disposed of. For exposure estimates, EPA reviewed peer-reviewed literature, gray literature, industry submissions, and modeling approaches to estimate both a central tendency and a high-end estimate for each route. Workers and ONUs are exposed by the inhalation route as formaldehyde is a volatile chemical and is known to off-gas from formaldehyde-based products. Workers are dermally exposed to formaldehyde from skin contact with formulations containing formaldehyde.

EPA did not evaluate occupational exposures to formaldehyde through the oral route. Workers and ONUs may inadvertently ingest inhaled particles that deposit in the upper respiratory tract. In addition, workers may transfer chemicals from their hands to their mouths. The frequency and significance of these exposure routes are dependent on several factors that are difficult to predict. Formaldehyde is highly volatile and generally not expected to adhere to dust or other particles, which could then be ingested. For certain COUs, wood or textile dust may act as a carrier for formaldehyde leading to inhalation via particulate that may be subsequently ingested. However, formaldehyde will continue to evaporate and there is uncertainty on the amount inhaled that is ingested. For this draft risk assessment, these exposures were evaluated as an inhalation exposure.

EPA primarily integrated discrete monitoring sampling data for the central tendency and high-end inhalation estimates. The inhalation exposure estimates ranged from 0.006 to 0.6 ppm for the central tendency results, and 0.006 to 14 ppm for the high-end results for 8-hour time-weighted average (TWA). The highest inhalation exposure estimates were for use of formulations containing formaldehyde in automotive care products. For 15-minute exposures, the inhalation estimates ranged from 0.07 to 1.9 ppm for the central tendency results, and 0.09 to 194 ppm for the high-end results. Where data was available, EPA estimated short-term and 12-hour TWA data as well. The short-term inhalation exposures ranged from 0.005 to 2.4 ppm for central tendency results, and 0.02 to 28 ppm for high-end results. Data was available to estimate 12-hour TWA inhalation exposures for the following OESs: Manufacturing, Processing as a reactant, Rubber product manufacturing, and Textile finishing. The results ranged from 0.02 to 0.04 for central tendency results, and 0.04 to 0.15 ppm for high-end results.

Dermal exposure estimates were driven by the expected dermal contact scenario (*e.g.*, routine or immersion) and the formaldehyde concentration within the formulation. Dermal exposure values ranged from 0.56 to 840 $\mu g/m^3$ for central tendency estimates and 0.84 to 3,090 $\mu g/m^3$ for high-end estimates. The highest dermal exposure estimates were for use of formulations containing formaldehyde for spray applications and use of formulations containing formaldehyde in automotive care products. EPA assumed that workers dermal loading during hand spraying conditions may be similar to an immersive dermal contact.

1 INTRODUCTION

EPA is currently evaluating risks from formaldehyde under both FIFRA and Frank R. Lautenberg Chemical Safety for the 21st Century Act that amended the Toxic Substances Control Act (TSCA). This occupational exposure assessment specifically focuses on worker exposures to formaldehyde resulting from conditions of use (COUs) permitted under TSCA as part of the Formaldehyde Risk Evaluation.

Formaldehyde is used in several processing activities, including use as a reactant, incorporation into articles, and incorporation into a formulation, mixture, or reaction product for various industrial, commercial, and consumer applications. Formaldehyde is widely used in industrial, commercial, and consumer applications such as textiles, foam bedding/seating, resins, glues, composite wood products, paints, coatings, plastics, rubber, construction materials (including insulation and roofing), furniture, toys, and various adhesives and sealants.

Formaldehyde is subject to federal and state regulations and reporting requirements. Formaldehyde is a Toxics Release Inventory (TRI)-reportable substance. It is also on EPA's initial list of hazardous air pollutant (HAPs) under the Clean Air Act (CAA), is a designated hazardous substance under the Clean Water Act (CWA), and EPA has established a drinking water health advisory (non-enforceable guidelines) under the Safe Drinking Water Act (SDWA). Formaldehyde has an Occupational Safety and Health Administration (OSHA) standard OSHA 1910.1048. The permissible exposure limit (PEL) is 0.75 parts per million (ppm) over an 8-hour (full shift) workday, time-weighted average (TWA) and a short-term exposure limit (STEL) of 2 ppm. The OSHA standard also includes, but is not limited to requirements for exposure monitoring, dermal protection, recordkeeping, use of personal protection equipment (PPE) if other exposure controls are not feasible, and hazard communication.

There are also recommended exposure limits established for formaldehyde by other governmental agencies and independent groups. The American Conference of Governmental Industrial Hygienists (ACGIH) set a Threshold Limit Value (TLV) at 0.1 ppm TWA and 0.3 ppm STEL in 2017. This chemical also has a NIOSH Recommended Exposure Limit (REL) of 0.016 ppm TWA and 15-minute Ceiling limit of 0.1 ppm (see NIOSH Pocket Guide to Chemical Hazards).

1.1 Scope

EPA assessed occupational exposures for COUs as described below in Table 1-1. EPA did not include in the scope of the risk evaluation activities described below that the Agency does not consider to be COUs. TSCA section 3(2) excludes from the definition of "chemical substance" "any food, food additive, drug, cosmetic, or device (as such terms are defined in Section 201 of the Federal Food, Drug, and Cosmetic Act [21 U.S.C. 321]) when manufactured, processed, or distributed in commerce for use as a food, food additive, drug, cosmetic, or device" as well as "any pesticide (as defined in the Federal Insecticide, Fungicide, and Rodenticide Act [7 U.S.C. 136 et seq.]) when manufactured, processed, or distributed in commerce for use as a pesticide." EPA has determined that the following uses of formaldehyde are non-TSCA uses and therefore the following exposure scenarios are not assessed in this report:

- use in food packaging;
- use in manufacturing medical devices;
- use in sterilization of kidney dialysis machines;
- use in nail and hair care products;
- use in the manufacture of animal feeds (CFR 573.460);
- use as a drug in fish hatcheries (21 CFR 529);

- use as a biocide in fumigation at poultry hatcheries, citric houses; and
- use as an embalming fluid or preservative for biological specimen.

Formaldehyde can be emitted from many types of combustion, from naturally occurring wildfires to household appliance and industrial combustion turbines. These sources can also include tailpipe emissions (including cars, trucks and boats); and emissions form fires (including wildfires, accidental fires and agricultural burning). Some of the combustion activities that occur at industrial sites may have been integrated into the other associated TSCA COUs. Workers such as firefighters or staff at transportation terminals may have heightened occupational exposures from formaldehyde due to these combustion sources. For this risk evaluation, given the number of potential combustion sources, EPA did not include formaldehyde from the combustion sources independent of other TSCA COUs due to their abundant nature. EPA provides summaries of select monitoring studies in *Supplemental Formaldehyde Occupational Monitoring Data Summary* and the full list of studies identified in *Draft Risk Evaluation for Formaldehyde (HCHO) – Systematic Review Supplemental File: Data Quality Evaluation and Data Extraction Information for Environmental Release and Occupational Exposure*.

EPA identified occupational exposure scenarios (OESs) related to the in-scope COUs of formaldehyde. An OES is based on a set of facts, assumptions, and inferences that describe how releases and exposures take place within an occupational COU. For each OES, EPA has developed assessment approaches to provide estimates of central tendency and high-end exposures that are representative of the OES. The central tendency and high-end exposures represent the 50th and 95th percentile of exposure estimates, respectively. EPA may define only a single OES for multiple COUs, while in other cases multiple OESs may be developed for a single COU. EPA will make this determination by considering variability in the use conditions and whether the variability can be captured as a distribution of exposure or instead requires discrete scenarios. Figure 1-1 depicts three ways that COUs may be mapped to OES.

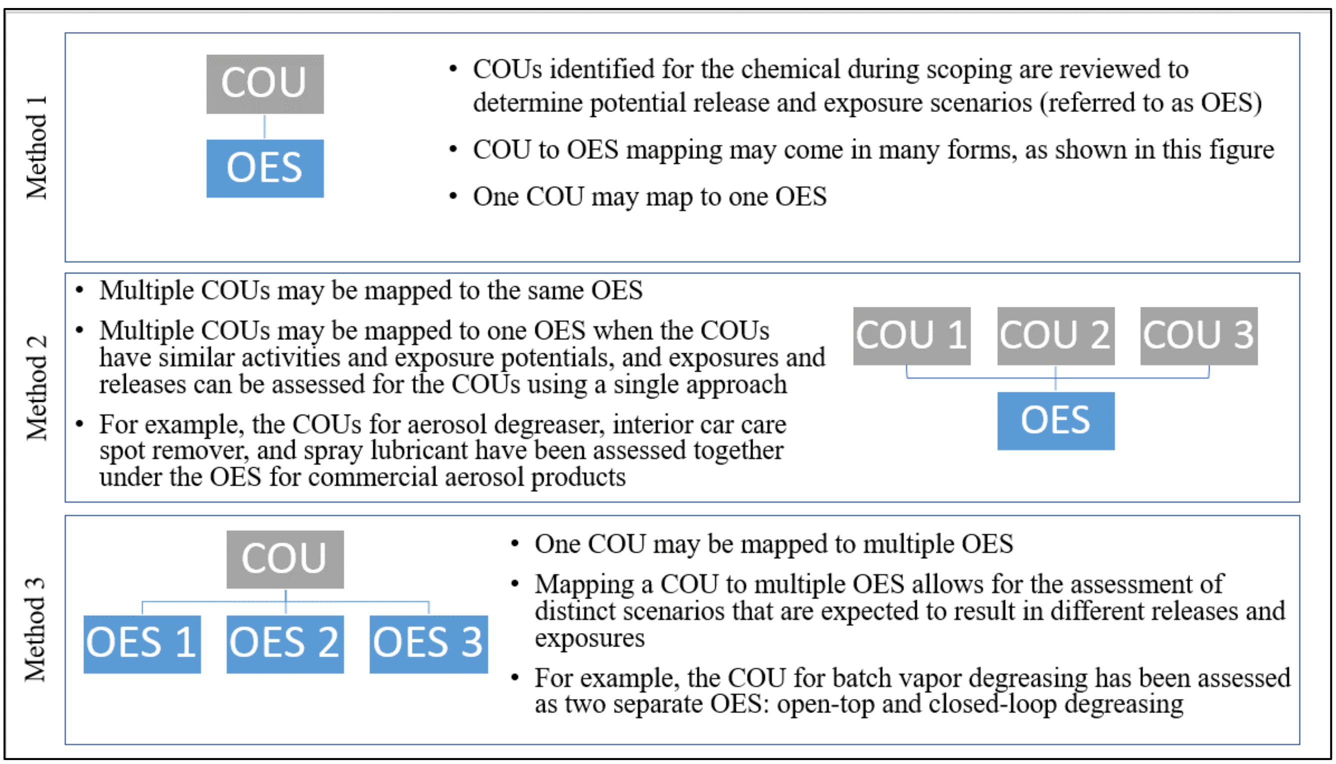


Figure 1-1. Condition of Use to Occupational Exposure Mapping

For the purposes of the Draft Formaldehyde Risk Evaluation, OESs were developed solely to support the occupational exposure assessment and it is not specifically used for the release assessment.

Table 1-1 shows mapping between the TSCA COUs to the OESs assessed in this report. As listed in the table, EPA identified 49 COUs under manufacturing, processing, and industrial/commercial uses. Several of the COU categories and subcategories were grouped and assessed together in a single OES due to similarities in the processes or lack of data to differentiate between them. In other cases, COU subcategories were further delineated into multiple OESs based on expected differences in processes and associated exposure potentials between facilities. This resulted in 36 OESs that were assessed, as listed in Table 1-1.

The occupational exposure assessment of each occupational exposure scenario (OES) comprises the following components:

- **Process Description:** A description of the OES, including the function of the chemical in the OES; physical forms and weight fractions of the chemical throughout the process; the total production volume (PV) associated with the OES; per site throughputs/use rates of the chemical; operating schedules; and process vessels, equipment, and tools used during the TSCA COU use.
- **Estimates of Number of Facilities:** An estimate of the number of sites that use formaldehyde for the given OES.
- **Worker Activities:** A description of the worker activities, including an assessment for potential points of worker and occupational non-user (ONU) exposure. Workers are jobs expected to handle formaldehyde and have direct contact with the chemical, while ONUs work in the general vicinity of workers but do not handle formaldehyde and do not have direct contact with formaldehyde.
- **Number of Workers and ONUs:** An estimate of the number of workers and ONUs potentially exposed to the chemical for the given OES.
- **Occupational Inhalation Exposure Results:** Central tendency and high-end estimates of inhalation exposure to workers and occupational non-users. See Section 2.5 for a discussion of EPA's statistical analysis approach for assessing inhalation exposure.
- **Occupational Dermal Exposure Results:** Central tendency and high-end estimates of dermal exposure to workers. See Section 2.6 for a discussion of EPA's approach for assessing dermal exposure.

Table 1-1. Crosswalk of Subcategories of Use Listed in the Final Scope Document to Occupational Exposure Scenarios Assessed in the Risk Evaluation

Condition of Use (COU)			Occupational Exposure Scenario (OES) Mapped to COU
Life Cycle Stage	**Category**	**Subcategory**	
Manufacturing	Domestic Manufacturing	Domestic manufacturing	Manufacturing of Formaldehyde
	Importing[a]	Importing	Import and/or Repackaging of Formaldehyde
Processing	Reactant	Adhesives and sealant chemicals in: Plastic and resin manufacturing; Wood product manufacturing; Paint and coating manufacturing; basic organic chemical manufacturing	Processing as a Reactant
Processing	Reactant	Intermediate in: Pesticide, fertilizer, and other agricultural chemical manufacturing; Petrochemical manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; basic organic chemical manufacturing; Plastic materials and resin manufacturing; Adhesive manufacturing; chemical product and preparation manufacturing; Paper manufacturing; Paint and coating manufacturing; Plastic products manufacturing; Synthetic rubber manufacturing; Wood product manufacturing; Construction; Agriculture, forestry, fishing, and hunting	
Processing	Reactant	Functional fluid in: Oil and gas drilling, extraction, and support activities	
Processing	Reactant	Processing aids, specific to petroleum production in all other basic chemical manufacturing	
Processing	Reactant	Bleaching agent in wood product manufacturing	
Processing	Reactant	Agricultural chemicals in agriculture, forestry, fishing, and hunting	
Processing	Incorporation into an article	Finishing agents in textiles, apparel, and leather manufacturing	Textile Finishing
			Leather Tanning
Processing	Incorporation into an article	Paint additives and coating additives not described by other categories in transportation equipment manufacturing (including aerospace)	Use of Coatings, Paints, Adhesives, or Sealants
			Use of Coatings, Paints, Adhesives, or Sealants
Processing	Incorporation into an article	Additive in rubber product manufacturing	Rubber Product Manufacturing

Condition of Use (COU)			Occupational Exposure Scenario (OES) Mapped to COU
Life Cycle Stage	**Category**	**Subcategory**	
Processing	Incorporation into an article	Adhesives and sealant chemicals in wood product manufacturing; plastic material and resin manufacturing (including structural and fireworthy aerospace interiors); construction (including roofing materials); paper manufacturing	Composite Wood Product Manufacturing Paper Manufacturing Plastic Product Manufacturing Other Composite Material Manufacturing
Processing	Incorporation into a formulation, mixture, or reaction product	Petrochemical manufacturing, petroleum, lubricating oil and grease manufacturing; fuel and fuel additives; lubricant and lubricant additives; basic organic chemical manufacturing; petroleum and coal products manufacturing	Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products
	Incorporation into a formulation, mixture, or reaction product	Asphalt, paving, roofing, and coating materials manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Solvents (which become part of a product formulation or mixture) in paint and coating manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Processing aids, specific to petroleum production in: oil and gas drilling, extraction, and support activities; chemical product and preparation manufacturing; and basic inorganic chemical manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Paint additives and coating additives not described by other categories in: Paint and coating manufacturing; Plastic material and resin manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Intermediate in: all other basic chemical manufacturing; all other chemical product and preparation manufacturing; plastic material and resin manufacturing; oil and gas drilling, extraction, and support activities; wholesale and retail trade	
	Incorporation into a formulation, mixture, or reaction product	Solid separation agents in miscellaneous manufacturing	

Condition of Use (COU)			Occupational Exposure Scenario (OES) Mapped to COU
Life Cycle Stage	**Category**	**Subcategory**	
Processing	Incorporation into a formulation, mixture, or reaction product	Agricultural chemicals (nonpesticidal) in: Agriculture, forestry, fishing, and hunting; pesticide, fertilizer, and other agricultural chemical manufacturing	Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products
	Incorporation into a formulation, mixture, or reaction product	Surface active agents in plastic material and resin manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Ion exchange agents in adhesive manufacturing and paint and coating manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Lubricant and lubricant additive in adhesive manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Plating agents and surface treating agents in all other chemical product and preparation manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Soap, cleaning compound, and toilet preparation manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Laboratory chemicals	
	Incorporation into a formulation, mixture, or reaction product	Adhesive and sealant chemical in adhesive manufacturing	
	Incorporation into a formulation, mixture, or reaction product	Bleaching agents in textile, apparel, and leather manufacturing	
	Repackaging	Sales to distributors for laboratory chemicals	Import and/or Repackaging of Formaldehyde
	Recycling	Recycling	Recycling
Distribution	Distribution	Distribution in Commerce	Storage and Retail Stores

Condition of Use (COU)			Occupational Exposure Scenario (OES) Mapped to COU
Life Cycle Stage	**Category**	**Subcategory**	
Industrial Use	Non-incorporative activities	Process aid in: Oil and gas drilling, extraction, and support activities; process aid specific to petroleum production, hydraulic fracturing	Use of Formaldehyde for Oilfield Well Production
Industrial Use	Non-incorporative activities	Used in: construction	Furniture Manufacturing
Industrial Use	Non-incorporative activities	Oxidizing/reducing agent; processing aids, not otherwise listed (*e.g.*, electroless copper plating)	Processing Aid
Industrial Use	Chemical substances in industrial products	Paints and coatings; adhesives and sealants; lubricants	Use of Coatings, Paints, Adhesives, or Sealants
			Use of Coatings, Paints, Adhesives, or Sealants
			Industrial Use of Lubricants
			Foundries
Commercial Use	Chemical substances in furnishing treatment/care products	Floor coverings; Foam seating and bedding products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles; Cleaning and furniture care products; Leather conditioner; Leather tanning, dye, finishing impregnation and care products; Textile (fabric) dyes; Textile finishing and impregnating/ surface treatment products.	Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public and Commercial Buildings, and Other Structures
	Chemical substances in treatment products	Water treatment products	Use of Formulations containing Formaldehyde for Water Treatment
	Chemical substances in treatment/care products	Laundry and dishwashing products	Use of Formulations Containing Formaldehyde in Laundry and Dishwashing Products
	Chemical substances in construction, paint, electrical, and metal products	Adhesives and Sealants; Paint and coatings	Use of Coatings, Paints, Adhesives, or Sealants
			Use of Coatings, Paints, Adhesives, or Sealants
	Chemical substances in furnishing treatment/care products	Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public and Commercial Buildings, and Other Structures

Condition of Use (COU)			Occupational Exposure Scenario (OES) Mapped to COU
Life Cycle Stage	**Category**	**Subcategory**	
Commercial Use	Chemical substances in electrical products	Machinery, mechanical appliances, electrical/electronic articles; Other machinery, mechanical appliances, electronic/electronic articles	Use of Electronic and Metal Products
	Chemical substances in metal products	Construction and building materials covering large surface areas, including metal articles	
	Chemical substances in automotive and fuel products	Automotive care products; Lubricants and greases; Fuels and related products	Use of Formulations Containing Formaldehyde in Automotive Care Products
			Use of Automotive Lubricants
			Use of Formulations containing Formaldehyde in Fuels
	Chemical substances in agriculture use products	Lawn and garden products	Use of Fertilizers Containing Formaldehyde in Outdoors Including Lawns
	Chemical substances in outdoor use products	Explosive materials	Use of Explosive Materials
	Chemical substances in packaging, paper, plastic, hobby products	Paper products; Plastic and rubber products; Toys, playground, and sporting equipment	Use of Packaging, Paper, Plastics, and Hobby Products
	Chemical substances in packaging, paper, plastic, hobby products	Arts, crafts, and hobby materials	Use of Craft Materials
	Chemical substances in packaging, paper, plastic, hobby products	Ink, toner, and colorant products; Photographic supplies	Use of Printing Ink, Toner, and Colorant Products Containing Formaldehyde
			Photo Processing Using Formulations Containing Formaldehyde
	Chemical substances in products not described by other codes	Laboratory Chemicals	General Laboratory Use

Condition of Use (COU)			Occupational Exposure Scenario (OES) Mapped to COU
Life Cycle Stage	Category	Subcategory	
Disposal[b]	Disposal	Disposal	Worker Handling of Wastes

[a] The repackaging scenario covers only those sites that purchase formaldehyde or formaldehyde containing products from domestic and/or foreign suppliers and repackage the formaldehyde from bulk containers into smaller containers for resale. Sites that import and directly process/use formaldehyde are assessed in the relevant OES. Sites that that import and either directly ship to a customer site for processing or use or warehouse the imported formaldehyde and then ship to customers without repackaging are assumed to have no exposures or releases and only the processing/use of formaldehyde at the customer sites are assessed in the relevant OES.

[b] Each of the COU of Formaldehyde may generate waste streams of the chemical that are collected and transported to third-party sites for disposal, treatment, or recycling. Industrial sites that treat, dispose, or directly discharge onsite wastes that they themselves generate are assessed in each COU assessment. This section only assesses wastes of Formaldehyde that are generated during a COU and sent to a third-party site for treatment, disposal, or recycling.

2 APPROACH AND METHODOLOGY

For workplace exposures, EPA considered exposures to both workers who directly handle formaldehyde and workers designated as occupational nonusers (ONUs) who do not directly handle formaldehyde but may be exposed to vapors, particulates, or mists that enter their breathing zone while working in locations near where formaldehyde is being used. EPA evaluated inhalation exposures to both workers and ONUs and dermal exposures to workers only as ONUs are not expected to have direct contact with formaldehyde. EPA's estimates of occupational exposure presented in this document do not assume the use of PPE; however, the effect of respiratory and dermal protection factors on EPA's occupational exposure estimates can be explored in the "Draft Risk Evaluation for Formaldehyde – Supplemental Information File: Risk Calculator for Occupational Exposures." For more discussion on respiratory protection and glove protection, refer to Appendix F.

For each OES, EPA provides high-end and central tendency, full-shift (typically 8-hour) TWAs for inhalation exposure concentrations as well as high-end and central tendency acute potential dermal dose rates (APDR).

A central tendency is assumed to be representative of occupational exposures in the center of the distribution for a given OES from the observed dataset. For risk evaluation, it is EPA's preference to provide the 50th percentile (median). However, if the full distribution is not known, the Agency may assume that the mean (arithmetic or geometric), mode, or midpoint values of a distribution represents the central tendency depending on the appropriate statistics available for the distribution.

A high-end is assumed to be representative of occupational exposures that occur at probabilities above the 90th percentile but below the exposure of the individual with the highest exposure (U.S. EPA, 1992a). For risk evaluation, EPA provided high-end results at the 95th percentile of the available data. If the 95th percentile is not available, EPA used a different percentile greater than or equal to the 90th percentile but less than or equal to the 99.9th percentile, depending on the statistics available for the distribution. If the full distribution is not known and the preferred statistics are not available, EPA estimated a maximum or bounding estimate in lieu of the high-end.

For the inhalation exposure concentrations and ADPRs, EPA follows the following hierarchy in selecting data and approaches for assessing occupational exposures:

1. Monitoring data:
    a. Personal and directly applicable
    b. Area and directly applicable
    c. Personal and potentially applicable or similar
    d. Area and potentially applicable or similar
2. Modeling approaches:
    a. Surrogate monitoring data
    b. Fundamental modeling approaches
    c. Statistical regression modeling approaches
3. Occupational exposure limits:
    a. Company-specific occupational exposure limits (OELs) (for site-specific exposure assessments; *e.g.*, there is only one manufacturer who provides to EPA their internal OEL but does not provide monitoring data)
    b. OSHA PELs
    c. Voluntary limits (American Conference of Governmental Industrial Hygienists [ACGIH] Threshold Limit Values [TLV], National Institute for Occupational Safety and Health

[NIOSH] recommended exposure limits [RELs], Occupational Alliance for Risk Science (OARS) workplace environmental exposure level (WEELs; formerly by AIHA)

Generally, EPA calculated the estimated high-end and central tendency full-shift TWA inhalation exposure concentrations using discrete inhalation data. Exposure metrics for inhalation exposures include acute concentrations (AC), average daily concentrations (ADC), and lifetime average daily concentrations (LADC). AC exposures are usually characterized as lasting no longer than a day, and for the formaldehyde assessment, it is peak exposures lasting more than 15 minutes used for acute inhalation risks. The ADC is the inhalation concentration averaged over a year, which is used for chronic, noncancer inhalation risk estimates. An ADC for sub-chronic (averaged over a month) is also calculated for sub-chronic noncancer inhalation risk estimates. The LADC is the inhalation concentration averaged over a lifetime, which is used for chronic, cancer inhalation risk estimates. The approach to estimating each exposure metric is described in *Draft Human Health Risk Assessment for Formaldehyde* (U.S. EPA, 2024)

2.1 Approach and Methodology for Process Descriptions

EPA performed a literature search to find descriptions of processes involved in each OES. Where data were available to do so, EPA included the following information in each process description:

- total PV associated with the OES;
- name and location of sites the OES occurs;
- facility operating schedules (*e.g.*, year-round, 5 days/week, batch process, continuous process, multiple shifts)
- key process steps;
- physical form and weight fraction of the chemical throughout the process steps;
- information on receiving and shipping containers; and
- ultimate destination of chemical leaving the facility.

Where formaldehyde-specific process descriptions were unclear or not available, EPA referenced generic process descriptions from literature, including relevant Emission Scenario Documents (ESDs) or Generic Scenarios (GSs). Process descriptions for each OES can be found in Section 4.

2.2 Approach and Methodology for Estimating Number of Facilities

To estimate the number of facilities within each OES, EPA used a combination of bottom-up analyses of EPA reporting programs and top-down analyses of U.S. economic data and industry-specific data. Generally, EPA used the following steps to develop facility estimates:

1. Identify or "map" each facility reporting for Formaldehyde in the 2016 and 2020 CDR (U.S. EPA, 2020a, 2016), 2016 to 2021 TRI (U.S. EPA, 2022f), 2015 to 2022 Discharge Monitoring Report (DMR) (U.S. EPA, 2022c) and 2017 National Emissions Inventory (NEI) (U.S. EPA, 2022e) to an OES. The full details of the methodology for mapping facilities from EPA reporting programs is described in Appendix D. In brief, mapping consists of using facility reported industry sectors (typically reported as either North American Industry Classification System [NAICS] or Standard Industrial Classification [SIC] codes), and TRI sub-use information to assign the most likely OES to each facility.
2. Based on the reporting thresholds and requirements of each dataset, evaluate whether the data in the reporting programs is expected to cover most or all the facilities within the OES. If so, no further action was required, and EPA assessed the total number of facilities in the OES as equal to the count of facilities mapped to the OES from each dataset. If not, EPA proceeded to Step 3.

3. Supplement the available reporting data with U.S. economic and market data using the following method:
   a. Identify the NAICS codes for the industry sectors associated with the OES.
   b. Estimate total number of facilities using the U.S. Census' Statistics of US Businesses (SUSB) data on total establishments by 6-digit NAICS.
   c. Use market penetration data (*e.g.,* market share of specific product) to estimate the percentage of establishments likely to be using formaldehyde instead of other chemicals.
   d. Combine the data generated in Steps 3a through 3c to produce an estimate of the number of facilities using formaldehyde in each 6-digit NAICS code and sum across all applicable NAICS codes for the OES to arrive at a total estimate of the number of facilities within the OES. Typically, EPA assumed this estimate encompasses the facilities identified in Step 1; therefore, EPA assessed the total number of facilities for the OES as the total generated from this analysis.
4. If market penetration data required for Step 3c are not available, use generic industry data from GSs, ESDs, and other literature sources on typical throughputs/use rates, operating schedules, and the formaldehyde PV used within the OES to estimate the number of facilities. In cases where EPA identified a range of operating data in the literature for an OES, EPA used stochastic modeling to provide a range of estimates for the number of facilities within an OES. EPA provided the details of the approaches, equations, and input parameters used in stochastic modeling in the relevant OES sections throughout this report.

2.3 Identifying Worker Activities

EPA performed a literature search to identify worker activities that could potentially result in occupational exposures. Where worker activities were unclear or not available, EPA referenced relevant ESDs or GSs. Worker activities for each COU can be found in Section 4.

2.4 Estimating Number of Workers and Occupational Non-users

Where available, EPA used Chemical Data Reporting (CDR) data to provide a basis to estimate the number of workers and ONUs. The CDR Rule requires manufacturers and importers under TSCA to provide EPA with information on the production and use of chemicals in commerce. More specifically, CDR provides basic exposure-related information including the types, quantities, and uses of chemical substances produced domestically and imported into the United States. EPA supplemented the available CDR data with U.S. economic data using the following method:

1. Identify the NAICS codes for the industry sectors associated with these uses.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (BLS Data).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census' SUSB data on total employment by 6-digit NAICS.
4. Use market penetration data to estimate the percentage of employees likely to be using formaldehyde instead of other chemicals.
5. Where market penetration data are not available, use the estimated workers/ONUs per site in the 6-digit NAICS code and multiply by the number of sites estimated from TRI, DMR and/or NEI. In DMR data, sites report SIC codes rather than NAICS codes; therefore, EPA mapped each reported SIC code to a NAICS code for use in this analysis.
6. Combine the data generated in Steps 1 through 5 to produce an estimate of the number of employees using formaldehyde in each industry/occupation combination and sum these to arrive at a total estimate of the number of employees with exposure within the COU.

The number of workers and ONU for each OES is described in Appendix G. For further details on the approach and methodology used for estimating the number of workers and ONUs, refer to Appendix G.

There are uncertainties surrounding the estimated number of workers potentially exposed to formaldehyde. First, BLS employment data for each industry/occupation combination are only available at the 3-, 4-, or 5-digit NAICS level, rather than at the full 6-digit NAICS level. This lack of specificity could result in an overestimate of the number of exposed workers if some 6-digit NAICS are included in the less granular BLS estimates but are not likely to use formaldehyde for the assessed applications. EPA addressed this issue by refining the OES estimates using total employment data from the U.S. Census' SUSB. However, this approach assumes that the distribution of occupation types (Standard Occupational Classification, or SOC, codes) in each 6-digit NAICS is equal to the distribution of occupation types at the parent 5-digit NAICS level. If the distribution of workers in occupations with formaldehyde exposure differs from the overall distribution of workers in each NAICS, then this approach will result in inaccuracy. The effects of this uncertainty on the number of worker estimates are unknown, as the uncertainties may result in either over or underestimation of the estimates depending on the actual distribution.

Second, EPA's determinations of industries (represented by NAICS codes) and occupations (represented by SOC codes) that are associated with the OES assessed in this report are based on EPA's understanding of how formaldehyde is used in each industry. The designations of which industries and occupations have potential exposures is a matter of professional judgement; therefore, the possibility exists for the erroneous inclusion or exclusion of some industries or occupations. This may result in inaccuracy but would be unlikely to systematically either overestimate or underestimate the count of exposed workers.

2.5 Inhalation Exposure Approaches

2.5.1 Inhalation Monitoring Data

EPA reviewed workplace inhalation monitoring data collected by government agencies such as OSHA and NIOSH, monitoring data found in published literature (*i.e.*, personal exposure monitoring data and area monitoring data), and monitoring data submitted via public comments. Studies were evaluated using the evaluation strategies presented in the *Draft Systematic Review Protocol Supporting TSCA Risk Evaluations for Chemical Substances, Version 1.0* (U.S. EPA, 2021b).

Exposures are calculated from the monitoring datasets provided in the sources using the discrete data. For datasets with six or more data points, central tendency and high-end exposures were estimated using the 50th percentile and 95th percentile. For datasets with three to five data points, central tendency exposure was calculated using the 50th percentile and the maximum was presented as the high-end exposure estimate. For datasets with two data points, the midpoint was presented as a midpoint value and the higher of the two values was presented as a higher value. If the data for an OES contained only one data point, the report presents the single exposure value. For datasets including exposure data that were reported as below the limit of detection (LOD), EPA estimated the exposure concentrations for these data, following EPA's *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a).

That report recommends using the $\frac{LOD}{\sqrt{2}}$ if the geometric standard deviation of the data is less than 3.0 and $\frac{LOD}{2}$ if the geometric standard deviation is 3.0 or greater.

If the 8-hour TWA personal breathing zones (PBZ) monitoring samples were not available, area samples were used for exposure estimates.

For each COU, EPA endeavors to distinguish exposures for workers and ONUs. Normally, a primary difference between workers and ONUs is that workers may handle formaldehyde and have direct contact with the chemical, while ONUs are working in the general vicinity of workers but do not handle formaldehyde and do not have direct contact with formaldehyde being handled by the workers. EPA recognizes that worker job titles and activities may vary significantly from site to site; therefore, EPA typically identified samples as worker samples unless it was explicitly clear from the job title (*e.g.*, inspectors) and the description of activities in the report that the employee was not directly involved in the scenario. Samples from employees determined not to be directly involved in the scenario were designated as ONU samples.

The primary strength of the approaches is that the monitoring data is chemical-specific and directly applicable to the exposure scenario. The use of applicable monitoring data is preferable to other assessment approaches such as modeling or the use of OELs/PELs.

The principal limitation of the monitoring data is the uncertainty in the representativeness of the data due to some scenarios having limited exposure monitoring data in literature. Where few data are available, the assessed exposure levels are unlikely to be representative of worker exposure across the entire job category or industry. This may particularly be the case when monitoring data were available for only one site. Additionally, site locations may introduce uncertainty, since OSHA and NIOSH reports tend to target facilities with higher exposures. Differences in work practices and engineering controls across sites can introduce variability and limit the representativeness of monitoring data.

Age of the monitoring data can also introduce uncertainty due to differences in workplace practices and equipment used at the time the monitoring data were collected compared those currently in use. Therefore, older data may overestimate or underestimate exposures, depending on these differences. The effects of these uncertainties on the occupational exposure assessment are unknown, as the uncertainties may result in either overestimation or underestimation of exposures depending on the actual distribution of formaldehyde air concentrations and the variability of work practices among different sites.

In some scenarios where monitoring data were available, EPA did not find sufficient data to determine complete statistical distributions. Ideally, EPA will present 50th and 95th percentiles for each exposed population. In the absence of percentile data for monitoring, the mean or midpoint of the range may serve as a substitute for the 50th percentile of the actual distributions. Similarly, the highest value of a range may serve as a substitute for the 95th percentile of the actual distribution. However, these substitutes are uncertain. The effects of these substitutes on the occupational exposure assessment are unknown, as the substitutes may result in either overestimation or underestimation of exposures depending on the actual distribution.

OSHA Chemical Exposure Health Data

A key source of monitoring data is samples collected by OSHA during facility inspections. Air sampling data records from inspections are entered into the OSHA Chemical Exposure Health Data (CEHD) that can be accessed online. The database includes PBZ monitoring data, area monitoring data, bulk samples, wipe samples, and serum samples. The collected samples are used for comparing to OSHA's PELs and STELs. OSHA's CEHD website indicates that they do not (1) perform routine inspections at every business that uses toxic/hazardous chemicals, (2) completely characterize all exposures for all employees every day, or (3) always obtain a sample for an entire shift. Rather, OSHA performs targeted inspections of certain industries based on national and regional emphasis programs, often attempts to evaluate worst case chemical exposure scenarios, and develops "snapshots" of chemical exposures and assess their significance (*e.g.,* comparing measured concentrations to the regulatory limits).

EPA took the following approach to analyzing OSHA CEHD:

1. **Downloaded monitoring data for Formaldehyde from 1992 to 2022.** See Section 2.7 for evidence integration notes on targeted years.
2. **Organized data by site** (*i.e.*, grouped data collected at the same site together).
3. **Removed data in which all measurements taken at the site were recorded as "0" or below the LOD.** EPA could not be certain the chemical of interest was at the site at the time of the inspection (Note that sites where bulk samples were collected that indicate formaldehyde was present were not removed from the dataset).
4. **Removed serum samples, bulk samples, wipe samples, and blanks**. These data are not used in EPA's assessment.
5. **Assigned each data point to an OES.** EPA used a crosswalk of SIC code to NAICS code, and then established a mapping between NAICs code to OES. In some instances, EPA was unable to determine the OES from the information in the CEHD; in such cases, the Agency did not use the data in the assessment. EPA also removed data determined to be likely for non-TSCA uses or otherwise out of scope.
6. **Combined samples from the same worker.** In some instances, OSHA inspectors will collect multiple samples from the same worker on the same day (these are indicated by sample ID numbers). In these cases, EPA combined results from all samples for a particular sample ID to construct an exposure concentration based on the totality of exposures from each worker. In some cases, blank samples were non-zero, and the associated samples were not used.
7. **Calculated 8-hour TWA results from combined samples**. Where the total sample time was less than 8 hours (480 minutes), but greater than 330 minutes, EPA calculated an 8-hour TWA by assuming exposures were zero for the remainder of the shift. EPA divided the summed products of sample duration and sample result by the sum total of field sample durations when the summed duration exceeded 480 minutes. This calculates an extended-shift TWA exposure, which EPA assumes is representative of 8-hour TWA exposure. For any calculated 8-hour TWA exposures that were equal to zero or non-detects, EPA replaced this value with the LOD divided by either two or the square root of two (see step 8). EPA did consider all samples for 8-hour TWA that were marked 'eight-hour calculation used' in the OSHA CEHD database with no adjustment.
8. **Addressed less than LOD samples**. Occasionally, all of the samples associated with a single sample number measured below the LOD. Because the samples were often on different time scales (*e.g.,* 1 vs. 4 hours), EPA did not include these data in the statistical analysis to estimate values below the LOD as described previously in this section. Sample results from different time scales may vary greatly as short activities my cause a large, short-term exposure that when averaged over a full-shift are comparable to other full-shift data. Therefore, including data of different time scales in the analysis may give the appearance of highly skewed data when in fact the full-shift data is not skewed. Therefore, EPA performed the statistical analysis (as needed) using all the non-OSHA CEHD data for each OES and applied the approach determined by the analysis to the non-detects in the OSHA CEHD data. Where all the exposure data for an OES came from CEHD, EPA used only the 8-hour TWAs that did not include samples that measured below the LOD to perform the statistical analysis.

9. **Extracted 15-minute STEL Measurements.** For estimating peak exposures, EPA assumes that when OSHA inspectors measured for 15-minutes, it was for comparison to the STEL and for activities expected to be peak exposures for the worker.

OSHA CEHD does not provide job titles or worker activities associated with the samples; therefore, EPA assumed all data were collected on workers and not ONUs.

The crosswalk used for assigning OSHA CEHD data to OESs using NAICS codes is provided in C.8. An analysis on the OSHA CEHD and the underlying assumptions and impact on exposure estimates are provided in Appendix E. Specific details related to the use of monitoring data for each COU can be found in Sections 4.1.1.3 through 4.30.1.3.

2.5.2 Inhalation Exposure Modeling

As mentioned above, EPA primarily relied on monitoring data to develop exposure estimates. Where inhalation exposures are expected for an OES but monitoring data were not available, EPA attempted to utilize models to estimate inhalation exposures. Outputs from models may be the result of deterministic calculations, stochastic calculations, or a combination of both deterministic and stochastic calculations. For each OES with modeled inhalation exposures, EPA followed these steps to estimate exposures:

1. Identify worker activities/sources of exposures from process.
2. Identify or develop model equations for estimating exposures from each source.
3. Identify model input parameter values from relevant literature sources, including activity durations associated with sources of exposures.
4. If a range of input values is available for an input parameter, determine the associated distribution of input values.
5. Calculate exposure concentrations associated with each activity.
6. Calculate full-shift TWAs based on the exposure concentration and activity duration associated with each exposure source.
7. Calculate exposure metrics (AC, ADC, LADC) from full-shift TWAs.

For exposure models that utilize stochastic calculations, EPA performed a Monte Carlo simulation using the Palisade @Risk software with 100,000 iterations and the Latin Hypercube sampling method. Detailed descriptions of the model approaches used for each OES, model equations, input parameter values, and associated distributions are provided in Appendix C.

EPA addressed variability in inhalation models by identifying key model parameters to apply a statistical distribution that mathematically defines the parameter's variability. EPA defined statistical distributions for parameters using documented statistical variations where available. Where the statistical variation was unknown, assumptions were made to estimate the parameter distribution using available literature data, such as GSs and ESDs. However, there is uncertainty as to the representativeness of the parameter distributions with respect to the modeled scenario because the data are often not specific to sites that use formaldehyde. In general, the effects of these uncertainties on the exposure estimates are unknown, as the uncertainties may result in either overestimation or underestimation on exposures depending on the actual distributions of each of the model input parameters.

There is also uncertainty as to whether the model equations generate results that represent actual workplace air concentrations. Some activity-based modeling may not account for exposures from other sources. Another uncertainty is lack of consideration of engineering controls. The GS/ESDs assume that all activities occur without any engineering controls or PPE, and in an open-system environment where vapor and particulates freely escape and can be inhaled. Actual exposures may be less than estimated depending on engineering control and PPE use.

A strength of the assessment is the variation of the model input parameters as opposed to using a single static value. This parameter variation increases the likelihood of true occupational inhalation exposures falling within the range of modeled estimates. An additional strength is that all data that EPA used to inform the modeling parameter distributions have overall data quality determinations of either high or medium from EPA's systematic review process.

2.6 Dermal Exposure Approach

EPA only evaluated dermal exposures for workers, as ONUs are not expected to directly handle formaldehyde and therefore dermal exposure is not expected for these individuals. Formaldehyde dermal exposure data were not reasonably available for any of the COUs considered in this assessment. As a result, EPA modeled dermal loading using a modified version (Equation 2-1) of the EPA Dermal Exposure to Volatile Liquids Model.

Equation 2-1.

$$Dexp = \frac{S\ x\ Qu\ \times\ fabs\ \times\ Yderm\ \times\ FT}{BW}$$

Where:

D_{exp}	=	the dermal retained dose (mg/kg-day)
S	=	the surface area of contact (cm^2)
Qu	=	the quantity remaining on the skin after an exposure event (high-end: 2.1 mg/cm^2-event, central tendency 1.4 mg/cm^2-event)
Y_{derm}	=	the weight fraction of the chemical of interest in the liquid (wt %)
FT	=	the frequency of events (Default: 1 event/day)
$fabs$	=	the fraction of applied mass that is absorbed (%)
BW	=	the body weight (kg)

The standard model considers an assumed amount of liquid on skin during one contact event per day (*Qu*), an absorption factor (*abs*), surface area of the hands (*S*) and the weight fraction of formaldehyde (Y_{derm}) in the formulation to calculate a dermal dose.

As the health effect of concern for formaldehyde is the result of exposure at the point of contact, as opposed to the chemical absorbing into the skin, the absorption factor, body weight, and surface area were not necessary for the calculation of dermal exposure.

The dermal loading calculation (Equation 2-2) reduces to an assumed amount of liquid on the skin during one contact event per day adjusted by the weight fraction of formaldehyde in the liquid to which the worker is exposed.

Equation 2-2.

$$D[\mu g/cm^2] = \frac{Qu\ \times\ Yderm\ \times\ FT\ \times\ 1000}{1}$$

Where:

D	=	the dermal loading of the chemical onto the worker's skin ($\mu g/cm^2$)
Qu	=	the quantity remaining on the skin after an exposure event (routine, high-end: 2.1 mg/cm^2 -event, central tendency 1.4 mg/cm2-event)
Y_{derm}	=	the weight fraction of the chemical of interest in the liquid (wt %)

FT = the frequency of events (Default: 1 event/day)

For spray applications, EPA expects dermal exposures to be higher. In these cases, EPA calculated dermal exposures based on a higher amount of formaldehyde remaining on skin upon immersion (high end: 10.3 mg/cm^2-event, central tendency 3.8 mg/cm^2-event). Specific details of the dermal exposure assessment for each OES can be found in Section 4, and for additional discussion of the dermal model, refer to 4.30.1.5C.8.

The Dermal Exposure to Volatile Liquids Model assumes a single exposure event per day based on existing framework of the EPA/OPPT 2-Hand Dermal Exposure to Liquids Model and does not address variability in exposure duration and frequency. For this risk evaluation, effects from dermal exposure are acute effects. Additionally, dermal exposures to formaldehyde vapor that may penetrate clothing and the potential for associated direct skin contact with clothing saturated with formaldehyde vapor are not included in quantifying exposures, which could potentially result in underestimates of exposures. A strength of the assessment is that all data that EPA used to inform the modeling parameter distributions have overall data quality determinations of either high or medium from EPA's systematic review process.

2.7 Evidence Integration for Occupational Exposure

Evidence integration for the occupational exposure assessment includes analysis, synthesis and integration of information and data to produce estimates of occupational inhalation and dermal exposures. During evidence integration, EPA considered the likely location, duration, intensity, frequency, and quantity of exposures while also considering factors that increase or decrease the strength of evidence when analyzing and integrating the data. Key factors EPA considered when integrating evidence includes the following:

1. **Data Quality.** EPA only integrated data or information rated as high, medium, or low obtained during the data evaluation phase. Data is rated through the following metrics: methodology, geographic scope, applicability, temporal representativeness, sample size, and metadata completeness. For example, a source may get a high data quality rating if it has an approved methodology, data from the United States, and recently collected data. Data and information rated as *uninformative* are not used in exposure evidence integration. In general, higher rankings are given preference over lower ratings; however, lower ranked data may be used over higher ranked data when specific aspects of the data are carefully examined and compared. For example, a lower ranked data set that precisely matches the OES of interest may be used over a higher ranked study that does not as closely match the OES of interest.
2. **Data Hierarchy.** EPA used both measured and modeled data to obtain representative estimates (*e.g.*, central-tendency, high-end) of the occupational exposures resulting directly from a specific source, medium, or product. If available, measured exposure data are given preference over modeled data, with the highest preference given to data that are both chemical-specific and directly representative of the OES/exposure source.
    a. As sufficient monitoring data was identified for formaldehyde, preference was given to monitoring data sampled after the latest PEL update. The 8-hour TWA OSHA PEL was updated in 1992 to 0.75 ppm from the prior PEL of 1 ppm (1987), which was an update from the pre-1987 PEL of 3 ppm.

EPA considered both data quality and data hierarchy when determining evidence integration strategies. The final integration of occupational exposure evidence combined decisions regarding the strength of the available information, including information on plausibility and coherence across each evidence stream.

2.7.1 Weight of Scientific Evidence in Dermal Exposure Estimates

EPA had moderate weight of scientific evidence conclusions for all dermal scenarios assessed. The primary strength of the dermal assessment is that most of the data that EPA used to inform the modeling parameter distributions have overall data quality determinations of either high or medium from EPA's systematic review process, such as the 2020 CDR (U.S. EPA, 2020a). There are some limitations due to limited information on the range of formaldehyde weight concentrations for the process or product, yet overall, EPA has a moderate weight of scientific evidence.

3 SUMMARY OF OCCUPATIONAL EXPOSURE ESTIMATES

EPA's general approach for estimating inhalation exposures is explained in Section 2.5 and the specific basis for each estimate is discussed for each OES in the relevant subsection of Section 4. Exposure estimates were divided into 12-hour TWA, 8-hour TWA, short(task) based, and 15-minute peak worker samples.

Monitoring data was available to support exposure estimates for all TSCA COUs except for three TSCA COUs that relied on modeled estimates: (1) Commercial use – chemical substances in automotive and fuel products – automotive care products; lubricants and greases; fuels and related products; (2) Commercial use – chemical substances in agriculture use products – lawn and garden products; and (3) Commercial use – chemical Substances in treatment products – water treatment products.

Across COUs for peak exposures estimates, the central tendency estimates ranged from 86 to 2,002 µg/m^3(0.07 to 1.63 ppm) and high-end estimates ranged from 112 to 237,902 µg/m^3 (0.09 to 193.7 ppm). The TSCA COU of Manufacturing showed formaldehyde concentrations above other scenarios, with high-end and central tendency results of 237,902 µg/m^3 and 590 µg/m^3, respectively. The underlying scenario was based on monitoring data from manufacturing sites within the US, which included job tasks where workers wore respiratory protection.

Across COUs for full-shift estimates, the central tendency estimates ranged from 12.5 to 499.3 µg/m^3 (0.01 to 0.40 ppm) and high-end estimates ranged from 12.5 to 17,353.3 µg/m^3 (0.01 to 13.9 ppm). The TSCA COU of Commercial use – chemical substances in automotive and fuel products – automotive care products; lubricants and greases; fuels and related products showed formaldehyde concentrations above other scenarios, with high-end and central tendency results of 17,353.3 µg/m^3 and 499.3 µg/m^3, respectively. The underlying scenario was modeled using a Monte Carlo simulation, assumed that no engineering controls were present, and that formaldehyde within the automotive care product is completely evaporated during application.

EPA's general approach for estimating dermal exposures is explained in Section 2.6 and the specific basis for each OES in the relevant subsection of Section 4. All dermal retained doses are per event.

The dermal exposure estimates ranged from 0.56 to 840 µg/cm^2 for central tendency exposures and 0.84 to 3,090 µg/cm^2 for high-end exposures. The highest dermal exposure estimates (HE: 3,090 µg/m^3) were for the use of formulations containing formaldehyde for spray applications. This is based on the EPA assumption that workers dermal loading during hand spraying conditions might be similar to an immersive dermal contact.

4 OCCUPATIONAL EXPOSURE ASSESSMENT

The following sections contain process descriptions, inhalation, and dermal exposure estimates for the assessment for each COU. As previously stated, EPA provides estimates for the exposure scenario, in which a COU could have multiple occupational exposure scenarios. When there were multiple scenarios for one COU, EPA selected a "representative" scenario for risk characterizations for the COU. The Agency followed the steps below for selecting the representative scenario unless otherwise noted:

- For peak exposures, EPA selected the scenario with the highest high-end peak exposure estimate;
- For dermal exposures, EPA selected the scenario with the highest high-end dermal exposure estimate; and
- For chronic, long-term exposures, EPA selected the scenario with the highest full-shift (8 or 12 hour) central tendency exposure estimate.

4.1 Manufacturing – Domestic Manufacturing

4.1.1 Manufacturing of Formaldehyde

4.1.1.1 Process Description

Currently, most formaldehyde is manufactured using one of two methods using methanol and air as feedstocks: a silver-catalyst-based process and a metal-oxide-catalyst-based process (Kralj, 2015; Gerberich and Seaman, 2013; NICNAS, 2006; U.S. EPA, 1991b; ICFI, 1984; IARC, 1982; NIOSH, 1981a). Both processes mix preheated air with vaporized methanol, feed the gaseous mixture into a reactor, cool the reactor products, and then separate the products through absorption towers and distillation columns to recover an aqueous formaldehyde solution (Gerberich and Seaman, 2013; NICNAS, 2006; ICFI, 1984). The silver-catalyst-based process uses a feed that is rich in methanol and completely converts the oxygen while the metal-oxide-based process uses a feed that is lean in methanol and completely converts the methanol. Both processes must keep the mixture of methanol and oxygen outside of the flammable range. Approximately 70 percent of newly installed formaldehyde production capacity uses the metal oxide process (Gerberich and Seaman, 2013). Methanol arrives at the facility in tank trucks or railroad tank cars and is transferred to a large bulk storage tank, where it is then pumped to a methanol vaporizer (NICNAS, 2006; Dunn et al., 1983b; Dunn et al., 1983a; Monsanto Research Corp, 1981). The manufacture of formaldehyde is an enclosed continuous process (NICNAS, 2006).

The silver-catalyst-based process operates the reactor at approximately atmospheric pressure and a temperature of 450 to 650 °C (Gerberich and Seaman, 2013). The byproducts include carbon monoxide, carbon dioxide, methyl formate, formic acid, and hydrogen (Gerberich and Seaman, 2013; NICNAS, 2006). The separation process uses absorption, distillation, and anion exchange to produce a product of aqueous formaldehyde solution that is up to 55 weight percent (wt%) formaldehyde and less than 1.5 percent methanol. This process can achieve an overall yield of 86 to 90 percent on a methanol basis (Gerberich and Seaman, 2013).

The metal-oxide-based process uses metal oxide catalysts such as vanadium oxide and iron oxide-molybdenum oxide (Gerberich and Seaman, 2013). The reactor operates at approximately atmospheric pressure and a temperature of 300 to 400 °C. The byproducts include carbon monoxide and dimethyl ether with smaller amounts of carbon dioxide and formic acid (Gerberich and Seaman, 2013; NICNAS, 2006). The separation process uses absorption and ion exchange to produce a product of an aqueous formaldehyde solution that is up to 55 wt% formaldehyde and less than 1 percent methanol. This process can achieve an overall yield of 88 to 92 percent on a methanol basis (Gerberich and Seaman, 2013).

New production processes are in development, including the partial oxidation of methane and the dehydrogenation of methanol, but no units were commercial as of 2013 (Gerberich and Seaman, 2013).

Common formaldehyde grades include formulations of 37, 44, 50, and 56 wt% (Kralj, 2015; Gerberich and Seaman, 2013; NIOSH, 1986; Dunn et al., 1983b; Monsanto Research Corp, 1983; IARC, 1982; NIOSH, 1981a). In the 2016 CDR, all 31 facilities that reported domestically manufacturing formaldehyde in 2015 reported manufacturing formaldehyde in liquid form. Formaldehyde was reported to be manufactured at concentrations of 30 to 60 wt% by 30 facilities and at a concentration of 90 wt% or greater by one facility (U.S. EPA, 2016). The physical form and concentration of formaldehyde reported by manufacturing facilities in the 2020 CDR are summarized in the Table 4-1 and Table 4-2 below (U.S. EPA, 2020a).

Table 4-1. Physical Forms of Formaldehyde Reported in 2020 CDR

Data Source	Physical Form of Formaldehyde	Number of Facilities Reporting this Physical Form	Reported Activity (Manufacture or Import)
2020 CDR	Liquid	33	Manufacture
2020 CDR	Gas or vapor	4	Manufacture
2020 CDR	CBI	1	Manufacture

Table 4-2. Formaldehyde Concentrations Reported in 2020 CDR

Data Source	Formaldehyde Concentration (wt%)	Physical Form	Number of Facilities Reporting this Concentration	Reported Activity (Manufacture or Import)
2020 CDR	30–60%	Liquid	30	Manufacture
		CBI or left blank	2	
2020 CDR	90%	Liquid	2	Manufacture
		Gas or vapor	3	
2020 CDR	CBI	CBI	1	Manufacture
2020 CDR	Not known or reasonably ascertainable (NKRA)	NKRA	1	Manufacture

Liquid solutions of formaldehyde are unstable and can precipitate paraformaldehyde (Gerberich and Seaman, 2013). Methanol can be added as an inhibitor to minimize paraformaldehyde formation. Both low-methanol and methanol-added grades of formaldehyde solution are available for sale. Formaldehyde solutions are shipped in stainless steel or lined carbon steel storage vessels. The shipping and storage of formaldehyde must consider the shelf life of the solution, which is a function of the temperature and composition of the solution. Storage at low temperatures can minimize the formation of formic acid but increase the formation of paraformaldehyde. Manufacturers recommend minimum temperatures for storing the formaldehyde solution, which is a function of the weight percent (wt%) of both formaldehyde and methanol inhibitors. For example, the minimum temperature to store 37 wt% formaldehyde for 1 to 3 months while minimizing paraformaldehyde formation is 35 °C with less than 1 wt% methanol and 6 °C with 12 wt% methanol (Gerberich and Seaman, 2013).

4.1.1.2 Worker Activities

During manufacturing of formaldehyde, workers may be exposed to formaldehyde when transferring the finished product from the separator into storage/shipment drums and during sampling. A public comment submitted by Celanese Corporation stated the PPE required in their formaldehyde manufacturing plant included full-face respirators, fire-resistant clothing, cut resistance gloves, safety glasses/goggles, ear plugs, and non-permeable steel-toed boots. During specific tasks with potential for high formaldehyde exposure, workers were reported to use APF 50 respirators, however, this may not be representative of all manufacturing facilities (Celanese Corp, 2022). The only reported engineering control in literature is ventilation.

ONUs include employees (*e.g.*, supervisors, managers) at the manufacturing facility, where manufacturing occurs, but who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.1.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during the manufacturing of formaldehyde is listed in Table 4-3 and described in detail below. Table 4-4 summarizes the 8-hour TWA, 12-hour TWA, 15-minute and short-term monitoring data for the manufacturing of formaldehyde.

Table 4-3. Manufacturing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Formaldehyde drum filling	PBZ monitoring data	1	High	(NICNAS, 2006)
Several worker activities described including operator, project engineer, lab personnel, and industrial hygienist.	PBZ monitoring data	45	High	(Celanese Corp, 2022)
Unknown	PBZ monitoring data	12	Medium	(OSHA, 2019)
Field process operator	PBZ monitoring data	13	High	(Analytics Corporation, 2020a, b, 2019a, b, 2018a, b, 2017b, 2016a, b)
Unknown	PBZ monitoring data	4	High	(Analytics Corporation, 2021)
Environmental health and safety, quality control/quality assurance, logistics, maintenance, and operators.	PBZ monitoring data	4,401	High	(Stantec ChemRisk, 2023)

For the 15-minute data, 12 of the 15 of the worker samples were from OSHA CEHD and 3 of the samples were from (Celanese Corp, 2022). EPA reviewed OSHA CEHD database for current and past manufacturers of formaldehyde using facility information available in 2016 and 2020 CDR (U.S. EPA, 2020a, 2016) and a previous EPA publication (U.S. EPA, 1991b). The data used is 15-minute sampling data from two former formaldehyde manufacturers sampled in 1992. EPA also integrated recent data from a study that measured three operators for specific tasks where the workers were equipped with APF 50 respirators (Celanese Corp, 2022).

For the 8-hour TWA data, 3,975 of the worker samples and 426 of the ONU samples were from a public comment submitted by the American Chemistry Council (ACC) (Stantec ChemRisk, 2023). This data was collected by the ACC from 17 major U.S. formaldehyde manufacturing facilities and were measured between 2012 and 2020. The study indicates that manufacturing data includes sites that solely manufacture formaldehyde and sites that both manufacture formaldehyde and process formaldehyde as a reactant. These manufacturing facilities included Celanese Corporation; therefore, EPA did not integrate 8-hour TWA sampling data from Celanese Corporation (Celanese Corp, 2022) for the 8-hour TWA estimates for manufacturing. However, EPA used the 12-hour TWA measurements included in the study to inform the 12-hour TWA estimates. In addition, seventeen sampling data points measured between 2016 to 2021 from Perstorp Polyols' formaldehyde department were also integrated.

For the 8-hour TWA data, it should be noted that 24 percent of the worker samples and 41 percent of the ONU samples measured below the LOD. Additionally, only one short-term worker sample was available. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 15-minute, short-term, 8-hour and 12-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-4**.**

Table 4-4. Summary of Inhalation Exposure Monitoring Data for Manufacturing OES

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hour TWA	0.05	0.25	3,998	0.03	0.14	426	Medium to High
12-hour TWA	0.02	0.06	20	0.01	0.02	22	High
15-minute TWA	0.48	193.70	15	EPA did not identify 15-minute data for ONUs			Medium to High
Short-term TWA	0.50		1	EPA did not identify short-term data for ONUs			Medium to High

EPA identified additional studies with personal breathing zone monitoring data for the manufacturing of formaldehyde that did not provide discrete data that could be integrated into the inhalation estimates. Therefore, the data were not included in the exposure estimates listed above. Overall, these monitoring data were all conducted in sites in other countries but reported similar concentrations during manufacturing of formaldehyde. In the 2006 formaldehyde NICNAS report, monitoring data from two Australian sites ranged from 0.1 to 0.3 ppm for operators, maintenance workers, chemists, and loading staff monitored at their manufacturing sites. The formaldehyde operators had 12-hour shifts while other job categories ranged from 8 to 12-hour shifts. ECHA (2019) collected monitoring data from an unknown number of formaldehyde manufacturers within the EU, the 90th percentile of the long-term monitoring data was 0.18 ppm (0.23 mg/m^3; n = 94) and short-term monitoring data was 0.24 ppm (0.30 mg/m; n = 39). OECD (2002) measured worker exposures at German manufacturing sites in the 1990s, which was approximately between 0.016 to 0.30 ppm (0.02 to 0.37 mg/m^3).

4.1.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for inhalation exposure estimates. Exposure to workers at formaldehyde manufacturing sites is assessed using formaldehyde personal breathing zone monitoring data collected at workplaces directly applicable to this OES. The data were determined to have quality ratings ranging from medium to high, through EPA's systematic review process. Specifically, the data were determined to be recent and representative in geography. Additionally, there was many 8-hour TWA worker samples. Another strength of the 8-hour TWA estimates is that it incorporates monitoring data from 16 of the 38 current manufacturers. Most of the sources provide metadata including sample type and sample duration but lacked worker activities and process information. One of the major sources used, however, lacked additional meta-data on worker activities and the sites were not specified or differentiated. This leads to some uncertainty on how these measurements vary from site to site and between worker tasks, and on the relative contributions per site. Based on these strengths, EPA has concluded that the weight of scientific evidence for this assessment is moderate to robust for the full-shift estimates and provides a plausible estimate of exposures. For 15-minute data, EPA determined that the weight of scientific evidence conclusion is moderate.

4.1.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 60 percent, based on a range of 30 to 60 percent maximum concentration reported by 30 manufacturers (U.S. EPA, 2020a). Two manufacturers reported a maximum of 90 percent as a liquid, which EPA expects would need to be kept at high temperatures to prevent polymerization. EPA expects workers are more likely to have the potential for dermal contact with formaldehyde formulations below 60 percent. The calculated occupational dermal exposures for this OES are 840 $\mu g/cm^2$ as the central tendency value and 1,260 $\mu g/cm^2$ as the high-end value.

4.2 Manufacturing – Importing

4.2.1 Import and/or Repackaging of Formaldehyde

4.2.1.1 Process Description

Import

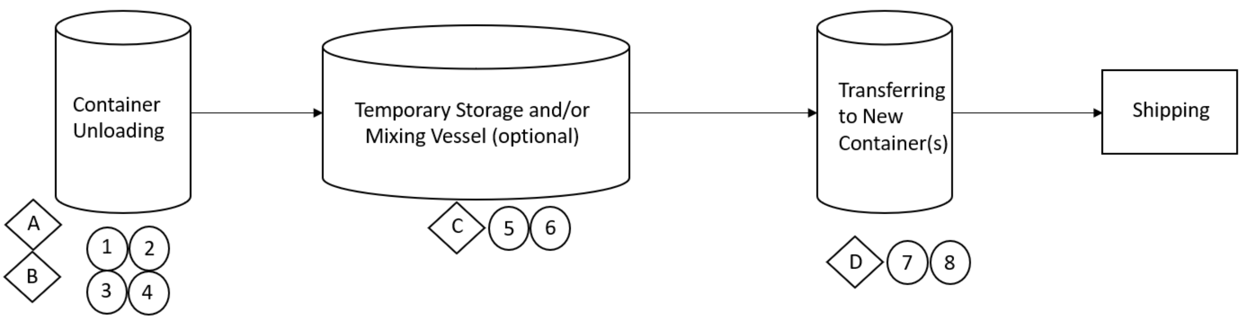
Commodity chemicals such as formaldehyde may be imported into the United States in bulk via water, air, land, and intermodal shipments (Tomer and Kane, 2015). These shipments take the form of oceangoing chemical tankers, railcars, tank trucks, and intermodal tank containers. Chemicals shipped in bulk containers may be repackaged into smaller containers for resale, such as drums or bottles. Domestically manufactured commodity chemicals may be shipped within the United States in liquid cargo barges, railcars, tank trucks, tank containers, intermediate bulk containers (IBCs)/totes, and drums. Both imported and domestically manufactured commodity chemicals may be repackaged by wholesalers for resale, such as repackaging bulk packaging into drums or bottles. The type and size of the container will vary depending on customer requirements. In some cases, quality control samples may be taken at import and repackaging sites for analyses. Some import facilities may only serve as storage and distribution locations, and repackaging/sampling may not occur at all import facilities (Tomer and Kane, 2015).

In the 2016 CDR, four facilities reported importing formaldehyde into the U.S.; one reported importing formaldehyde in a liquid formulation at a concentration of 30 to 60 weight percent (wt%), one reported formaldehyde in a liquid formulation at a concentration of 1 to 30 wt%, one reported it in a liquid formulation at a concentration of less than 1 wt%, and the last one reported it as a solid or liquid at a concentration of 1 to 30 wt% (U.S. EPA, 2016). In the 2020 CDR, five facilities reported importing formaldehyde in 2019, two reported importing formaldehyde as a liquid at a concentration of 30 to 60 wt%, two reported it as a liquid at a concentration of 1 to 30 wt%, and the last one reported it as a liquid at a concentration of less than 1 wt% (U.S. EPA, 2020a). The concentration of formaldehyde in an aqueous solution (formalin) is 37 percent, and it is assumed that repackaging facilities will target this concentration for their final product (Mirabelli et al., 2011).

The container sizes are not included in CDR. According to NICNAS, in Australia, formalin (16 to 40% formaldehyde) is imported in different-sized packages, such as 220 kg drums, 20 L drums, 22 kg carboys, 2.5 L bottles, 500 mL bottles, and 10 mL ampoules (NICNAS, 2006). Imported formalin is transported in pallets in full container loads or on trucks (NICNAS, 2006).

Most repackaging of formalin or product containing formaldehyde is from 200 L drums to smaller containers, such as 5 L and 20 L containers (NICNAS, 2006). They are decanted into smaller containers either through a pump (enclosed process) or fed via gravity. Repackaging is usually not a continuous operation and the duration and frequency of the operation vary from site to site (NICNAS, 2006). Based on data referenced in Chemical Repackaging - Generic Scenario, chemicals were repackaged at rates ranging from 1 to 315,479 kg/site-yr, with the 50th percentile at 7,000 kg/site-yr and 95th percentile at 42,000 kg/site-yr (U.S. EPA, 2022a). Formalin is also repacked from large storage tanks. The material is pumped into storage tanks and transferred into various size containers using a pump and an enclosed tubing system (NICNAS, 2006).

Figure 4-1 presents a generic flowchart for chemical repackaging scenarios and shows the different exposure and release points in the process. Repackaging operations for liquid chemicals typically involve pumping or pouring the product in between the original larger container into a new smaller container (U.S. EPA, 2022a). Chemicals typically are received at repackaging sites in larger bulk containers or drums (U.S. EPA, 2022a). Exposures and releases are expected to occur at facilities that repackage domestically manufactured formaldehyde, as well as facilities that repackage and import formaldehyde. Exposures and releases during repackaging are not expected to occur at facilities that import but do not repackage formaldehyde.



Occupational Exposures:

A. Inhalation exposures to formaldehyde and dermal exposure to solids and liquids from unloading import/transport containers.
B. Inhalation exposures to formaldehyde and dermal exposure to solids and liquids from transport container cleaning.
C. Inhalation exposures to formaldehyde and dermal exposure to solids and liquids from equipment cleaning.
D. Inhalation exposures to formaldehyde and dermal exposure to solids and liquids from loading transport containers.

Figure 4-1. Typical Release and Exposure Points During Chemical Repackaging (U.S. EPA, 2022a)

4.2.1.2 Worker Activities

During repackaging, workers are potentially exposed to formaldehyde, liquids, and during loading and unloading of import/transport containers. Workers may also be exposed via inhalation or dermal pathways during container and equipment cleaning. EPA did not find information that indicates the extent of engineering controls and use of PPE by workers at facilities that repackage formaldehyde from import/transport drums into smaller containers.

ONUs include employees (*e.g.*, supervisors, managers) at the repackaging site who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.2.1.3 Inhalation Exposure Estimates

The information and data quality evaluation to assess occupational exposures during repackaging is listed in Table 4-5 and described in detail below. Table 4-6 summarizes the 8-hour TWA monitoring data for the repackaging of formaldehyde and formaldehyde products.

Table 4-5. Repackaging Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Repackaging of imported beads containing formaldehyde	PBZ monitoring data	6	High	(Manuel Rodriguez and Aristeguieta, 2009)
Unknown	PBZ monitoring data	20	Medium	(OSHA, 2019)

EPA identified two sources with monitoring data applicable to this OES: OSHA CEHD for two sites under the other chemical and allied product merchant wholesalers sector and (Manuel Rodriguez and Aristeguieta, 2009). Rodriguez (2009) monitored formaldehyde exposures during the repackaging of reflective glass beads. The source of formaldehyde was unspecified within the report. For further discussion of OSHA CEHD data, refer to Section 2.5.1. EPA pulled 15-minute data from OSHA CEHD for the same industrial sector as the 8-hour TWA data.

Data were not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate 8-hour TWA exposures for ONUs.

For the 8-hour TWA data, it should be noted that 6 percent of the samples measured below the LOD. Additionally, it should be noted that four of the samples had a concentration between the minimum detectable (0.0019 ppm) and minimum quantifiable concentration (0.0055 ppm), leading to higher uncertainty. For the 15-minute data, 73 percent of the 15-minute monitoring at the wholesale facilities were below the LOD. To estimate exposure concentrations for this data, EPA followed *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a) as discussed in Section 2.5.1.

The high-end and central tendency values for the 15-minute and 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized below in Table 4-6.

Table 4-6. Summary of Inhalation Exposure Monitoring Data for Repackaging

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.07	0.14	15	0.07	0	Medium to High
15-minute TWA	0.07	9.34	11	EPA did not identify 15-minute data for ONUs.		Medium
Short-term TWA	EPA did not identify short-term data for workers or ONUs.					N/A

4.2.1.1 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which were determined to have confidence ratings ranging from medium to high, through EPA's systematic review process. The primary limitation is that several of the samples were between the minimum detectable and minimum quantifiable concentration, which leads to more uncertainty. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. Rodriguez (2009) provides worker activities but does not specify the source of formaldehyde, resulting in uncertainty on whether the source of formaldehyde fits the expected source for this OES. For 15-minute data, an additional limitation is that 73 percent of the data points were below the detection limit. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight to moderate for the peak and full-shift estimates but provides a plausible estimate of exposures.

4.2.1.2 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 60 percent based on a range of 30 to 60 percent for processing-repackaging in the 2020 CDR (U.S. EPA, 2020a). The calculated occupational dermal exposures for this OES are 840 µg/cm^2 as the central tendency value and 1,260 µg/cm^2 as the high-end value.

4.3 Processing – Reactant – [All Functions] in [All Industries]

One exposure scenario (Processing as a reactant) is used for the following group of COUs:

- Adhesives and sealant chemicals in: plastic and resin manufacturing; Wood product manufacturing; Paint and coating manufacturing; All other basic organic chemical manufacturing;
- Intermediate in: pesticide, fertilizer, and other agricultural chemical manufacturing; Petrochemical manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; All other basic organic chemical manufacturing; Plastic materials and resin manufacturing; Adhesive manufacturing; All other chemical product and preparation manufacturing; Paper manufacturing; Paint and coating manufacturing; Plastic products manufacturing; Wood product manufacturing; Construction; Agriculture, forestry, fishing, and hunting;
- Functional fluid in: oil and gas drilling, extraction, and support activities;

- Processing aids, specific to petroleum production in all other basic chemical manufacturing;
- Bleaching agent in wood product manufacturing; and
- Agricultural chemicals in agriculture, forestry, fishing, and hunting.

4.3.1 Processing as a Reactant

4.3.1.1 Process Description

Processing as a reactant or intermediate is the use of formaldehyde as a feedstock in the production of another chemical product via a chemical reaction in which formaldehyde is consumed to form the product. In the 2020 CDR, 40 submitters reported the use of formaldehyde for processing as a reactant (U.S. EPA, 2020a). The CDR indicates that formaldehyde is processed as a reactant in the following industrial sectors: plastics product manufacturing; wood product manufacturing; paper manufacturing; plastics material and resin manufacturing; all other basic organic chemical manufacturing; agriculture, forestry, hunting, and fishing; paint and coating manufacturing; construction; adhesive manufacturing; petrochemical manufacturing; and synthetic rubber manufacturing (U.S. EPA, 2020a). Within these industrial sectors, formaldehyde is listed under the industrial function categories of intermediate, monomer, plasticizer, adhesion/cohesion promoter, and "other" (used as a reactant with urea, used as a reactant with phenol and cresols, antibacterial skin lotion, and not reasonably known or ascertainable).

Formaldehyde is used during the manufacturing of urea (U.S. EPA, 1995b). This process consists of seven major unit operations as shown in Figure 4-2 (U.S. EPA, 1995b). Formaldehyde is injected into the urea product during the coating process and reacts to form methylenediurea, which is a conditioning agent (U.S. EPA, 1995b). Urea is primarily an agricultural product used in fertilizer mixtures and animal feed supplements (U.S. EPA, 1995b).

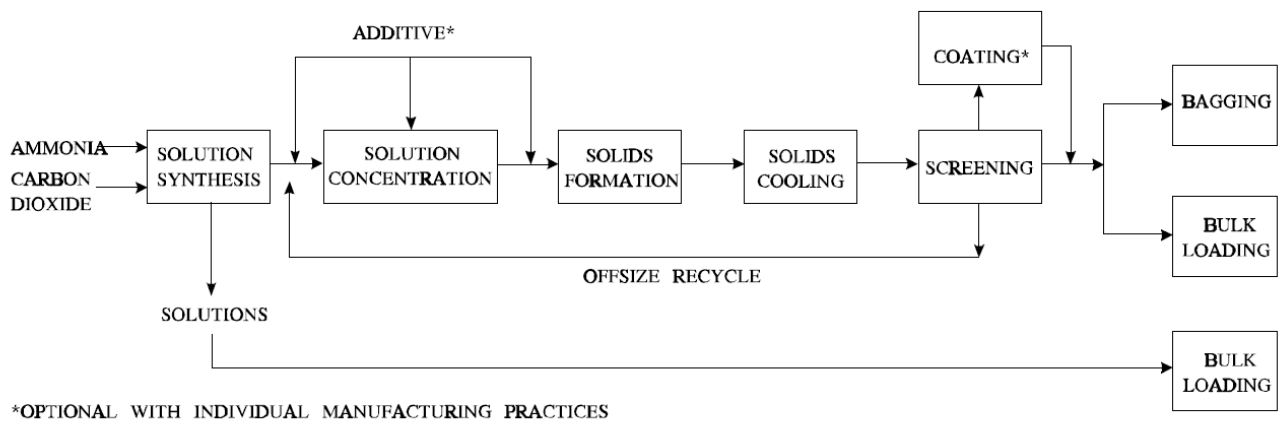


Figure 4-2. Process Flow Diagram for the Manufacturing of Urea (U.S. EPA, 1995b)

In 1991, over 60 percent of formaldehyde in the United States that was processed as a reactant was used to create a form of resin (U.S. EPA, 1991b). In the manufacturing of resins from formaldehyde, formaldehyde arrives at the site in the form of formalin, a solution that typically consists of 37 to 40 percent formaldehyde (NIOSH, 1981d). The processing typically begins with the input components being charged into the reactor at concentrations and temperatures necessary to meet customer specifications (NIOSH, 1981d; Roper, 1976). The list of inputs will vary depending on the desired resin; as an example, raw materials for phenol formaldehyde resins may include formalin, phenol, sodium hydroxide, concentrated sulfuric acid, hexamethylenetetramine (HMT), ethanol, methanol, and xylene (NIOSH, 1981d). Resin production is typically conducted in a batchwise process with a single batch usually taking 8 to 12 hours to produce—although in some cases the batch may take anywhere from 5 to 30 hours to produce (NICNAS, 2006). The reaction mechanism to form the resin differs depending on the type of resin being made (U.S. EPA, 1991b). Acetal resin, also known as polyoxymethylene, is the general name for homopolymers of formaldehyde (Garbassi and Po, 2001).

Example Reaction Products

- Urea-formaldehyde resins
- Phenol-formaldehyde resins
- Acetal resins
- Melamine-formaldehyde resins
- Chelating agents
- Trimethylol propane
- Acrylic esters
- Hexamethylenetetramine
- Pentaerythritol
- 1,4-butanediol
- Other acetylenic chemicals
- Urea-formaldehyde concentrates
- 4,4-methylenedianiline
- Pyridine compounds, and nitroparaffins

EPA does not know the specific starting concentration of formaldehyde for each process under processing as a reactant, but it is expected to vary between different desired reaction products. The Agency did not identify specific information about containers used for processing formaldehyde as a reactant; however, EPA expects formaldehyde to arrive as a liquid in tank trucks, drums, or rail cars received directly from manufacturing sites.

4.3.1.2 Worker Activities

When processing formaldehyde as a reactant, workers are potentially exposed to formaldehyde during unloading of raw materials, the drumming of finished products, and changing of ventilation filters (Dow Chemical, 2017c). Some expected PPE and engineering controls in a facility processing formaldehyde as a reactant include ventilation and respirators (Dow Chemical, 2017c). One study reported that workers wore Ansell II gloves, safety glasses and a face shield while unloading formalin (AECOM, 2019).

ONUs include employees (*e.g.*, supervisors, managers) at the processing as a reactant site who do not directly handle formaldehyde. Therefore, ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.3.1.3 Inhalation Exposure Estimates

The information and data quality evaluation to assess occupational exposures during processing as a reactant is listed in Table 4-7 and described in detail below. Table 4-8 summarizes the 8-hour TWA, 12-hour TWA, 15-minute, and short-term monitoring data for the processing of formaldehyde as a reactant.

EPA integrated a total of 232 peak and full-shift samples from industry submitted information at U.S. facilities from 2012 to 2020, as indicated in Table 4-7. An integrated dataset of existing monitoring data were provided for two facilities indicated to be processing formaldehyde as a reactant (Stantec ChemRisk, 2023). The study provided 51 worker and 41 ONU full-shift samples (Stantec ChemRisk, 2023). The dataset also included monitoring data for sites that both manufacture and process formaldehyde as a reactant, those data was incorporated into the Manufacturing of Formaldehyde OES. From one manufacturer, EPA received data specific to the workers and associated activities during processing as a reactant, which were then integrated into this OES. This study included 50 sampling measurements including 8- and 12-hour TWA measurements for workers (Celanese Corp, 2022). That dataset included measurement of a range of job categories involved in formaldehyde processing.

EPA integrated 158 samples from the OSHA CEHD database. These sites were attributed to the OES from the provided NAICS codes. The NAICS codes used most for this OES were Plastic Material and Resin Manufacturing, Adhesive Manufacturing, Petrochemical Manufacturing, and All Other Miscellaneous Chemical Product and Preparation Manufacturing. The full crosswalk of NAICS to OES used for integration of OSHA CEHD data is provided in Appendix D.

EPA integrated two full-shift samples from a study completed at a formaldehyde resin production factory in Portugal. Viegas (2013) monitored worker exposure for 6 to 7 hours during impregnation and quality control activities. Based on the information in the study, EPA assumes the data is representative of full-shift exposures. All of the monitored data were below the detection limit.

Table 4-7. Processing as a Reactant Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source(s)
Various activities during resin manufacturing including tanker unloading, kettle operator, plant operators, and laboratory staff	PBZ monitoring data	7	High	(NICNAS, 2006)
Various activities during resin manufacturing such as operator of impregnation machine and resin sample analysis	PBZ monitoring data	2	High	(Viegas et al., 2013)
Various activities such as operator, lab operator, and control room board operator	PBZ monitoring data	50	High	(Celanese Corp, 2022)
Drumming finished products and changing filters, pulling process samples, unknown worker activities during resin manufacturing	PBZ monitoring data	25	Medium to High	(Dow Chemical, 2019a, b, c, 2017a, c, d)
Operator, assistant operator, power house operator, mechanic, insulator and E/I technician	PBZ monitoring data	57	High	(Analytics Corporation, 2020a, b, 2019a, b, 2018a, b, 2017b, 2016a, b)
Operator during blending operators	PBZ monitoring data	5	High	(FRM Risk, 2019)
Exchanging drums of formalin, Lab technician	PBZ monitoring data	3	High	(AECOM, 2019)
Environmental health and safety, quality control/quality assurance, logistics, maintenance, and operators	PBZ monitoring data	92	High	(Stantec ChemRisk, 2023)
Unknown	PBZ monitoring data	158	Medium	(OSHA, 2019)

Dow Chemical provided workplace monitoring data from 2016 to 2019, mostly short-term and 15-minute samples as workers change filters, took samples, and loaded finished products (Dow Chemical, 2019a, b, c, 2017a, c, d). EPA also integrated 57 samples expected to be taken during reactant processes at Perstrop polyols (Analytics Corporation, 2020a, b, 2019a, b, 2018a, b, 2017b, 2016a, b).

Data was obtained from two industrial hygiene studies from two U.S. facilities (AECOM, 2019; FRM Risk, 2019). FRM Risk (2019) monitored one blend operator while handling supersacks of paraformaldehyde, a reaction product of formaldehyde. Three 15-minute samples were monitored during blending operations at the same site. For this site, the workers wore full facepiece air purifying respirator (APF 50) during the monitored 15-minute activities. AECOM (2019) measured one 15-minute sample for a worker unloading a drum of formalin and one 15-minute and a 98-minute sample for a lab technician conducting quality control tests. EPA assumes that the activities measured for these studies would be representative of the expected activities to occur at sites that process formaldehydye as a reactant.

Data were not available to estimate 12-hour TWA ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

For the 8-hour TWA data, it should be noted that 9 percent of the worker samples and 56 percent of the ONU samples measured below the LOD. For the 15-minute worker data, 36 percent of the samples were below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 15-minute, short-term, 8-hour, and 12-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-8.

Table 4-8. Summary of Inhalation Exposure Monitoring Data for Processing as a Reactant

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hour TWA Exposure Concentration	0.05	0.81	192	0.01	0.03	41	Medium to High
12-hour TWA Exposure Concentration	0.03	0.15	34	0.03		0	High
15-minute TWA Exposure Concentration	0.15	3.1	96	EPA did not identify 15-minute data for ONUs.			Medium to High
Short-term TWA Exposure Concentration	0.06	2.9	19	EPA did not identify short-term data for ONUs			High

EPA identified additional studies with personal breathing zone monitoring data for the processing of formaldehyde as a reactant that lacked the discrete data that could be incorporated into the inhalation estimates. These data were not included in the exposure estimates listed above. In the 2006 formaldehyde NICNAS report, monitoring data from an Australian resin manufacturing site ranged from 0.1 to 2.0 ppm for various worker activities such as resin operators, laboratory staff, tanker unloading, and maintenance workers. The resin operators and chemists had 12-hour shifts while other job categories ranged from 8- to 12- hour shifts. Plant operators, technical personnel, and maintenance workers also had short-term monitoring data (NICNAS, 2006). ECHA (2019) collected monitoring data from an unknown number of sites involved in resin manufacturing within the EU, the 90th percentile of the long-term monitoring data was 0.37 mg/m^3 (n = 116) and short-term monitoring data was 0.64 mg/m^3 (n = 17).

Four other studies monitored facilities outside the United States at sites that produce formaldehyde-melamine resins, the data ranged from 0.033 to 5.6 ppm for full-shift worker exposures (Zendehdel et al., 2017; Bassig et al., 2016; Seow et al., 2015; Zhang et al., 2010). Three of the facilities were in China and one was in Iran. Armstrong (2001) measured worker exposures to formaldehyde at an adhesive manufacturing facility in Malaysia, the arithmetic mean was 0.43 ppm.

4.3.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for inhalation exposure estimates. Exposure to workers at formaldehyde processing sites is assessed using formaldehyde PBZ monitoring data collected at workplaces directly applicable to this OES. The data were determined to have confidence ratings ranging from medium to high, through EPA's systematic review process. Specifically, the data were determined to be highly reliable and representative in geography. Additionally, there was a large number of worker samples. Most of the sources provide metadata including sample type and sample duration but lack additional information on worker activities. There is some uncertainty in the 8-hour TWA ONU estimates because 56 percent of the samples were below the LOD. Based on these strengths and limitations, EPA concluded that the weight of scientific evidence for this assessment is moderate to robust for both 15-minute and 8-hour and provides a plausible estimate of exposures.

4.3.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration identified for this OES was 60 percent based a maximum range of 30 to 60 percent reported for processing as a reactant in the 2020 CDR (U.S. EPA, 2020a). The calculated occupational dermal exposures for this OES are 840 µg/cm^2 as the central tendency value and 1,260 µg/cm^2 as the high-end value.

4.4 Processing – Incorporation into an Article – Finishing Agents in Textile, Apparel, and Leather Manufacturing

EPA has evaluated two exposure scenarios for this COU:

- Textile finishing, and
- Leather tanning.

Note, although, leather tanning has a higher central tendency estimate, the representative scenario for this COU was textile finishing. Full shift estimates for leather tanning OES rely on a limited amount (n = 2) of monitoring data from 1988.

4.4.1 Textile Finishing

4.4.1.1 Process Description

One of the formaldehyde's uses under incorporation is as a finishing agent in textile processing (U.S. EPA, 2020b; NICNAS, 2006). Formaldehyde can be either used alone, together with other reagents such as softeners or wetting agents, or in the form of simple formaldehyde derivatives (NIOSH, 1981c; Hovding, 1959). Resins containing formaldehyde are used as cross-linking agents and can impart beneficial characteristics upon fabric such as wear and crease resistance, water repellency, increased fabric resistance, and aiding in dye fixation (NICNAS, 2006; Cornwell, 1988; NIOSH, 1984a, 1981c). This COU was not reported in the 2020 CDR; however, information from the 2016 CDR indicates that formaldehyde is used as a finishing agent in textiles, apparel, and leather manufacturing (U.S. EPA, 2016). Formaldehyde content in raw materials is typically 37 percent, while end products generally range from 0.01 to 2 percent (Rovira and Domingo, 2019; Patankar et al., 2015; Greeson et al., 2012; NICNAS, 2006; Bajaj, 2002; Scheyer et al., 2001; Hovding, 1961).

Textile finishing can be divided into three main steps: fabric pretreatment (*e.g.*, washing, bleaching, de-sizing, etc.); coloring; and functional finishing (OECD, 2004a; Bendix Corp, 1979). Formaldehyde is only included in the functional finishing. During the finishing process, resins containing formaldehyde are combined with catalysts and cured in ovens at high temperatures to form the "permanent-press" treatment of fabrics. "Several varieties of resins and catalysts are used in the textiles industry. Their application depends to a large extent on the effects desired in the finished product" (NIOSH, 1974b).

Such treated fabrics may be cut, bundled, then sewn to assemble a garment at the same site or sold to downstream users for these processes (Burton and Monestersky, 1996; Echt, 1993).

4.4.1.2 Worker Activities

For finishing processes, workers are potentially exposed to formaldehyde in textile finishing agents during unloading and transferring product, transport container cleaning, and machine operation (OECD, 2017). Workers may connect transfer lines or manually unload chemicals from transport containers into finishing equipment or storage. Dermal exposure is expected for both automated and manual unloading activities. Workers may experience inhalation and dermal exposure to formaldehyde while rinsing containers used to transport finishing agents. Workers may also be exposed to formaldehyde present in the curing oven during removal of treated goods after batch processes or during handling of finished rolls of material. All of these activities are all potential sources of worker exposure through dermal contact and inhalation of formaldehyde present in liquid finishing agents (OECD, 2017).

For the final steps of the process, workers may be exposed from formaldehyde off-gassing from the pre-cured permanent press fabrics (Echt, 1993). These include exposures during sewing, cutting, or assembling garments. According to the ESD on the Use of Textile Dyes, workers at sites that use textile finishing agents may wear proper chemical-specific PPE, including safety glasses, goggles, aprons, respirators, and/or masks (OECD, 2017). One apparel manufacturer installed roof-top ventilators (Echt, 1993). EPA did not find information that indicates the extent of engineering controls and the use of PPE by the workers at facilities that use textiles finishing agents in the United States.

ONUs include employees who work at the sites where textile finishing agents are used, but who do not directly handle chemicals and are, therefore, expected to have lower inhalation exposures and are not expected to have dermal exposures through contact with liquids or solids. ONUs for this scenario include supervisors, managers, and other employees who may be in the finishing area but do not perform tasks that result in the same level of exposure as those workers who engage in tasks related to the use of textile finishing agents.

4.4.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during textile finishing is listed in Table 4-9 and described in detail below. Table 4-10 summarizes the 8- and 12-hour TWA monitoring data for the use of formaldehyde in textile finishing. Short-term and 15-minute data were not available to estimate worker exposures.

Table 4-9. Textile Finishing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Sewer, cutter, and bundler during sportswear manufacturing	PBZ monitoring data	8	High	(Echt, 1993)
Sewer, bundler, inspector, cutter, and supervisor at a knitting mill	PBZ monitoring data	14	High	(Burton and Monestersky, 1996)[a]
Unknown	PBZ monitoring data	200	Medium	(OSHA, 2019)

[a] All samples were below the limit of quantification but above the LOD.

A majority of the 8-hour TWA worker samples were from OSHA's CEHD in the textile and fabric mills and textile product mills sectors. For further discussion of OSHA CEHD data, refer to Section 2.5.1. All other 8-hour TWA samples came from two NIOSH HHEs investigating exposure to formaldehyde at a sportswear manufacturing facility and a knitting mill (Burton and Monestersky, 1996; Echt, 1993). The dataset included measurement of a range of workers involved in garment manufacturing.

Data were not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures because ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA used worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

It should be noted that 11 percent of the 8-hour TWA samples measured below the LOD and 69 percent of the 15-minute samples were below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1. All of the samples for the 12-hour data were between the minimum detectable concentration and minimum quantifiable concentration, these values were not adjusted.

The high-end and central tendency values for the 8- and 12-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-10.

Table 4-10. Summary of Inhalation Exposure Monitoring Data for Textile Finishing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm			
8-hour TWA	0.06	0.41	141	0.1	Medium to High
12-hour TWA	0.04	0.04	2	0.04	High
15-minute TWA	0.1	0.9	80	EPA did not identify 15-minute data for ONUs	N/A
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs	N/A

A public comment provided discrete monitoring data at U.S. sites for processing-incorporation into article (Stantec ChemRisk, 2023). EPA did not integrate the data as no additional process or worker activity information was provided to attribute to individual occupational exposure scenarios (*e.g.*, type of produced article). The reported 50th percentile and 95th percentile full-shift exposures were 0.08 and 0.313 ppm, respectively. These estimates generally fit within the range estimated for this exposure scenario.

4.4.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. Exposure to workers at textile finishing sites is assessed using formaldehyde personal breathing zone monitoring data collected at workplaces directly applicable to this OES. The data were determined to have confidence ratings of medium to high through EPA's systematic review process. Specifically, the data were determined to be highly reliable, representative in geography, and integrated a large number of monitoring data. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. Of note, more than half of the 15-minute samples were below the LOD. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate to robust for 8-hour TWA estimates and moderate for 15-minute exposure estimates, but still provides a plausible estimate of exposures.

4.4.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The COU for textile finishing OES was not reported in 2020 CDR, but was reported in 2016 CDR. The maximum concentration identified for processing-incorporation into an article- textiles, apparel, and leather manufacturing was 1 to 30 percent (U.S. EPA, 2020a). However, formaldehyde content in raw materials is typically 37 percent for textile processing, while end products generally range from 0.01 to 2 percent (Rovira and Domingo, 2019; Patankar et al., 2015; Greeson et al., 2012; NICNAS, 2006; Bajaj, 2002; Scheyer et al., 2001; Hovding, 1961). The weight concentration of 37 percent was used. The calculated occupational dermal exposures for this OES are 518 μg/cm^2 as the central tendency value and 777 μg/cm^2 as the high-end value.

4.4.2 Leather Tanning

COU: Processing – incorporation into an article – finishing agents in textiles, apparel, and leather manufacturing

4.4.2.1 Process Description

Formaldehyde has been identified as a preservative, finishing agent, and fixing agent in leather tanning (U.S. EPA, 2020b; Cuadros et al., 2016; NICNAS, 2006; U.S. EPA, 2001). Tanning is a general term for the processing steps involved in converting animal hides or skins to leather (OECD, 2004a). This COU was not reported in the 2020 CDR; however, information from the 2016 CDR indicates that formaldehyde is used as a finishing agent in textiles, apparel, and leather manufacturing (U.S. EPA, 2016). Formalin containing 10 to 37 percent formaldehyde is used in leather tanning; however, the formalin is diluted into a 1:10 working solution before use (NICNAS, 2006). Formaldehyde concentrations in the final leather articles are typically less than 1 percent (NICNAS, 2006). One source indicates that the concentrations of formaldehyde in leather articles range between 4.5 to 414 mg formaldehyde per kg leather (Cuadros et al., 2016).

According to the ESD on Leather Processing, hide and skins that are flayed at abattoirs may be cured, chilled, or cooled before transferring to tanning facilities (OECD, 2004a). The types of hides most often used in tanning processes are from cattle, sheep, and pigs. At tanning facilities, the production process typically begins with hide and skin storage and beamhouse operations, which prepare the raw material for tanning. Preparation may involve trimming, soaking, unhairing, liming, and fleshing (OECD, 2004a; U.S. EPA, 2001).

The most common tanning processes are chromium tanning or vegetable tanning (OECD, 2004a; U.S. EPA, 2001). Chromium tanning typically utilizes a one-bath process which takes place in large rotating vessels for approximately 4 to 24 hours. Vegetable tanning is used in the production of heavy leathers or sole leathers and may take anywhere from one day (in drums) to six weeks (in pits) to complete. The hide is strung on frames in large vats containing tannin. The hides are then transferred to different bins containing an increasing amount of tannin until the extract has penetrated the pelt (OECD, 2004a; U.S. EPA, 2001). In the case of white sheepskin tanning, commercial grade formaldehyde (11%) is added to the depickled skins in a drum and allowed to sit overnight (Hernon, 1981). Tanning may be followed by draining, sammying, or shaving to reduce moisture content. Mechanical action may occur to adjust the thickness of the hide (OECD, 2004a; U.S. EPA, 2001).

Post-tanning processes typically involve neutralization, washing, re-tanning, dyeing, and fatliquoring (OECD, 2004a). This generally takes place in the same vessel. Following post-tanning, mechanical finishing operations such as staking, buffing, polishing, and plating/embossing may take place. Surface coats are typically applied to meet customer requirements (OECD, 2004a). Figure 4-3 shows a diagram of the typical leather tanning process (U.S. EPA, 2001).

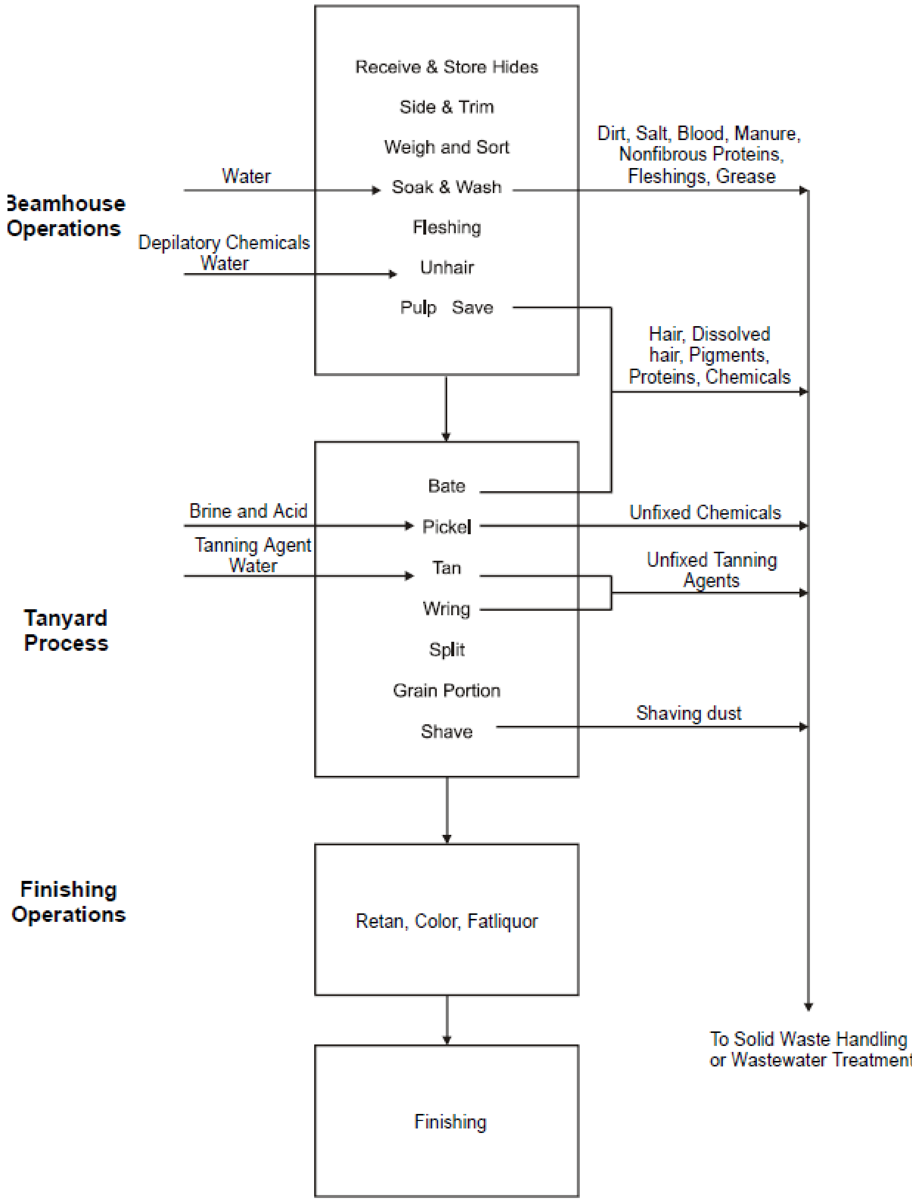


Figure 4-3. Typical Leather Tanning Process (U.S. EPA, 2001)

4.4.2.2 Worker Activities

Workers are potentially exposed to formaldehyde during leather tanning from performing finishing operations such as conditioning, staking, buffing, finishing, plating, measuring, or grading (Stern et al., 1987). EPA did not find information that indicates the extent of engineering controls and use of PPE by workers at facilities that perform leather tanning operations.

ONUs include employees (*e.g.*, supervisors, managers) at leather tanning sites who do not directly handle formaldehyde. Therefore, ONUs are expected to have lower inhalation exposures and no expected dermal exposure.

4.4.2.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during leather tanning is listed in Table 4-11 and described in detail below. Table 4-12 summarizes the 8-hour TWA monitoring data for the use of formaldehyde in leather tanning.

Table 4-11. Leather Tanning Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	12	Medium	(OSHA, 2019)

EPA identified monitoring data from OSHA CEHD under NAICS code 316110 – Leather and Hide Tanning and Finishing from three sites. For two of the three sites upon further review, EPA concluded that those sites were not involved in leather tanning. EPA did not identify an 8-hour TWA for sites within the leather and hide tanning and finishing sector from 1992 to 2020. Therefore, EPA integrated OSHA CEHD data sampled in 1988 for the SIC code 3111 leather tanning and finishing. The worker activities conducted during the sampling is unknown. For further discussion of OSHA CEHD data, refer to Section 2.5.1. Due to a lack of available data, EPA did not identify samples for short-term worker exposures. Additionally, EPA did not identify any ONU monitoring data.

For 15-minute peak exposures, 33 percent of the samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a) as discussed in Section 2.5.1.

The high-end and central tendency values for the 15-minute and 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-12.

Table 4-12. Summary of Inhalation Exposure Monitoring Data for Leather Tanning

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.63	1.00	2	EPA did not identify 8-hour data for ONUs.		Medium
15-minute TWA	2.15	2.33	4	EPA did not identify 15-minute data for ONUs		N/A
Short-term TWA	EPA did not identify short-term data for workers or ONUs					N/A

4.4.2.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data from OSHA's CEHD to assess 15-minute and 8-hour inhalation exposures, which has a medium data quality rating from the systematic review process. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. The primary limitation of this data is that monitoring data is limited and may be outdated to current industry conditions. In addition, there is uncertainty in the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, and that there was only two 8-hour samples available to estimate exposures. EPA also assumed 8 exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures for this scenario. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight for 8-hour TWA and slight to moderate for 15-minute estimates, yet they provide a plausible estimate of exposures.

4.4.2.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for the Leather Tanning OES was 37 percent (NICNAS, 2006). It is expected that formalin will be used and diluted in the process to a concentration of less than 1 percent (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 518 $\mu g/cm^2$ as the central tendency value and 777 $\mu g/cm^2$ as the high-end value.

4.5 Processing – Incorporation into an Article – Paint Additives and Coating Additives Not Described by Other Categories in Transportation Equipment Manufacturing

EPA has evaluated two exposure scenarios for this COU use:

- Use of Coatings, Paints, Adhesives, or Sealants (non-spray applications); and
- Use of Coatings, Paints, Adhesives, or Sealants (*e.g.,* spray or roll).

4.5.1 Use of Coatings, Paints, Adhesives, or Sealants

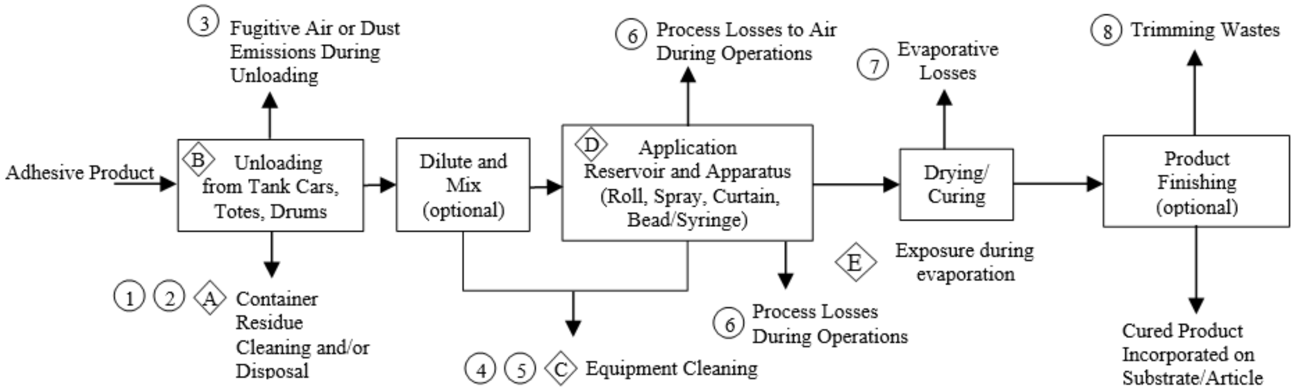
4.5.1.1 Process Description

Formaldehyde containing resins used as adhesives in wood and engineered wood product manufacturing as well as in tire manufacturing were assessed in Section 4.7.1 and Section 4.6.1, respectively (USTMA, 2019; Jahromi, 2005; Williams, 2002).

Adhesives and Sealants

Public comments indicate that formaldehyde is present in trace amounts in most raw materials used for adhesives and sealants, including those used in the aerospace industry (NASA, 2020; ACA, 2019; AIA, 2019). These comments indicated that concentration of formaldehyde in the final product may range from 0.1 to 1 percent, although formulators expect the actual concentration of formaldehyde to be lower (ACA, 2019). However, submitters in the 2020 CDR indicated 1 to 30 percent maximum concentration for two-component glues (U.S. EPA, 2020a).

EPA did not identify formaldehyde-specific process information; however, according to the ESD on the Use of Adhesives, a typical process begins with liquid formulations being manually poured from transport containers directly into a coating reservoir (OECD, 2015b). Solid formulations received are loaded directly into dispensing equipment. The application procedure depends on the type of adhesive or sealant formulation and the type of substrate. Typically, the formulation is loaded into the application reservoir or dispensing equipment and applied to the substrate via spray, roll, curtain, syringe, or bead application. A diagram of the adhesive application process is shown below in Figure 4-4 (OECD, 2015b).



◇ = Occupational Exposures:

A. Inhalation to volatilized formaldehyde and dermal exposure to adhesives during container cleaning
B. Inhalation to volatilized formaldehyde and dermal exposure during equipment loading/container unloading
C. Inhalation to volatilized formaldehyde and dermal exposure during equipment cleaning
D. Inhalation to volatilized formaldehyde or mist (spray application) and dermal exposure during application
E. Inhalation exposure to volatilized formaldehyde during solvent evaporation

Figure 4-4. Typical Release and Exposure Points for the Use of Adhesives Containing Formaldehyde (OECD, 2015b)

Roll coating is typically used for two-dimensional objects that can be wound, such as tapes (OECD, 2015b). During roll coating, a continuous spinning roller brush applies the adhesive to the moving substrate. A roller carries the adhesive from the reservoir to the substrate. A blade may be used to control the thickness of the adhesive. Variants of roll coating include direct, reverse, off-set, and gravure (OECD, 2015b).

During curtain coating, the adhesive is applied as the substrate passes through a liquid curtain (OECD, 2015b). A curtain is formed by the adhesive issued from precision die, typically 20-30 cm above the substrate. A blade may be used to control the thickness of the adhesive. Additional adhesive not transferred to the substrate is dripped into collection tunnels and either recycled to the feed reservoir or disposed of (OECD, 2015b).

Syringe or bead application may be used when the adhesive only needs to be applied to specific locations, such as electronic circuit boards or furniture manufacturing (OECD, 2015b). During application, the adhesive is either extruded from a glue gun or squeezed out of a tube or syringe as a liquid onto the substrate. The adhesive may be applied in long lines or beads or applied in small amounts to an exact location (OECD, 2015b).

All application types may be manual or automated (OECD, 2015b). After application, the adhesive or sealant is allowed to dry or cure (OECD, 2015b). Transport containers may be cleaned off-site by a third party. EPA did not identify formaldehyde-specific application methods; therefore, EPA assumes any of the above methods may be used.

Use of Paint and Coatings

According to American Coating Association (ACA), formaldehyde is present in trace amounts in most raw materials used in paints, coatings, sealants, and adhesives with a range from 0.1 to 1 percent (ACA, 2019). A public comment indicates the use of formaldehyde in a wide range of coatings, such as primers, topcoats, and specialty coatings (AIA, 2019). Formaldehyde is in synthetic latex resins and is also found in fluorescent pigments. However, submitters in the 2020 CDR indicated 30 to 60 percent maximum concentration for solvent based paints (U.S. EPA, 2020a). EPA expects sites may receive concentrated formulation and dilute and mix on site for their desired needs.

EPA did not identify formaldehyde-specific process information; however, several sources provide generic process information. The formulation typically arrives at the facility as a liquid in 55-gallon drums and is loaded into the application reservoir (OECD, 2009b; Kinnes and Mortimer, 1999). In certain industries such as the aerospace industry, surface preparation is required which involves stripping and repainting. The paint or coating may be applied to the substrate via spray, roller, brush, dip, or flow and curtain coating system application (OECD, 2011b; Lee, 1988). In general, applications may be manual or automated. The first coat applied may be an adhesive promoter, which increases surface area on the part to promote adhesion of the subsequent coats (Kinnes and Mortimer, 1999).

In roll or curtain coating, the formulation is fed to the application reservoir via feed lines. During roll coating, a roller picks up the coating from a tray which is transferred to an application roller. In dry booths, the excess paint may be collected using a carton or fiber filter (OECD, 2011b; Vaajasaari et al., 2004). In the case of decorative coatings, brush and roller application are the primary methods used. Following application, the paint or lacquer is allowed to cure or dry. In curing, the resin forms a solid film through a chemical reaction. The curing process may involve air drying, baking, or radiation curing (OECD, 2009b). A diagram of the radiation curable application process is shown below in Figure 4-5 (OECD, 2011b).

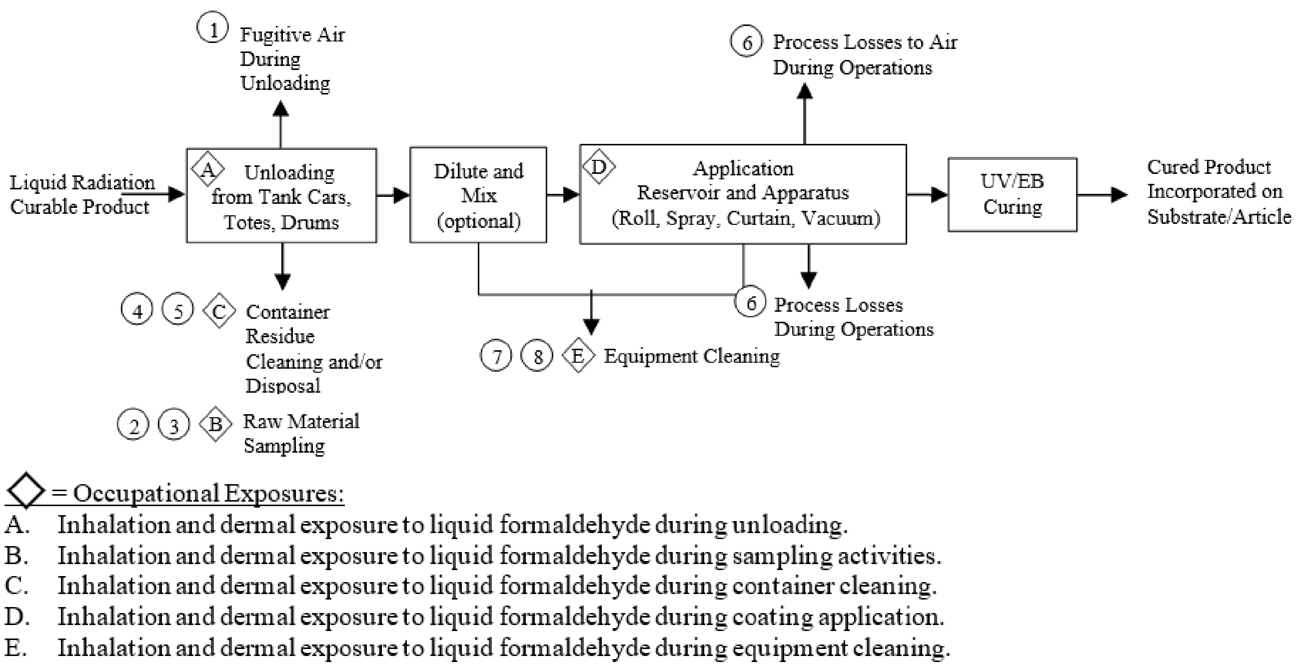


Figure 4-5. General Radiation Curable Coating Process (OECD, 2011b)

Formaldehyde is also present in waxes used to coat cardboard caulking tubes and composite cans (Kinnes, 1990). The concentration of formaldehyde in the wax is unknown. The cans are automatically transferred to the auto wax unit from the production lines. The wax is preheated with mineral oil in a 55-gallon drum and pumped to a reservoir in the wax unit. The wax is then applied via two duplex spray heads into the open end of the can (Kinnes, 1990).

Paint and Coating Additives in Transportation Equipment Manufacturing

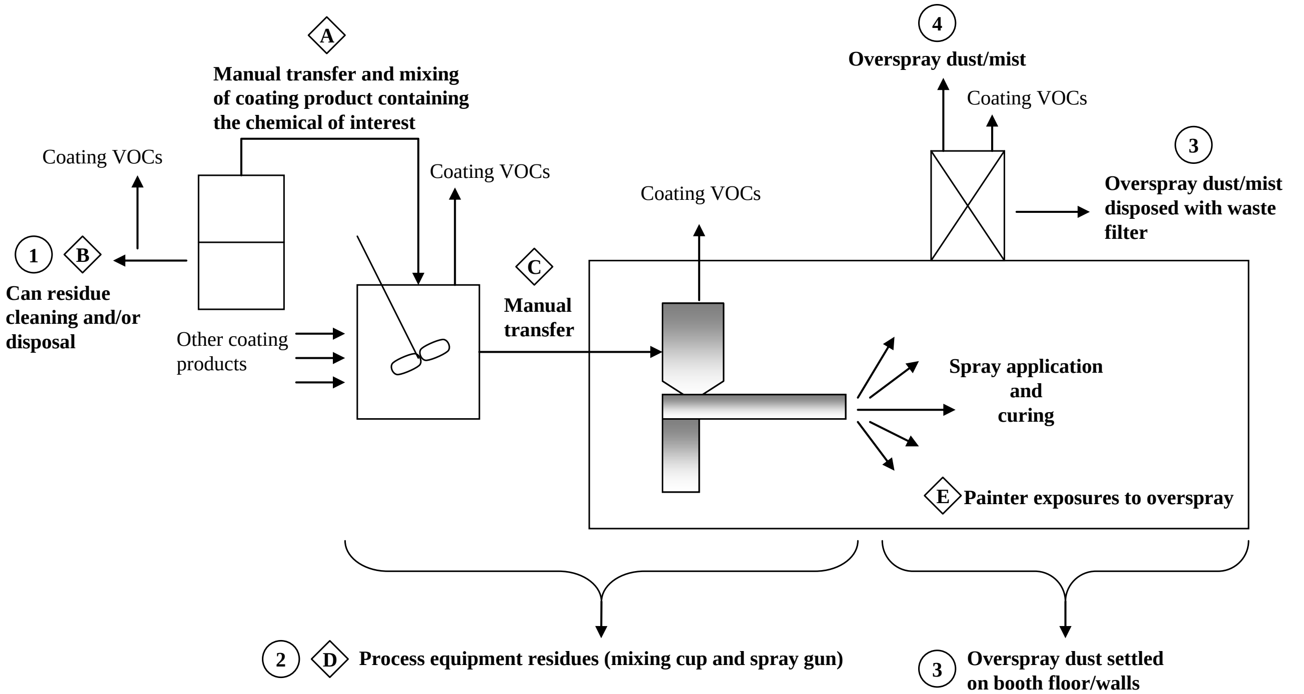
Information from a NIOSH HHE indicates that formaldehyde is incorporated into paints and coatings used in the manufacture of plastic automotive fascia (front and rear bumpers) (Kinnes and Mortimer, 1999).

Coatings are shipped to fascia manufacturing facilities in 55-gallon drums (Kinnes and Mortimer, 1999). Coatings are stored and prepared in a paint kitchen, which is a separate building attached to the main facility. The coatings are conveyed to a robotic paint line in the main facility through carrier lines from pneumatic mixing totes located in the paint kitchen. After the fascia is molded, they are placed on the robotic paint line. The part is sprayed with three different coats—an adhesive promoter, base coating, and clear coating. After the parts are painted, they are cured in an oven, allowed to cool, then prepared for shipment to an automotive assembly facility (Kinnes and Mortimer, 1999).

Automotive Industry

Spray application of paints and coatings is utilized in the automotive refinishing industry (OECD, 2011a). Liquid coating formulations typically arrive at refinishing facilities in 1-quart to 5-gallon containers. Various coating products such as hardeners, reducers, activators, atomizing agents, or colorants may be blended into their final formulations according to the paint manufacturer's specifications before application. Primers, clearcoats, and basecoats are typically mixed by hand. After mixing, the coatings are metered or poured by hand into a mixing cup or other apparatus, and then transferred to a spray gun cup. The primer is the first coating applied to the vehicle (OECD, 2011a). Primer sealer may be applied if the vehicle is new, otherwise, the vehicle is structurally repaired, and a high-solids surfacer is sprayed. The vehicle is lightly sanded and wiped down after primer application (OECD, 2011a; Heitbrink et al., 1993).

After priming, the basecoat color and clearcoat are applied and cured (OECD, 2011a). Conventional spray guns that use high-pressure and high-volume, low-pressure (HVLP) spray guns are the most common application tools. Both types have a mounted cup to hold the coating and are connected to a pressurized air supply via a hose. The pressurized air atomizes the coating formulation into a spray that is applied to the vehicle surface. Refinishing shops may use enclosed spray booths that trap the oversprayed paint mists. Following application, each layer of coating is dried or cured by air drying, a heated paint booth, or portable heat sources. Spray guns may be cleaned manually or with a cleaning system. For a diagram of the process as well as typical release and exposure points during the application of paints and coatings in the automotive refinishing industry, see Figure 4-6 (OECD, 2011a).



○ = Environmental Releases:

1. Container residue from formaldehyde transport container disposed to incineration or landfill.
2. Process equipment (mixing cup, spray gun, spray booth floors/walls) cleaning residues disposed to incineration or landfill.
3. Oversprayed formaldehyde mists/particles captured within spray area and other controls (e.g., dry filters) disposed to incineration or landfill.
4. Oversprayed formaldehyde mists/particles not captured by emission controls and vented to outside air.

◊ = Occupational Exposures:

A. Dermal exposure from unloading/mixing liquid formaldehyde into final coating, as sprayed.
B. Dermal exposure to cured/solid or liquid formaldehyde during container cleaning.
C. Dermal exposure to final mixed liquid formaldehyde during manual transfer from mixing cup to spray gun.
D. Dermal exposure to final mixed liquid formaldehyde during equipment cleaning of mixing cup, spray gun, and spray booth floors/walls.
E. Inhalation and dermal exposure to solid/liquid formaldehyde particulates (i.e., overspray mist) during spray application.

Figure 4-6. Automotive Refinishing Spray Coating Processes (OECD, 2011a)

4.5.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during coating, paints, adhesives, and sealant during loading/unloading transport containers, equipment and container cleaning, application of coatings, and sampling activities (OECD, 2015b, 2011b). Literature sources stated common engineering controls during use of coatings, paints, adhesives, or sealants to be general and local exhaust ventilation (Methner et al., 2014; Ceballos and Burr, 2011). EPA did not identify any information to indicate the extent to which workers used PPE in use of coatings, paints, adhesives, and sealants.

Only one literature source identified an engineering control in positive pressure ventilated spray booths (Parsons Engineering Science, 1997). EPA did not identify the extent to which workers used PPE at spray application facilities.

ONUs include employees (*e.g.*, supervisors, managers) at sites that use coating, paints, adhesives, or sealants who do not directly handle formaldehyde. Therefore, ONUs are expected to have lower inhalation exposures and no expected dermal exposure.

4.5.1.3 Inhalation Exposure Estimates (Spray or Unknown Application)

The information and data quality valuation to assess occupational exposures during use of formulations containing formaldehyde for spray or unknown applications (*e.g.*, spray or roll) is listed in Table 4-13 and described in detail below. Table 4-14 summarizes the 8-hour TWA monitoring data for use of formulations containing formaldehyde for spray applications.

Table 4-13. Use of Formulations Containing Formaldehyde for Spray or Unknown Applications (*e.g.*, Spray or Roll) Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	423	Medium	(OSHA, 2019)
Spray painting of lighting components for aerospace products	PBZ monitoring data	2	High	(Parsons Engineering Science, 1997)

EPA identified discrete monitoring data for peak and full-shift exposures for paints, coatings, adhesives and sealants only from OSHA and Parsons Engineering Science (1997). Of the 213 8-hour TWA samples available, 210 were from OSHA's CEHD, which does not provide worker activities or additional process information. EPA expects a wide variety of industries may be using formaldehyde in paints, coatings, adhesives, or sealants. EPA assumes that sites in transportation equipment manufacturing, metal product manufacturing, and other product manufacturing sites were likely using formaldehyde in this manner. The full crosswalk of NAICS to OES used for integration of OSHA CEHD data is in Appendix D. The other two were provided by Parsons Engineering. The latter study sampled spray painters while they painted lighting components for aerospace products. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures because ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-14.

Table 4-14. Summary of Inhalation Exposure Monitoring Data for Use of Formulations Containing Formaldehyde for Spray Applications (*e.g.*, Spray or Roll)

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.07	0.55	213	0.07	0	Medium to High
15-minute TWA	0.24	1.17	116	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		N/A

EPA identified one additional study with PBZ monitoring data for the use of formulations containing formaldehyde for spray applications that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the estimates listed above but support the exposure estimates. Thorud (2005) measured full-shift exposures to formaldehyde during manual and automatic spray painting at a facility in Norway. The samples ranged from 0.01 to 1.1 ppm, and the geometric means ranged from 0.11 to 0.16 ppm, depending on the worker activity.

Lyapina (2004) took full-shift measurements of workers whose job tasks involved the application of carbamide-formaldehyde glue at a site in Bulgaria. The application method is not specified. The samples ranged from 0.52 to 1.56 ppm and resulted in an arithmetic mean of 0.71 ppm (n = 29).

4.5.1.4 Inhalation Exposure Estimates (Non-spray applications)

EPA did not identify discrete data for specific applications except for spray applications. However, EPA did identify monitoring data for workers using different application methods (Thorud et al., 2005). The study collected monitoring data of workers while curtain painting, dip painting, and manual painting at 27 different facilities in the surface coating departments in Norway. The total duration sampled per worker are not provided but the study indicates two or three samples were measured per worker per shift. EPA assumes these exposure estimates are representative of a full-shift exposure. The study also indicates that some samples were monitored under an air-purifying mask, thus exposures without the impact of the respirator may be higher. These specific samples were not specified.

One study conducted in Sweden measured peak (15-minute) exposures of workers during house painting (Norback et al., 1995). The study monitored painters during construction of new buildings using water-based paints using rollers for about three to five hours per day.

The formaldehyde air concentrations for these non-spray applications and their data quality evaluation are provided in Table 4-15.

Table 4-15. Use of Coatings, Paints, Adhesives, or Sealants (Non-spray Applications) Inhalation Exposure Data

Coating Application	Number of Samples	Duration	Geometric Mean (ppm)	Range (ppm)	Overall Data Quality Determination	Source
Curtain painting	25	Full-shift	0.51	0.08–1.48	Medium	(Thorud et al., 2005)
Manual painting	16	Full-shift	0.07	0.05–0.16	Medium	(Thorud et al., 2005)
Dip painting	9	Full-shift	0.16	0.10–0.27	Medium	(Thorud et al., 2005)
House painters using rollers with water-based paints	12	Full-shift	0.033	<0.024–0.088	Medium	(Norback et al., 1995)
House painters using rollers with water-based paints	5	Peak (15-minute)	0.064	<0.024–0.112	Medium	(Norback et al., 1995)

The monitoring data available by application method indicates that exposures can vary by application methods with curtain painting being potentially a higher exposure application method. EPA used the geometric mean exposure estimates for dip painting and the maximum to inform central tendency and high-end exposures from non-spray applications from Thorud et al. (2005). For peak exposures, EPA used the geometric mean and maximum from Norback et al. (1995) for peak exposures.

Table 4-16. Summary of Inhalation Exposure Monitoring Data for Use of Coatings, Paints, Adhesives, or Sealants (Non-spray Applications)

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency	High-end					
8-hour TWA	0.16	1.48	50	0.16	0.16	0	Medium
15-minute TWA	0.064	0.112	5	EPA did not identify 15-minute exposures for workers or ONUs			Medium
Short-term TWA	EPA did not identify short-term exposures for workers or ONUs						N/A
EPA did not identify discrete data; therefore, EPA used summary data to estimate a CT (mean of three non-spray applications) and HE (maximum).							

4.5.1.5 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour inhalation exposures, which has a medium to high data quality rating from the systematic review process. For non-spray applications, EPA uses two studies conducted in other countries to support the exposure estimate. EPA expects the activities to be similar but notes that the country of the study, Norway, has a slightly lower legal formaldehyde exposure limit (0.5 ppm) than the U.S OSHA PEL (0.75 ppm). The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario,. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which process or worker activities these data cover and whether all potential worker activities are included in this data. EPA assumes a wide array of NAICS codes are applicable to paints, coatings, adhesives and sealants, there is some degree of uncertainty in this assumption. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for full-shift and peak estimates and provides a plausible estimate of exposures.

4.5.1.6 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6.

For non-spray applications, EPA assumes that routine dermal exposure may occur. EPA assessed at a concentration of 60 percent, based on a maximum concentration range of 30 to 60 percent reporting from solvent-based paints category in the 2020 CDR (U.S. EPA, 2020a). This relatively high concentration is conservatively assessed in cases that sites received concentrated raw materials that they may dilute or mix prior to application. The calculated occupational dermal exposures for this scenario are 840 $\mu g/cm^2$ as the central tendency value and 1,260 $\mu g/cm^2$ as the high-end value.

For spray application, EPA expects a higher quantity remaining on the skin. Based on the expected worker activities, high-end dermal exposures are calculated based on a higher amount of formaldehyde remaining on skin (immersive), 10.3 mg/cm^2 per event, and the central tendencies of 3.8 mg/cm^2 per event. While the reported range in CDR was 30 to 60 percent, it is not expected for formaldehyde to be present in final coating products at concentrations of 60 percent. EPA used a concentration of 30 percent. The calculated occupational dermal exposures for this OES are 420 µg/cm^2 as the central tendency value and 3,090 µg/cm^2 as the high-end value.

4.6 Processing – Incorporation into an Article – Additive in Rubber Product Manufacturing

4.6.1 Rubber Product Manufacturing

4.6.1.1 Process Description

Formaldehyde resins are used as an additive in rubber product manufacturing, including products such as tires (U.S. EPA, 2023a; USTMA, 2020, 2019; Gunter, 1977; NIOSH, 1973). In tire manufacturing, formaldehyde based resins are used as crosslinking agents or to build adhesion between different tire components. Formaldehyde may also be in coatings on fabric belts and tire mold release agents (USTMA, 2019). One source indicates a concentration of 8 percent phenol formaldehyde in a rubber-metal adhesive used for rubber manufacturing (van der Willigen et al., 1987); however, the amount of formaldehyde in other components that may be used is unknown.

Many of the rubber manufacturing facilities in the United States produce tires for automotive vehicles, airplanes, and farm machinery; however, many facilities produce other engineered rubber products (U.S. EPA, 2023a). The processes involved in these industries are similar but may differ in the raw rubber material and additives used, and the curing method implemented. In general, rubber product manufacturing involves six main stages: mixing, milling, extrusion, calendaring, curing, and grinding. The raw rubber (natural or synthetic) is first mixed with chemical additives, including accelerators, zinc oxides, retarders, antioxidants, softeners, carbon black or other fillers, and sulfur compounds. Mixing occurs in batch mixers at temperatures up to 330 °F (U.S. EPA, 2023a).

After mixing, the rubber product is processed into slab rubber or pellets via a drop mill, extruder, or pelletizer (U.S. EPA, 2023a). The rubber is cooled and then transferred to the component preparation area. Calendaring may be used to apply a rubber coat onto a continuous textile or mesh web. The final step in rubber product manufacturing is vulcanizing, also known as curing. After curing, grinding may be performed to remove rough edges from the final product (U.S. EPA, 2023a).

During tire manufacturing, low levels of formaldehyde are present in reinforcing and tackifying resins (USTMA, 2020, 2019). The formaldehyde resins are incorporated into the tire compound during mixing, which may occur at tire manufacturing facilities or separate mixing facilities. Tire compounding is the first stage of the tire manufacturing process and involves the selection of several types of rubber, oils, carbon black, pigments, and other additives (USTMA, 2020, 2019). The tire manufacturing industry primarily uses natural rubber, styrene-butadiene rubber, and polybutadiene rubber (U.S. EPA, 1995a). The raw materials are then mixed using a Banbury mixing machine to form a homogenized batch of material with a gum-like consistency. The mixing process is computer-controlled. The compounded materials then undergo further processing into sidewalls, treads, or other parts of the tire. After processing, the tire is cured by application of pressure (200-300 psig) and heat (330 to 350 °F). According to a public comment by the U.S. Tire Manufacturers Association, any formaldehyde present in the resins is expected to be fully consumed during curing (USTMA, 2020, 2019; U.S. EPA, 1995a).

Formaldehyde is also used during high-pressure hose manufacturing, which is used by the automotive, oil, and farming industries (Gunter, 1977; NIOSH, 1973). During rubber hose manufacturing, rayon or polyester cords are treated by a rewinder. The rewinding process involves dipping the cord into a solution containing formaldehyde. After the cord is treated with formaldehyde, a rubber hose is fed into a braiding machine. The braiding machine reinforces the rubber hose by braiding the treated cord around the rubber hose (Gunter, 1977; NIOSH, 1973). Due to a lack of information, EPA does not present site throughputs for rubber hose manufacturing. The concentration of formaldehyde used to treat rayon or polyester cords is unknown.

4.6.1.2 Worker Activities

Workers are potentially exposed to formaldehyde in rubber product manufacturing during loading/unloading transport containers, cleaning empty transport containers, coating applications, and after removing cured products (U.S. EPA, 2023a; USTMA, 2019). According to literature sources, PPE may include safety glasses, gloves, and ear plugs (USTMA, 2020). Engineering controls may include point of generation ventilation and overhead exhaust ventilation (USTMA, 2020).

ONUs include employees (*e.g.*, supervisors, managers) at rubber product manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.6.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during rubber product manufacturing is listed in Table 4-17 and described in detail below. Table 4-18 summarizes the 8-hour TWA, short-term, and 15-minute monitoring data for the use of formaldehyde in rubber product manufacturing.

Table 4-17. Rubber Product Manufacturing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Press operator during rubber flooring manufacturing	PBZ monitoring data	1	Medium	(Burkhart, 1995)
Operator during automotive brake part manufacturing	PBZ monitoring data	6	High	(Mauer and Cook, 1999)
Mixing, milling, curing, block cutting, and machine operation	PBZ monitoring data	1,800	High	(USTMA, 2020)
Calendaring, raw material weighing, and receiving areas	Area monitoring data[a]	12	High	(USTMA, 2020)
Unknown	PBZ monitoring data	52	Medium	(OSHA, 2019)

[a] 8-hour TWA PBZ data were not available to estimate ONU exposures; therefore, EPA used area samples for the ONU 8-hour TWA estimates.

A majority of the monitoring data were from the U.S. Tire Manufacturers Association (USTMA) (USTMA, 2020). Nine member companies provided monitoring data to USTMA that represent full-shift and 15-minute exposure durations in various worker activities during tire manufacturing. EPA incorporated sampling data from two NIOSH HHEs investigating exposure to formaldehyde during rubber flooring manufacturing and automotive brake part manufacturing (Mauer and Cook, 1999; Burkhart, 1995). Additionally, EPA identified 52 samples from OSHA CEHD in the rubber product manufacturing subsector. For further discussion of OSHA CEHD data, refer to Section 2.5.1.

Personal breathing zone data were not available to estimate ONU exposures, therefore, EPA used area samples as surrogate data for the ONU 8-hour TWA estimates. EPA did not identify ONU data for 15-

minute or short-term estimates. EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU specific data, EPA used worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

For the 8-hour TWA data, it should be noted that 38 percent of the worker samples measured below the LOD. For the 12-hour TWA data, 5 percent of the worker samples measured below the LOD. For the 15-minute worker data, 23 percent of the samples were below the LOD. For the short-term data, 20 percent of the samples were below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-18.

Table 4-18. Summary of Inhalation Exposure Monitoring Data for Rubber Product Manufacturing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures[a]		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hour TWA	0.01	0.10	877	0.018	0.041	12	Medium to High
12-hour TWA	0.02	0.15	913	EPA did not identify 12-hour TWA for ONUs		0	High
15-minute TWA	0.07	0.49	65	EPA did not identify 15-minute TWA for ONUs		0	High
Short-term TWA	0.04	0.54	3	0.54		1	High

[a] Area samples from (USTMA, 2020), EPA used the area samples for the ONU estimates.

A public comment provided discrete monitoring data at U.S. sites for processing-incorporation into article (Stantec ChemRisk, 2023). EPA did not integrate the data as no additional process or worker activity information was provided to attribute to individual occupational exposure scenarios (e.g., type of produced article). The reported 50th percentile and 95th percentile full-shift exposures were 0.08 and 0.313 ppm, respectively. These estimates generally are above the range estimated for this exposure scenario but it is unclear if this data included rubber product manufacturing.

EPA identified additional studies with PBZ monitoring data for rubber product manufacturing that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the exposure estimates listed above. Clerc (2015) compiled monitoring data stored in the French COLCHIC database and German MEGA database for processes involving the manufacture of molded rubber parts, injection molding, and activities involving extruders. The databases contained short-term samples (i.e., between 30 and 240 minutes) with a median of 0.024 ppm, geometric mean of ~0.033 ppm, and a 95th percentile of 0.39 ppm (n = 246). Lee (2012) measured worker exposures at two tire manufacturing plants in Korea, which ranged from 0.009 to 0.029 ppm. The geometric means of the data ranged from 0.01 to 0.029 ppm. ECHA (2019) aggregated exposure data for workers in the tyre and rubber manufacturing industry with a long-term exposure value of 0.26 mg/m^3 (0.21 ppm; n = 10). The data consisted of personal long-term monitoring data.

4.6.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for inhalation exposure estimates. Exposure to workers at rubber product manufacturing sites is assessed using formaldehyde personal breathing zone monitoring data collected at workplaces directly applicable to this OES. The data were determined to have confidence ratings ranging from medium to high, through EPA's systematic review process. Specifically, the data were determined to be highly reliable, and representative in geography. Additionally, there was a large number of worker samples. Most of the sources provide metadata including job tasks and process information. There is some uncertainty in the 8-hour TWA ONU estimates since 58 percent of the samples were below the LOD. Additionally, area samples were used in lieu of PBZ samples. Based on these strengths and limitations, EPA concluded that the weight of scientific evidence for this assessment is moderate to robust for both full-shift and 15-minute estimates and provides a plausible estimate of exposures.

4.6.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The assessed concentration for this OES was 0.04 percent based on the 8 percent phenol formaldehyde resin concentration in rubber glue assuming a free formaldehyde content of 0.5 percent for the phenol-formaldehyde resin (Dunky, 2004; van der Willigen et al., 1987). The maximum concentration was used for both high-end and central tendency calculations. The calculated occupational dermal exposures for this OES are 0.56 µg/cm^2 as the central tendency value and 0.84 µg/cm^2 as the high-end value.

4.7 Processing – Incorporation into Article – Adhesives and Sealant Chemicals in Wood Product Manufacturing; Plastic Material and Resin Manufacturing (Including Structural and Fireworthy Aerospace Interiors); Construction (Including Roofing Materials); Paper Manufacturing

EPA evaluated four exposure scenarios for this COU:

- Composite wood product manufacturing,
- Other composite material manufacturing,
- Paper manufacturing, and
- Plastics product manufacturing.

4.7.1 Composite Wood Product Manufacturing

4.7.1.1 Process Description

Formaldehyde resins are incorporated into adhesives used to manufacture composite wood products (NICNAS, 2006; Van der Wal, 1982). These products include but are not limited to particleboard, fiberboard, oriented strand board, and plywood (Solenis, 2020; NICNAS, 2006; Van der Wal, 1982). Concentrations of formaldehyde in the resins used to manufacture these products range from less than 0.2 to 0.5 percent (NICNAS, 2006).

The process of incorporating formaldehyde resins into wood products involves injecting the resins with refined wood fiber, mixing, then rolling and pressing the wood product (NICNAS, 2006; Saary et al., 2001; NZ DOH, 1981; Breysse, 1980). Types of formaldehyde resins used include urea, phenol, melamine, or a combination of these resins (NICNAS, 2006). In the case of plywood, the formaldehyde resins are pumped into glue spreaders and applied to the veneer using rollers, which are then pressed (NICNAS, 2006; Breysse, 1980). The manufacture of compressed wood products is an automated process (Sussell, 1995). Compressed wood products can be used in several construction applications, such as residential buildings, commercial and industrial structures, furniture, and material handling such as pallets (NICNAS, 2006; Sussell, 1995).

4.7.1.2 Worker Activities

When manufacturing composite wood products, workers are potentially exposed to formaldehyde during various processing operations, such as pressing, finishing, milling, blending, sanding, and veneering (NICNAS, 2006; Lavoue et al., 2005; Sussell, 1995). Potential exposures are also expected during the storing/packaging of the composite wood products, as well as during the cleaning of process equipment and areas (Vangronsveld et al., 2010). The engineering controls described for composite wood product manufacturing primarily consisted of different forms of generic ambient ventilation (Sussell, 1995).

ONUs include employees (*e.g.*, supervisors, managers) at composite wood product manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.7.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during composite wood product manufacturing is listed in Table 4-19 and described in detail below. Table 4-20 summarizes the 8-hour TWA, short-term, and 15-minute monitoring data for the use of formaldehyde in composite wood products.

Table 4-19. Composite Wood Product Manufacturing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Foreman, cleaner, press operator, lab technician, and resin operator	PBZ monitoring data	7	Medium	(Lavoue et al., 2005)
Finishing area during plywood manufacturing	PBZ monitoring data	1	High	(Fransman et al., 2003)
Press operator during fiberboard manufacturing	PBZ monitoring data	3	High	(Sussell, 1995)
Unknown	PBZ monitoring data	261	Medium	(OSHA, 2019)

EPA identified four sources with discrete PBZ monitoring data applicable to this OES. A majority of the monitoring data is from OSHA CEHD from the wood product manufacturing sector. The other three sources monitored formaldehyde exposures during the manufacturing of fiberboard, plywood, particleboard, medium-density fiberboard, and oriented strand board (Lavoue et al., 2005; Fransman et al., 2003; Sussell, 1995).

EPA did not identify ONU data for 8-hour or 15-minute estimates. The Agency estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. For short-term estimates, the Agency only identified one ONU sample.

For the 8-hour TWA data, it should be noted that 5 percent of the worker samples were below the LOD. For the 15-minute worker data, 30 percent of the samples were below the LOD.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-20.

Table 4-20. Summary of Inhalation Exposure Monitoring Data for Composite Wood Product Manufacturing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.09	0.68	168	0.09	N/A	Medium to High
15-minute TWA	0.13	1.0	101	N/A	N/A	Medium to High
Short-term TWA exposure concentration	0.15	0.21	6	0.08	1	Medium

A public comment provided discrete monitoring data at U.S. sites for processing-incorporation into article (Stantec ChemRisk, 2023). EPA did not integrate the data as no additional process or worker activity information was provided to attribute to individual occupational exposure scenarios (*e.g.*, type of produced article). The reported 50th percentile and 95th percentile full-shift exposures were 0.08 and 0.313 ppm, respectively. These estimates generally fit within the range estimated for this exposure scenario.

In addition, EPA identified studies that contained personal worker monitoring data but the full distribution of samples was not available for integration into the inhalation estimates. Five studies measured at facilities outside of the United States reported worker exposures at plywood mills that use urea-formaldehyde or phenol-formaldehyde as adhesives (Lin et al., 2013; NICNAS, 2006; Fransman et al., 2003; Mäkinen et al., 1999). Fransman (2003) measured an average (GM) 8-hour worker TWA of 0.057 ppm, which is lower than the central tendency but within a similar range as our exposure estimates. Between the other four studies, long-term exposures measured at the plywood mills ranged from less than 0.01 ppm for feeding of wood scraps to 0.66 ppm for gluing of the veneers (Lin et al., 2013; NICNAS, 2006; Mäkinen et al., 1999). In Canada, Lavoue (2005) measured short-term exposures at 12 plants throughout Quebec that manufactured particleboard, medium density fiberboard, or oriented strand board. There was a total of 117 samples collected between the facilities, with geometric means ranging from 0.04 to 0.23 ppm based on job tasks (Lavoue et al., 2005). ECHA (2019) aggregated exposure data for workers in the wood panel production industry with an exposure value of 0.075 mg/m^3 (n = 81). The data consisted of personal long-term monitoring data.

In 2015, an analysis of the German MEGA and French COLCHIC databases that contain the records of government-collected worker monitoring data, was completed for formaldehyde. For the facilities within the industrial sector of manufacture of wood and furniture sector, the central tendency in the French and German database were 0.10 (n = 466) and 0.06 (n = 1,063) ppm, respectively. For the German database, the high-end (95th percentile) was 0.57 ppm while the French database's high-end of the dataset was 0.41 ppm (Clerc et al., 2015).

4.7.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for inhalation exposure estimates. Exposure to workers at composite wood product manufacturing sites is assessed using formaldehyde personal breathing zone monitoring data collected at workplaces directly applicable to this OES. The data were determined to have confidence ratings ranging from medium to high, through EPA's systematic review process. Specifically, the data were determined to be highly reliable, and representative in geography. Additionally, there was a large number of worker samples. Most of the sources provide metadata including sample type and sample duration. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which process or worker activities these data cover and whether all potential worker activities are included in this data. Due to a lack of available data, there is some uncertainty in the ONU estimates. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate to robust for both the 15-minute and 8-hour estimates and provides a plausible estimate of exposures.

4.7.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration identified for this OES was a reported range of 30 to 60 percent for Processing – incorporation into article – wood product manufacturing in the 2020 CDR (U.S. EPA, 2020a). Other sources indicate the resins, which are the typical starting material used in wood product manufacturing, contains approximately 0.2 to 6 percent free formaldehyde (NICNAS, 2006). EPA expects that the range reported in CDR may be the concentration of formaldehyde in the solutions used to produce the resins, which worker exposures for these activities are reflected in processing as a reactant. Some facilities may conduct both processes at their sites. The concentration used for this OES is 6 percent. The calculated occupational dermal exposures for this OES are 84 $\mu g/cm^2$ as the central tendency value and 126 $\mu g/cm^2$ as the high-end value.

4.7.2 Other Composite Material Manufacturing

4.7.2.1 Process Description

Formaldehyde resins are incorporated into adhesives used to manufacture composite materials such as fibrous insulation, asphalt roofing, and composite panels (ARMA, 2019; NAIMA, 2019; NICNAS, 2006). Fiber glass and mineral wool building insulation products typically contain 3 to 6 percent by weight cured formaldehyde binder (NAIMA, 2019).

Formaldehyde resins may be incorporated into binders used in fibrous insulation products (NAIMA, 2019). During fiberglass or mineral wool insulation manufacturing, aqueous solutions of formaldehyde resin are sprayed onto fibers. The fibers are then sent to a curing oven, in which the binder is thermally set. According to public comment, virtually all free formaldehyde content is eliminated during the curing process (NAIMA, 2019).

Urea-formaldehyde resins are incorporated into fiberglass mats used for asphalt roofing (ARMA, 2019). During the manufacture of fiberglass mats, a binder solution containing formaldehyde resin is uniformly applied to the surface of fiberglass mats. A vacuum removes excess binder solution for re-use. The mat is then passed through drying and curing ovens to remove moisture and set the binder (ARMA, 2019).

4.7.2.2 Worker Activities

When manufacturing other composite materials, workers are potentially exposed to formaldehyde during molding operations, resin spraying, and cleaning of mold using a cold blast (Daftarian et al., 2000). EPA did not find information that indicates the extent of engineering controls and use of PPE by workers at facilities that manufacture other composite materials using formaldehyde-based resins.

ONUs include employees (*e.g.*, supervisors, managers) at other composite materials manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.7.2.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during other composite material manufacturing is listed in Table 4-21 and described in detail below. Table 4-22 summarizes the 8-hour TWA monitoring data for other composite material manufacturing. EPA did not identify 12-hour TWA, short-term, and 15-minute monitoring data for workers or ONUs.

Table 4-21. Other Composite Material Manufacturing (*e.g.*, Roofing) Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	94	Medium	(OSHA, 2019)

Short-term data was not available to estimate worker exposures. The worker samples were from OSHA's CEHD, from the nonmetallic mineral product manufacturing sector.

For the 8-hour TWA data, it should be noted that 3 percent of the worker samples were below the LOD. For the 15-minute worker data, 81 percent of the samples were below the LOD. The methodology for obtaining and analyzing this data is described in EPA's *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Personal breathing zone data for ONUs was not available; therefore, EPA used central tendency of worker exposure to determine the 8-hour TWA exposure. Short-term and 15-minute data were not available to estimate ONU exposures.

The high-end and central tendency values for the 15-minute and 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-22.

Table 4-22. Summary of Inhalation Exposure Monitoring Data for Other Composite Material Manufacturing (*e.g.*, Roofing)

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures (ppm)	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.11	0.37	74	0.09	0	Medium
15-minute TWA	0.18	0.37	21	EPA did not identify 15-minute data for ONUs		N/A

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures (ppm)	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		N/A

A public comment provided discrete monitoring data at U.S. sites for processing-incorporation into article (Stantec ChemRisk, 2023). EPA did not integrate the data as no additional process or worker activity information was provided to attribute to individual occupational exposure scenarios (e.g., type of produced article). The reported 50th percentile and 95th percentile full-shift exposures were 0.08 and 0.313 ppm, respectively. These estimates generally fit within the range estimated for this exposure scenario.

4.7.2.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. Exposure to workers at composite material manufacturing sites is assessed using formaldehyde personal breathing zone monitoring data collected at workplaces directly applicable to this OES. The data were determined to have confidence ratings ranging from low to high, through EPA's systematic review process. Specifically, the data were determined to be highly reliable, and representative in geography. Most of the sources provide metadata including sample type and sample duration. Due to the large variation amongst sites that manufacture composite materials, there is some uncertainty in how representative the monitoring data is of typical sites. There is some uncertainty in the 15-min estimates since over 50 percent of the samples were below the LOD. Additionally, there is uncertainty in the ONU exposures due to a lack of PBZ data. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for 8-hour TWA and slight to moderate for 15-minute estimates. EPA has concluded that the estimates provide a plausible estimate of exposures.

4.7.2.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration identified for this OES was a reported range of 30 to 60 percent for processing-incorporation into article- construction in the 2020 CDR (U.S. EPA, 2020a). Other sources indicate the resins, which are used in fiberglass composite material manufacturing, contain up to 13 percent free formaldehyde (NICNAS, 2006). EPA expects that the range reported in CDR may be the concentration of formaldehyde in the solutions used to produce the resins, which worker exposures for these activities are reflected in processing as a reactant. Some facilities may conduct both processes at their sites. The concentration used for this OES is 13 percent. The calculated occupational dermal exposures for this OES are 182 μg/cm^2 as the central tendency value and 273 μg/cm^2 as the high-end value.

4.7.3 Paper Manufacturing

4.7.3.1 Process Description

Formaldehyde resins are incorporated into adhesives and sizing agents used in the manufacturing and finishing of paper products (Robinson et al., 1986). In the 2020 CDR, one reporter indicated the use of formaldehyde for paper manufacturing with a 2019 PV of 922,388 lbs (U.S. EPA, 2020a).

Paper manufacturing often takes place in the same plant which produced pulp (Robinson et al., 1986). The pulp product is mixed with water and additives such as sizing agents which can include formaldehyde compounds. The pulp slurry is then formed into sheets, then dried and coated. Formaldehyde can also be present in the final coating applied to the paper product (Apol and Thoburn, 1986). Potential formaldehyde exposures are expected to occur during paper rolling, sizing, dying, drying, glazing, and coating (Robinson et al., 1986).

The concentration of formaldehyde in the manufacturing of paper varies. Analyses from the NIOSH Health Hazard Evaluation from Equitable Bag Co. (Price, 1979) showed that the formaldehyde concentration in wet paper stock at the facility were 0.49 to 1.63 mg of formaldehyde per gram of paper. In the 2020 CDR, the reported concentration of formaldehyde used in paper manufacturing was 30 to 60 percent (U.S. EPA, 2020a). Another study on workers at pulp and paper mills (NICNAS, 2006) stated that the concentration of free formaldehyde in urea and melamine resins used as finishing agents for paper products was 1.5 percent.

4.7.3.2 Worker Activities

Workers are potentially exposed to formaldehyde in paper manufacturing during paper rolling, sizing, drying, dying, glazing, and coating (Robinson et al., 1986). EPA did not find information that indicates the extent of engineering controls and use of PPE by workers at facilities that perform leather tanning operations.

ONUs include employees (*e.g.*, supervisors, managers) at paper manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.7.3.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during paper manufacturing is listed in Table 4-23 and described in detail below. Table 4-24 summarizes the 8-hour TWA monitoring data for the use of formaldehyde in paper manufacturing. Short-term was not available to estimate worker exposures.

Table 4-23. Paper Manufacturing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	104	Medium	(OSHA, 2019)

All of the monitoring data is from OSHA's CEHD in the paper manufacturing sector. The worker activities conducted during sampling is unknown. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

For the 8-hour TWA data, it should be noted that 21 percent of the worker samples measured below the LOD. For the 15-minute worker data, 66 percent of the samples were below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency 8-hour TWA exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 15-minute and 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-24.

Table 4-24. Summary of Inhalation Exposure Monitoring Data for Paper Manufacturing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)		
8-hour TWA	0.04	0.39	72	0.04	N/A	Medium
15-minute TWA	0.40	0.1	32	EPA did not identify 15-minute samples for ONUs		Medium
Short-term TWA	EPA did not identify short-term data					

A public comment provided discrete monitoring data at U.S. sites for processing-incorporation into article (Stantec ChemRisk, 2023). EPA did not integrate the data as no additional process or worker activity information was provided to attribute to individual occupational exposure scenarios (*e.g.*, type of produced article). The reported 50th percentile and 95th percentile full-shift exposures were 0.08 and 0.313 ppm, respectively. These estimates generally fit within the range estimated for this exposure scenario.

EPA identified an additional study with PBZ monitoring data for paper manufacturing that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the exposure estimates listed above. ECHA (2019) aggregated exposure data for workers in the paper manufacturing industry with an exposure value of 0.65 mg/m^3 (n = 123). The data consisted of personal long-term monitoring data.

4.7.3.1 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data from OSHA's CEHD to assess 8-hour inhalation exposures, which has a medium data quality rating from the systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. There is some uncertainty in the 15-min estimates since over 50 percent of the samples were below the LOD. EPA also assumed 8 exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for 8-hour TWA and slight to moderate for 15-minute estimates and provides a plausible estimate of exposures.

4.7.3.2 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. For the maximum concentration, it was reported that the resins used in paper treating and coating contained a maximum of 1.5 percent free formaldehyde (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 21 µg/cm^2 as the central tendency value and 31.5 µg/cm^2 as the high-end value.

4.7.4 Plastic Product Manufacturing

4.7.4.1 Process Description

According to the 2020 CDR, formaldehyde was reported under incorporation into an article within the plastic materials and resin manufacturing sector as a binder (U.S. EPA, 2020a). EPA also identified that formaldehyde is a raw material in the manufacturing of polyoxymethylene (POM). Formaldehyde emissions from plastic product manufacturing were additionally identified in polyethylene processes, possibly from decomposition of the plastic during heating.

In general, for the manufacturing of plastic products, polymer resin is typically received at the compounding sites from the resin manufacturer in the form of pellets. The plastic resins are then typically heated and formed into products through extrusion, thermoforming, compression molding, calendaring, and encapsulation. After the heating and forming processes, the plastic may be further processed and molded into the finished product. These molding processes can include injection molding, transfer molding, compression molding, blow molding, and rotational molding. The final plastic product manufacturing operations are usually finishing and trimming. Solid waste from this process is typically sent to landfill or incineration (U.S. EPA, 2004a). A 2003 NIOSH HHE conducted at the Bemis plastic packaging manufacturing facility stated that the bag manufacturing process consisted of heat sealing and cutting bags through an automated process which released smoke containing formaldehyde (NIOSH, 2003a).

The concentration of formaldehyde reported in the 2020 CDR for incorporation into an article within the plastic materials and resin manufacturing sector as a binder was 30 to 60 percent (U.S. EPA, 2020a). EPA considers that this concentration may reflect use of formaldehyde to produce the plastic pellets, but that the free formaldehyde content in the plastic pellets to be much lower.

4.7.4.2 Worker Activities

Workers are potentially exposed to formaldehyde in plastic product manufacturing during if there is off-gassing of formaldehyde from the pellet and during heating operations (U.S. EPA, 2004a). Engineering controls used at plastic product manufacturing sites can include local exhaust ventilation and general mechanical ventilation (Li, 2017).

ONUs include employees (*e.g.*, supervisors, managers) at plastic product manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.7.4.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during plastic product manufacturing is listed in Table 4-25 and described in detail below. Table 4-26 summarizes the 8-hour

TWA, short-term, and 15-minute monitoring data for the use of formaldehyde in plastic product manufacturing.

Table 4-25. Plastic Product Manufacturing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown worker activities during polyethylene extrusion	PBZ monitoring data	1	Medium	(Tikuisis et al., 2010)
Primary and secondary operators	PBZ monitoring data	2	High	(NIOSH, 1998)
Unknown worker activities in the plastic extrusion department	PBZ monitoring data	3	Medium	(Methner et al., 2014)
Process techs within the polyethylene department	PBZ monitoring data	14	Medium	(Burkhart and Jennison, 1994)
Wicketer and flatbed bagger operator	PBZ monitoring data	12	High	(Li, 2017)
Maintenance mechanic	PBZ monitoring data	1	High	(Blade, 1996)
Bag machine operator and floater	PBZ monitoring data	4	High	(NIOSH, 2003a)
Unknown	PBZ monitoring data	364	Medium	(OSHA, 2019)

A majority of the 8-hour TWA monitoring data came from OSHA CEHD in the plastics product manufacturing and other miscellaneous manufacturing sectors. For further discussion of OSHA CEHD data, refer to Section 2.5.1. EPA also incorporated data from NIOSH HHEs and literature assessing worker exposures at sites associated with the manufacturing of plastic bags, plastic film, and plastic circuit breaker cases. All 15-minute samples were provided through a NIOSH HHE that evaluated worker exposure to formaldehyde at a plastic bag sealing plant (Li, 2017). The single short-term data point is from a maintenance mechanic at a facility that manufactures polyethylene plastic films and bags (Blade, 1996).

Only one short-term PBZ sample was available, therefore EPA used it for both the high and central tendency as stated in Section 2.5.1 (**Blade, 1996**). EPA identified a total of 12 15-minute worker samples (**Li, 2017**).

EPA did not identify ONU data for exposure estimates. EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate 8-hour and 15-minute TWA exposures for ONUs.

For the 8-hour TWA data, it should be noted that 11 percent of the samples measured below the LOD. For the 15-minute worker data, 17 percent of the samples were below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-26.

Table 4-26. Summary of Inhalation Exposure Monitoring Data for Plastic Product Manufacturing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)		
8-hour TWA Exposure Concentration	0.05	0.35	216	0.05	0	Medium to High
15-minute TWA	0.07	0.51	182	No 15-minute ONU data was available		High
Short-term TWA	0.02		1	No short-term ONU data was available		High

A public comment provided discrete monitoring data at U.S. sites for processing-incorporation into article (Stantec ChemRisk, 2023). EPA did not integrate the data as no additional process or worker activity information was provided to attribute to individual occupational exposure scenarios (*e.g.*, type of produced article). The reported 50th percentile and 95th percentile full-shift exposures were 0.08 and 0.313 ppm, respectively. These estimates generally fit within the range estimated for this exposure scenario.

EPA identified additional studies with PBZ monitoring data for plastic product manufacturing that did not provide the discrete data to be incorporated into the inhalation estimates. These additional studies suggest that exposures to formaldehyde may be more variable, likely dependent on temperature and type of plastic pellet. In a 2002 NIOSH HHE conducted at Rubbermaid, Inc., arithmetic means of the monitoring data ranged from 0.52 to 1.75 ppm for full-shift press operators (Barsan, 1994). Monitoring data from two Canadian sites involved in polyethylene extrusion ranged from 0.01 to 0.2 ppm for full-shift worker activities including extrusion coating, blown film, rotational film, blow molding, and pipe extrusion (Tikuisis et al., 2010; Tikuisis et al., 1995).

Bono et al. (2016) and Romanazzi et al. (2013) measured worker exposures at a plastics laminate plants in Italy. The arithmetic mean for the plant workers and ONUs were 0.17 and 0.03 ppm, respectively. Four studies measured at facilities in Italy reported worker exposures that use formaldehyde in plastic product manufacturing (Scarselli et al., 2017; Bono et al., 2016; Romanazzi et al., 2013). For workers, the arithmetic means ranged from 0.065 to 0.17 ppm, and for ONUs, the arithmetic mean was 0.03 ppm. Hosgood et al. (2013) and Rothman et al. (2017) measured worker exposures in China at a facility that uses formaldehyde-melamine resins to produc plastic utensils. The data ranged from 0.51 to 2.6 ppm, and the arithmetic mean was 1.28 ppm.

4.7.4.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which were determined to have confidence ratings ranging from medium to high, through EPA's systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario. In particular as formaldehyde is also possibly produced from the decomposition of the plastic during heating. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. There is uncertainty in the short-term exposure estimate, since there was only one sample available, and it was a non-detect. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for both 8-hour and 15-minute estimates and they provide a plausible estimate of exposures.

4.8 Processing – Incorporation into a Formulation, Mixture, or Reaction Products – [All Functions] in [All Industries]

COUs:

- Petrochemical manufacturing, petroleum, lubricating oil and grease manufacturing; fuel and fuel additives; lubricant and lubricant additives; all other basic organic chemical manufacturing; all other petroleum and coal products manufacturing;
- Asphalt, paving, roofing, and coating materials manufacturing;
- Solvents (which become part of a product formulation or mixture) in paint and coating manufacturing;
- Processing aids, specific to petroleum production in: oil and gas drilling, extraction, and support activities; all other chemical product and preparation manufacturing; and all other basic inorganic chemical manufacturing;
- Paint additives and coating additives not described by other categories in: Paint and coating manufacturing; Plastic material and resin manufacturing;
- Intermediate in: all other basic chemical manufacturing; all other chemical product and preparation manufacturing; plastic material and resin manufacturing; oil and gas drilling, extraction, and support activities; wholesale and retail trade;
- Other: Preservative in all other chemical product and preparation manufacturing;
- Solid separation agents in miscellaneous manufacturing;
- Agricultural chemicals (nonpesticidal) in: Agriculture, forestry, fishing, and hunting; pesticide, fertilizer, and other agricultural chemical manufacturing;
- Surface active agents in plastic material and resin manufacturing;
- Ion exchange agents in adhesive manufacturing and paint and coating manufacturing;
- Lubricant and lubricant additive in adhesive manufacturing;
- Plating agents and surface treating agents in all other chemical product and preparation manufacturing;
- Soap, cleaning compound, and toilet preparation manufacturing;
- Other: Laboratory chemicals;
- Adhesive and sealant chemical in adhesive manufacturing; and
- Bleaching agents in textile, apparel, and leather manufacturing.

4.8.1 Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products

4.8.1.1 Process Description

Incorporation into a formulation, mixture, or reaction product refers to the process of mixing or blending several raw materials to obtain a product or mixture. Formaldehyde can be incorporated into solvents which become part of a product formulation or mixture, processing aids, paint and coating additives, intermediates in basic chemical manufacturing, preservatives in chemical product and preparation manufacturing, solid separation agents, surface active agents, adhesives, functional fluids, laboratory chemicals, bleaching agents, and finishing agents (U.S. EPA, 2023b, 2020a, b; ACA, 2019; Bruno et al., 2018; Wicks and Jones, 2013; NICNAS, 2006; Kullman, 1989; Almaguer and Boiano, 1986; Rivera, 1976).

In the 2020 CDR, 41 reporters reported the use of formaldehyde for incorporation into formulations (U.S. EPA, 2020a). The CDR indicates that formaldehyde is incorporated into formulations in the following manufacturing industrial sectors: all other basic organic chemicals; all other chemical products and preparation; paint and coating; pesticide, fertilizer, and other agricultural chemicals; plastics material and resin; soap, cleaning compound, and toilet preparation; textiles, apparel, and leather; transportation equipment; and wood product manufacturing. Additionally, formaldehyde is incorporated into formulations in agriculture, forestry, hunting, and fishing; mining (except oil and gas) and support activities; oil and gas drilling, extraction, and support activities; wholesale and retail trade; other (laboratory chemical); and services (embalming agent) (U.S. EPA, 2020a). Within these industrial sectors, formaldehyde is incorporated into binders, laboratory chemicals, preservatives, dispersing agents, sealants, monomers, chelating agents, surfactants, processing aids specific to petroleum production, embalming agents, deodorizers, adhesion/cohesion promoters, soil amendments (fertilizer), and intermediates (U.S. EPA, 2020a)

Public comments have indicated the use of formaldehyde in the production of ion-exchange resins, pesticides, asphalt roofing materials, lubricants, and polymers, as well as electroless copper plating processes and petrochemical manufacturing (Celanese Corp, 2020; SIA, 2020; AIA, 2019; ARMA, 2019; IPC International, 2019; Material Research, 2019). Asphalt roofing manufacturing typically involves the following processes: coating, mineral surfacing, cooling, drying, product finishing, and packaging (ARMA, 2019; Apol and Okawa, 1977). Urea-formaldehyde concentrates are used for oilfields, refineries, and petrochemical applications (Material Research, 2019). The refinery industry employs a variety of processes and typically involves separation, petroleum conversion, petroleum treating, feedstock and product handling, and auxiliary facilities (U.S. EPA, 2023b).

EPA did not find specific container information for formaldehyde used in the formulation; however, EPA expects formaldehyde to arrive as a liquid in tank trucks, drums, or rail cars received directly from manufacturing sites.

Incorporation of formaldehyde into formulations is generally a batch process (NICNAS, 2006). Measured amounts of formaldehyde or products containing formaldehyde are added to mixing vessels to form end products. Formalin or other formaldehyde products containing 0.7 to 37 percent formaldehyde is typically used. The product is then pumped or manually transferred to containers and shipped to customers. Blending processes may vary from site to site. Small batch productions typically employ manual processes, including decanting, weighing, stirring, and cleaning. Large batch productions use automated processes such as mechanical stirring. Formulation batch times may take anywhere from 5 minutes to 3 days (NICNAS, 2006).

Several OECD ESDs provide general process descriptions for formulation of products. For example, adhesives are typically formulated by mixing volatile and non-volatile chemical components in sealed, unsealed, or heated processes (OECD, 2009a). Sealed processes are generally the most common for adhesive formulation because many adhesives are designed to set or react when exposed to ambient conditions (OECD, 2009a). Paint and coating formulation may involve processes such as dispersion, milling, mixing, and filtration (OECD, 2009b). Lubricant formulation generally comprises blending two or more components, including liquid and solid additives, together in a blending vessel (OECD, 2004b).

4.8.1.2 Worker Activities

Workers are potentially exposed to formaldehyde in processing of formaldehyde into formulations, mixtures, or reaction products during filtering and packaging activities, cleaning and maintenance of process equipment, and other process activities such as mixing, filling, and blending (NICNAS, 2006). Engineering controls for these processes can include general and local exhaust ventilation (NICNAS, 2006).

ONUs include employees (*e.g.*, supervisors, managers) at sites which process formaldehyde into formulations, mixtures, or reaction products who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.8.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during processing of formaldehyde into formulations, mixtures, or reaction products is listed in Table 4-27 and described in detail below. Table 4-28 summarizes the 8-hour TWA, short-term, and 15-minute monitoring data for the processing of formaldehyde into formulations, mixtures, or reaction products.

Table 4-27. Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Operator during consumer product formulation	PBZ monitoring data	2	High	(NICNAS, 2006)
Packaging and raw material weighing during biocide formulation	PBZ monitoring data	2	High	(NICNAS, 2006)
Pumping area during consumer product formulation	Area monitoring data[a]	2	High	(NICNAS, 2006)
Various worker activities such as field process operator, operator, and assistant operator	PBZ monitoring data	9	High	(Analytics Corporation, 2017a)
Loading/unloading trucks, making formulation batches	PBZ monitoring data	2	Medium	(Bayless Kilgore, 2020)
Environmental health and safety, quality control/quality assurance, logistics, maintenance, and operators	PBZ monitoring data	56	High	(Stantec ChemRisk, 2023)
Unknown	PBZ monitoring data	149	Medium	(OSHA, 2019)

[a] Discrete short-term PBZ samples were not available; therefore, EPA used discrete area samples for the short-term exposure estimate.

For the 8-hour TWA data, 56 of the worker samples were from ACC (Stantec ChemRisk, 2023). This data was collected by the ACC from major formaldehyde processing facilities in the U.S. Due to the wide range of facilities that provided data to ACC, it should be noted that this data may overlap with the other sources identified through the systematic review process. Additionally, EPA incorporated sampling data from OSHA CEHD in the chemical manufacturing sector, which provided 35 8-hour sampling data points. For further discussion of OSHA CEHD data, refer to Section 2.5.1.

Personal breathing zone data were not available to estimate short-term worker exposures. For short-term exposure estimates, EPA identified two area samples to use as surrogate data (NICNAS, 2006).

EPA did not identify ONU data for exposure estimates. EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate 8-hour TWA exposures for ONUs.

For the 8-hour TWA data, it should be noted that 19 percent of the samples measured below the LOD. For the 15-minute data, 43 percent of the samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-28.

Table 4-28. Summary of Inhalation Exposure Monitoring Data for Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)		
8-hour TWA	0.07	0.56	130	0.07	0	Medium to High
15-minute TWA	0.13	2.69	90	No 15-minute ONU data was available		Medium to High
Short-term TWA	0.10	0.19	2	No short-term ONU data was available		High

EPA identified additional studies with PBZ monitoring data for the processing of formaldehyde into formulations, mixtures, or reaction products that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the exposure estimates listed above. Dow Chemical (2016) measured full-shift worker exposures on the production line, ranging from 0.064 to 0.16 ppm. In the 2006 formaldehyde NICNAS report, monitoring data from an Australian film processing formulation site ranged from 0.1 to 2.0 ppm for full-shift exposures and 0.3 to 2.0 ppm for 15-minute exposures (NICNAS, 2006). The full-shift workers were involved in line setting, packaging, mixing, and filling, and the 15-minute worker activities involved cleaning and maintenance. ECHA (2019) aggregated exposure data for workers in the formulation industry with an exposure value of 0.11 mg/m^3 (n = 13). The data consisted of personal long-term monitoring data.

4.8.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which were determined to have confidence ratings ranging from medium to high, through

EPA's systematic review process. Specifically, the data were determined to be representative in geography and include a large data pool. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for both 15-minute and 8-hour TWAs, and that they provide a plausible estimate of exposures.

4.8.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 60 percent based on reporting from the Processing of formaldehyde into formulations OES in the 2020 CDR (U.S. EPA, 2020a). The minimum concentration reported for this OES was 0.7 percent based on data from the 2006 formaldehyde report from the NICNAS (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 840 μg/cm^2 as the central tendency value and 1,260 μg/cm^2 as the high-end value.

4.9 Processing-Repackaging- Sales to distributors for laboratory chemicals

EPA evaluated one exposure scenario for this COU:

- See Section 4.2.1, Import and/or Repackaging of Formaldehyde

4.10 Processing-Recycling

4.10.1 Recycling

COU: Processing – recycling

4.10.1.1 Process Description

Recycling of Medium-Density Fiberboard

The concentration of urea-formaldehyde (UF) in medium-density fiberboard (MDF) panels ranges from 8 to 12 percent (Wan et al., 2014). During the recycling process for MDF panels, there exists a potential for the emission of formaldehyde (Moezzipour et al., 2018).

The most common resins used in the production of MDF boards are urea-formaldehyde and melamine urea-formaldehyde. The goal of recycling these boards is to release the fibers from the resin matrix by breaking resin bindings. One of the methods for recycling MDF is hydrothermal (Moezzipour et al., 2018). When recycling MDF wastes by hydrothermal methods, first fibers are heated using steam (hydrothermal), and then they are separated using a refiner (Moezzipour et al., 2018). Fibers degenerate upon continuous heating at high temperatures and mechanical defibrillation (Moezzipour et al., 2018). Another common method for recycling MDF panels is through the process of electrical heating. The resin bindings in the panels are opened through the application of heat from an electrical source, and the fibers are then separated with a similar process to the hydrothermal separation (Moezzipour et al., 2018).

Recycling of Electronic Waste

Formaldehyde may be present during the process of recycling electronic waste (e-waste) as the polymer phenol formaldehyde (PF) is used in electronic applications (Flaris et al., 2009). The recycling process of e-waste typically begins with the recovery of waste from different storage facilities (Flaris et al., 2009). The waste then usually undergoes a pretreatment technology consisting of washing, size reduction, sorting, and melt filtration (Flaris et al., 2009). The sorting of plastics is the typical next step in the process and may use separation techniques such may include density-based sorting, electrostatic sorting, and others (Flaris et al., 2009). The formal recycling process can consist of either a mechanical, chemical or thermal recycling process (Flaris et al., 2009).

4.10.1.2 Worker Activities

For recycling activities, workers are potentially exposed to formaldehyde during loading and unloading of transport containers, and during pretreatment processes such as washing and sorting. Workers may also be exposed via inhalation or dermal pathways during container and equipment cleaning. EPA did not find information that indicates the extent of engineering controls and use of PPE by workers at facilities that recycle formaldehyde.

ONUs include employees (*e.g.*, supervisors, managers) at the recycling site who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, and no expected dermal exposure.

4.10.1.3 Inhalation Exposure Estimates

EPA did not identify any PBZ monitoring data to assess exposures during the recycling of formaldehyde containing products. Recycling typically involves breaking down the product (*e.g.*, shredding, grinding, melting). Products containing formaldehyde that are typically recycled include paper, plastic products, and composite wood products. EPA assumes that the recycling process is similar to the original manufacturing of these products. Therefore, EPA assessed inhalation exposures during recycling formaldehyde products using monitoring data from the OES with the most conservative estimates, which is composite wood product manufacturing. The information and data quality valuation to assess occupational exposures during composite wood product manufacturing is described in detail in Section 4.7.1.

4.10.1.1 Weight of Scientific Evidence in Inhalation Exposure Estimates

Exposure to workers and ONUs is assessed using formaldehyde PBZ monitoring data collected at facilities manufacturing wood products as a surrogate for facilities recycling formaldehyde. The primary limitation is the use of surrogate monitoring data, which was determined to have confidence ratings ranging from medium to high through EPA's systematic review process. Although these data are not directly applicable to the recycling facilities, EPA expects a high degree of overlap of worker tasks at both wood product manufacturing sites and sites recycling formaldehyde products. Another limitation is that the OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight to moderate for both 8-hour and 15-minute estimates, and they provide a plausible estimate of exposures.

4.10.1.2 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 5 percent based on a study of the phenol-urea-formaldehyde resin concentration in oriented strandboard (Oh and Kim, 2015). The calculated occupational dermal exposures for this OES are 70 $\mu g/cm^2$ as the central tendency value and 105 $\mu g/cm^2$ as the high-end value.

4.11 Distribution in Commerce

4.11.1 Storage and Retail Stores

COU: Distribution in commerce

4.11.1.1 Process Description

Distribution into commerce includes any distributive activity (*e.g.*, transportation) in which benefit is gained by the transfer, even if there is no direct monetary gain. EPA anticipates that formaldehyde and its products are distributed throughout commerce for the COUs evaluated throughout other lifecycle stages assessed in this evaluation. The physical form of formaldehyde in transit can vary amongst the different COUs in this report. Domestically manufactured commodity chemicals, such as formaldehyde, may be shipped within the United States in liquid cargo barges, railcars, tank trucks, tank containers, intermediate bulk containers (IBCs)/totes, and drums. Both imported and domestically manufactured commodity chemicals may be repackaged by wholesalers for resale, such as repackaging bulk packaging into drums or bottles (Tomer and Kane, 2015).

Distribution in commerce may include loading and unloading activities that occur during other life cycle stages (*e.g.*, manufacturing, processing, use, disposal), transit activities that involve the movement of formaldehyde (*e.g.*, via motor vehicles, railcars, water vessels), and temporary storage and warehousing of the chemical during distribution (excluding repackaging and other processing activities, which are included in other COUs). Therefore, EPA assessed the distribution in commerce activities resulting in releases and exposures (*e.g.*, loading, unloading) throughout the various life cycle stages and COUs rather than a single distribution scenario (U.S. EPA, 2020b). Data for assessing releases and exposures occurring during the transportation of chemicals between facilities, such as those from accidental spills, are generally not available.

4.11.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during distribution in commerce of formaldehyde and formaldehyde products, primarily during loading and unloading activities, and transit activities (U.S. EPA, 2020b). EPA did not find information that indicates the extent of engineering controls and PPE used by workers at facilities that perform distribution in commerce operations.
ONUs include employees (*e.g.*, supervisors, managers) at distribution in commerce sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.11.1.3 Inhalation Exposure Results

The information and data quality valuation to assess occupational exposures during storage and retail is listed in Table 4-29 and described in detail below. Table 4-30 summarizes the 8-hour TWA, monitoring data for the use of formaldehyde in storage and retail.

Table 4-29. Storage and Retail Stores Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	97	Medium	(OSHA, 2019)

All of the monitoring data is from OSHA's CEHD in the merchant wholesalers, durable and nondurable goods sectors. The worker activities conducted during sampling is unknown. The methodology for obtaining and analyzing this data is described in Section 2.5.1. Data were not available to estimate 15-

minute and short-term exposures.

For the 8-hour TWA data, it should be noted that 10 percent of the samples measured below the LOD. For the 15-minute data, 57 percent of the samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

EPA did not identify ONU data for exposure estimates. EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate 8-hour TWA exposures for ONUs.

The high-end and central tendency values for the 15-minute and 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-30.

Table 4-30. Summary of Inhalation Exposure Monitoring Data for Storage and Retail

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.15	0.62	60	0.15	0	Medium
15-minute TWA	0.1	1.2	37	EPA did not identify 15-minute data for ONUs		N/A
Short-term TWA	EPA did not identify data for workers or ONUs					N/A

EPA did not identify any non-discrete PBZ data for workers or ONUs during in storage and retail stores.

4.11.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which were determined to have confidence ratings of medium, through EPA's systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. There is some uncertainty in the 15-minute estimates since over 50 percent of the samples were below the LOD. EPA also assumed 8 exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for both 8-hour TWA and peak (15-minute) estimates but they provide a plausible estimate of exposures.

4.12 Industrial Use – Non-incorporative Activities – Used in: Construction

4.12.1 Furniture Manufacturing

COU: Industrial use – non-incorporative activities – used in: construction

4.12.1.1 Process Description

Furniture manufacturing includes several sources of formaldehyde exposures including use of composite wood products, coatings and adhesives containing formaldehyde, textile products, and others. Liquid spray coatings are used in the metal and wooden furniture industry (U.S. EPA, 2004b). Coatings may be used directly from the manufacturer, or they may be mixed with a solvent or other components to achieve the desired viscosity. If coatings are used directly as received from the manufacturer, they are typically stirred to ensure that all components in the coating are uniformly distributed. Coatings may be continuously mixed in tanks that are sized appropriately for the expected usage of the coating.

Metal furniture requires surface cleaning before coating application. Cleaning typically involves alkaline or acidic cleaning, water rinse, phosphate treatment, another water rinse, pretreatment (application of rust inhibitor or adhesion promotor), and/or water rinse, and finally drying. Coatings are applied either manually or automatically in spray booths that contain dry filters to collect overspray. Overspray may be disposed of as waste or reused. After the application of a coating, metal furniture is transferred to a flash-off area and then to a curing oven, whereas wooden furniture is cured between each coating application. The wooden furniture may be sent through coating and curing multiple times before the final wooden part is produced. Interior wooden furniture may require additional finishing steps such as staining, wash coating, filling, and sealing. Exterior wooden furniture finishing involves similar steps as interior wooden furniture, except exterior furniture is typically primed with fungicide and water-repellant. After the wooden furniture has been stained or painted, a topcoat such as a varnish or shellac may be applied (U.S. EPA, 2004b).

4.12.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during furniture manufacturing, primarily during cutting and machining of the panel boards and coating application processes. Workers may also be exposed via inhalation and dermal pathways during loading/unloading of transport containers lamination, and container and equipment cleaning (Peteffi et al., 2015). EPA did not find information that indicates the extent of engineering controls and PPE used by workers at facilities that perform furniture manufacturing in the United States.

ONUs include employees (*e.g.*, supervisors, managers) at furniture manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.12.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during furniture manufacturing is listed in Table 4-31 and described in detail below. Table 4-32 summarizes the 8-hour TWA and short-term monitoring data for furniture manufacturing.

Table 4-31. Furniture Manufacturing Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Sewer and cushion finisher to make cushions for outdoor furniture	PBZ monitoring data	6	High	(Marlow, 1995)
Packaging, lamination, edge painting, machining and drilling, board cutting	PBZ monitoring data	7	Medium	(Peteffi et al., 2015)
Spray painting during furniture manufacturing	PBZ monitoring data	61[a]	Medium	(Akinyemi et al., 2019)
Spray coating during furniture manufacturing	PBZ monitoring data	1	Medium	(Ioras et al., 2010)
Unknown	PBZ monitoring data	267	Medium	(OSHA, 2019)

[a] EPA used the median value out of 61 short-term PBZ samples.

EPA recognizes that worker job titles and activities may vary significantly from site to site; therefore, EPA typically identified samples as worker samples unless it was explicitly clear from the job title (*e.g.*, inspectors) and the description of activities in the report that the employee was not directly involved in furniture manufacturing during the sampling period.

Discrete short-term PBZ samples were not available, therefore EPA used a sample with a maximum concentration of 2.18 ppm for the high-end and a median sample of 1.6 ppm for the central tendency. The source for the high-end concentration sampled spray coating at furniture manufacturers in Malaysia, Indonesia, Thailand, and Vietnam in 2009 (Ioras et al., 2010). The source for the central tendency sampled spray painting at furniture manufacturers in Nigeria in 2018 (Akinyemi et al., 2019).

Of the 142 8-hour TWA PBZ samples available, 129 were from OSHA's CEHD in the furniture and related product manufacturing sector. The methodology for obtaining and analyzing this data is described in Section 2.5.1. The other two sources sampled furniture manufacturing in Brazil in 2015, and cushion manufacturing in the United States in 1995 (Peteffi et al., 2015; Marlow, 1995).

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

It should be noted that 8 percent of the 8-hour TWA PBZ, 53 percent of the 15-minute and one of the short-term samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 15-minute, short-term, 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-32.

Table 4-32. Summary of Inhalation Exposure Monitoring Data for Furniture Manufacturing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.09	0.76	169	0.09	N/A	Medium to High
15-minute TWA	0.11	1.0	111	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	1.63	2.18	2	EPA did not identify short-term data for ONUs		Medium

EPA identified additional studies with PBZ monitoring data for furniture manufacturing that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the exposure estimates listed above. Vinzents (1993) measured full-shift worker exposures during furniture painting and gluing in a Denmark furniture manufacturing site. The geometric mean of the data collected during painting was 0.16 ppm (n = 43), and during gluing was 0.91 ppm (n = 396). Thetkathuek (2016) conducted monitoring data at a medium-density fiberboard manufacturing site in Thailand. The full-shift worker exposures ranged from 0.0 to 21 ppm, with arithmetic means ranging from 0.57 to 8.3 ppm. The worker activities included drilling, edging, laminating, and packing. The study also measured ONU exposures ranging from 0.0 to 4.2 ppm, with an arithmetic mean of 1.52 ppm (n = 12). Ioras (2010) collected short-term monitoring data for workers conducting spray coating at furniture manufacturing sites in Malaysia, Indonesia, Thailand, and Vietnam. The samples ranged from 1.7 to 2.2 ppm, with an arithmetic mean of 1.9 ppm (n = 2000). ECHA (2019) aggregated exposure data for workers in the furniture industry with an exposure value of 0.88 mg/m^3 (n = 36). The data consisted of personal and stationary long- and short-term monitoring data.

4.12.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour TWA and short-term inhalation exposures, both of which have a predominantly medium data quality rating from the systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, the lack of worker descriptions, and the datedness of the samples. There is some uncertainty in the 15-min estimates since over 50 percent of the samples were below the LOD. EPA also assumed 8 exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate to robust for 8-hour TWA and moderate for peak (15-minute) exposure estimates and provides a plausible estimate of exposures.

4.12.1.5 Dermal Exposure Results

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 30 percent, based on CDR data on adhesives and varnishes that may be used in furniture manufacturing. The calculated occupational dermal exposures for this OES are 420 µg/cm^2 as the central tendency value and

630 µg/cm^2 as the high-end value.

4.13 Industrial Use – Non-incorporative Activities – Oxidizing/Reducing Agent, Processing Aids, Not Otherwise Listed

4.13.1 Processing Aid

4.13.1.1 Process Description

Formaldehyde is used as a reducing agent in the electroless copper plating process to reduce Cu^{2+} ions to Cu^0 (IPC International, 2019). The electroless copper plating process includes hole formation, hole wall prep, electroless copper hole wall plating, and electrolytic hole wall plating. The formaldehyde concentration for electroless copper plating processes ranges from 3 to 6 g/L (IPC International, 2019).

Formaldehyde is used in the semiconductor manufacturing industry as a processing aid for metal plating formulations (SIA, 2020). Formaldehyde may be present in semiconductor products as a byproduct in concentrations less than 10 ppm. Semiconductor device fabrication creates integrated circuits present in electronic devices. The fabrication process starts with a semiconductor material wafer. During the photolithography step, the wafer is coated with photoresist material and covered with a mask that defines patterns to be retained or removed in the following processing steps. Formaldehyde may be present in the photoresist material utilized in this step of the process (SIA, 2020).

4.13.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of formaldehyde as a processing aid during the application of photolithographic materials and the manufacturing of semiconductors (SIA, 2020). EPA did not find information that indicates the extent of engineering controls and PPE used by the workers at facilities that perform semiconductor manufacturing operations.

ONUs include employees (*e.g.*, supervisors, managers) at semiconductor manufacturing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.13.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of formaldehyde as a processing aid is listed in Table 4-33 and described in detail below. Table 4-34 summarizes the 8-hour TWA and short-term monitoring data for use of formaldehyde as a processing aid.

Table 4-33. Processing Aid Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	76	Medium	(OSHA, 2019)
Unknown worker activities during electroplating	Area monitoring data[a]	2	Medium	(Ho et al., 2013)
[a] Discrete short-term PBZ samples were not available; therefore, EPA used discrete area samples for the short-term exposure estimate.				

All 8-hour TWA PBZ samples available were from OSHA's CEHD in the fabricated metal product manufacturing and the computer and electronic product manufacturing sectors. The methodology for obtaining and analyzing this data is described in Section 2.5.1. Short-term PBZ samples were not available, however EPA provides area samples provided by Ho, collected in an electroplating factory in China (Ho et al., 2013).

It should be noted that 7 percent of the 8-hour TWA PBZ, 66 percent of the 15-minute TWA and one of the short-term samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-34.

Table 4-34. Summary of Inhalation Exposure Monitoring Data for Processing Aid

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.04	0.25	44	0.04	N/A	Medium
15-minute TWA	0.07	0.18	32	EPA did not identify 15-minute data for ONUs		N/A
Short-term TWA	0.019	0.023	2	EPA did not identify short-term data for ONUs		Medium

4.13.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour inhalation exposures and area concentrations for short-term exposures, both of which have a medium data quality rating from the systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, the lack of worker descriptions, and the datedness of the samples. There is some uncertainty in the 15-min estimates since over 50 percent of the samples were below the LOD. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for 8-hour TWA and for 15-minute data.

4.13.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 35 percent based on data provided by IPC International via public comment (IPC International, 2019). The minimum concentration reported was 0.1 percent based on data provided by the Semiconductor Industry Association via public comment (SIA, 2020). The calculated occupational dermal exposures for this

OES are 490 μg/cm² as the central tendency value and 735 μg/cm² as the high-end value.

4.14 Industrial Use – Non-incorporative Activities – Process Aid in: Oil and Gas Drilling, Extraction, and Support Activities; Process Aid Specific to Petroleum Production, Hydraulic Fracturing

4.14.1 Use of Formaldehyde for Oilfield Well Production

4.14.1.1 Process Description

Hydraulic Fracturing

Public comments have identified formaldehyde as a chemical of concern in hydraulic fracturing fluid (EDF, 2019). Facilities have also self-reported to FracFocus 3.0 that formaldehyde is present in hydraulic fracturing fluid additives as an inhibitor aid, corrosion inhibitor, friction reducer, bactericide (Green-Cide 25G), surfactant, acid, breaker, gelling agent, crosslinker, iron cont. (GWPC and IOGCC, 2022).

Hydraulic fracturing stimulates an existing oil or gas well by injecting a pressurized fluid containing chemical additives into the well (U.S. EPA, 2022d). EPA did not find specific container information for formaldehyde in hydraulic fracturing; however, the Draft ESD on Hydraulic Fracturing indicates that hydraulic fracturing fluids typically arrive as a liquid in totes, drums, or bulk containers (U.S. EPA, 2022d). Hydraulic fracturing fluid formulations are usually charged to a temporary storage tank, or fracturing fluid additives are charged to a mixing tank with other additives to formulate the final fracturing fluid that is injected into the well (U.S. EPA, 2022d).

Once fracturing fluid is formulated to the desired specification, the injection process may begin (U.S. EPA, 2022d). The hydraulic fracturing fluid is pumped into a wellbore where it cracks and permeates the rock below (U.S. EPA, 2022d). A portion of the fracturing fluid, including any chemical additives such as formaldehyde, may remain in the underground shale formation (U.S. EPA, 2022d). The remaining fluid will return to the surface in water that flows back to the surface from the well (U.S. EPA, 2022d). This is known as flow-back water. Initially, this flow-back water is mostly fracturing fluid, which includes chemical additives, but as time goes on, it becomes water produced from the rock formation (U.S. EPA, 2022d).

Wastewater containing chemical additives such as formaldehyde is usually stored and accumulated at the surface for eventual reuse or disposal (U.S. EPA, 2022d). Typical storage facilities include open-air impoundments and closed containers. This wastewater is collected and may be taken to disposal wells, recyclers, wastewater treatment plants (on- or off-site), or in some cases the water may be left in pits to evaporate or infiltrate (U.S. EPA, 2022d).

Traditional Oil Well Production

Traditional oil extraction is comprised of four main steps: (1) exploration, (2) well development, (3) petroleum production, and (4) site abandonment. The scope of this COU will focus on the petroleum production portion of the extraction process (OECD, 2012).

According to the Emission Scenario Document for Oil Well Production, the main activities typically involved in petroleum production are bringing the fluid to the surface and separating each component in the extracted fluid. The extracted mixture is typically first processed to remove the gaseous components, followed by the removal of solids from the resulting emulsion. The remaining oil-water emulsion is then further treated to separate the oil.

Petroleum production is typically divided into three stages: primary production, secondary recovery, and tertiary recovery (OECD, 2012). Primary production is the first stage of production where natural well pressure is used to recover oil (OECD, 2012). This segment of the production process usually only utilizes maintenance chemicals, such as corrosion inhibitors, to protect metallic components of the piping and well structure (OECD, 2012). After primary production is no longer feasible, secondary recovery is then employed (OECD, 2012). This process typically involves the injection of water into the well to re-pressurize the reservoir. The only chemicals in this stage of the process are those which remain from primary production (OECD, 2012). Tertiary recovery is the final stage of petroleum production which is typically used only when the other methods have been exhausted (OECD, 2012). The chemicals involved in this process may include surfactants, friction reducers, gases, acids, and proppants (OECD, 2012). The goal of this stage is to modify the physical characteristics of the crude oil to make it more conducive to flow. The main occupational exposure for petroleum production is chemical unloading (Figure 4-7) (OECD, 2012).

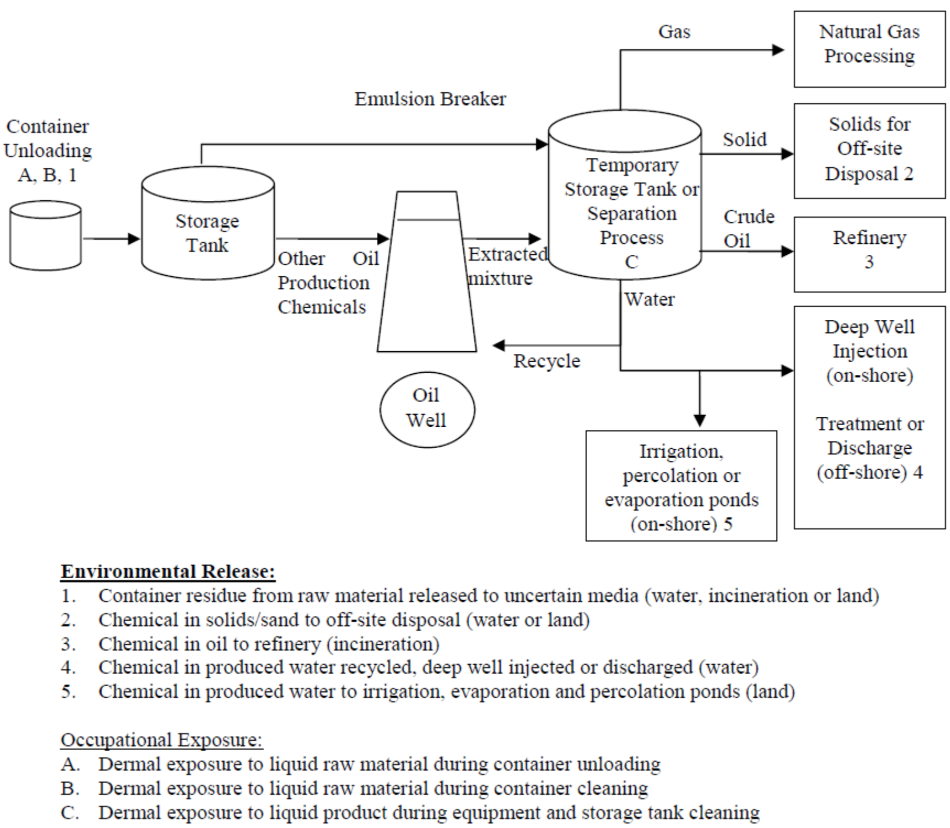


Figure 4-7. Preliminary Process Flow Diagram with Releases and Exposures for Oil Well Production (OECD, 2012)

4.14.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during oilfield well production during loading/unloading of liquid raw material from transport containers, during container cleaning, and during equipment and storage tank cleaning (OECD, 2012). EPA did not find information that indicates the extent of engineering controls and use of PPE by workers at facilities that perform oilfield well production operations.

ONUs include employees (*e.g.*, supervisors, managers) at oilfield well production sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.14.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of formaldehyde for oilfield well production is listed in Table 4-35 and described in detail below. Table 4-36 summarizes the 8-hour TWA monitoring data for use of formaldehyde in oilfield well production.

Table 4-35. Use of Formaldehyde for Oilfield Well Production Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	5	Medium	(OSHA, 2019)

Short-term was not available. All of the 15-minute data in OSHA CEHD was below the LOD and was not incorporated. One 8-hour TWA PBZ samples available were from OSHA's CEHD in the oil and gas extraction sector. The worker activities conducted during the sampling period are unknown. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-36.

Table 4-36. Summary of Inhalation Exposure Monitoring Data for the Use of Formaldehyde for Oilfield Well Production

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.01	0.23	5	0.01	N/A	Medium

EPA did identify one study that measured formaldehyde exposures for workers adding formaldehyde as a biocide during water injection at an oil well in Norway with a range of 0.049 to 0.24 ppm (n = 6), and a mean of 0.11 (Steinsvag et al., 2007). While this use is a non-TSCA activity, the activities may be similar to TSCA activities during oilfield well production.

4.14.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour inhalation exposures, which has a medium data quality rating from the systematic review process. The primary limitations of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, the limited samples available, and the datedness of the samples. In addition, EPA mapped these sites to this OES based on a SIC to NAICS code crosswalk, and the SIC code 2819 (Industrial Inorganic Chemicals) can be applicable to several NAICS codes. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight for 8-hour TWA yet provides a plausible estimate of exposures.

4.14.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 60 percent. Corrosion inhibitors generally arrive in formulations between 10 to 50 percent, but other types of inhibitors arrive at higher concentrations (OECD, 2012). FracFocus had a large range of concentrations cited from 0.01 to 100 percent . However, EPA did not consider these concentrations when calculating dermal exposures as formaldehyde would be in the gas phase or at elevated temperatures. The calculated occupational dermal exposures for this OES are 840 µg/cm^2 as the central tendency value and 1,260 µg/cm^2 as the high-end value.

4.15 Industrial Use – Chemical Substances in Industrial Products – Paints and Coatings; Adhesives and Sealants; Lubricants

EPA has evaluated three occupational exposure scenarios:

- Use of coatings, paints, adhesives, or sealants (non-spray applications) and (spray applications) (see Section 4.5.1);
- Industrial use of lubricants; and
- Foundries.

4.15.1 Industrial Use of Lubricants

4.15.1.1 Process Description

Formaldehyde is used in industrial lubricants in concentrations of greater than 0.2 percent (NICNAS, 2006). Lubricants are used to reduce friction between surfaces in relative motion with each other (OECD, 2004b). A public comment submitted by the Aerospace Industries Association indicates that formaldehyde is a component of dry film lubricants, general lubricants, and lubricating oil used in the aerospace industry (AIA, 2019).

EPA did not identify container-specific information on formaldehyde in lubricants; however, EPA assumes formulations to arrive at the facility in large containers (OECD, 2004b). Conveyor lubricant is a type of industrial lubricant containing 0.3 percent formaldehyde and is used to provide protection and lubrication for conveyor belts made of plastic and steel (NICNAS, 2006). The lubricant is manually diluted with water to a formaldehyde concentration of 0.1 percent. The lubricant is continuously distributed onto the conveyor belt via an enclosed automated system (NICNAS, 2006). After use, the spent oil may be disposed of in a landfill or incineration, reused as fuel oil, reprocessed, or regenerated (OECD, 2004b). Lubricants may be replaced every one to five years, depending on the type of lubricant (OECD, 2004b). EPA did not identify specific process information for dry film lubricants, general lubricants, or lubricating oil; although, EPA expects the process to be similar to conveyor lubricants.

4.15.1.2 Worker Activities

Workers are potentially exposed to formaldehyde in industrial processes that use formaldehyde as a lubricant during container unloading and container cleaning (OECD, 2020). EPA did not find information that indicates the extent of engineering controls and PPE used by workers at facilities that perform industrial use of lubricants.

ONUs include employees (*e.g.*, supervisors, managers) at industrial use of lubricants sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.15.1.3 Inhalation Exposure Estimates

EPA did not identify inhalation monitoring data to assess exposures during industrial use of lubricants. Therefore, EPA estimated inhalation exposures using a Monte Carlo simulation of models based on the OES. EPA assumed that the formaldehyde-containing product arrives at the site in its final formulation and is used with no engineering controls present. Actual exposures may differ based on worker activities, formaldehyde throughputs, and facility processes.

For this scenario, EPA applied the EPA Mass Balance Inhalation Model to exposure points in the OECD ESD on Chemical Additives used in Automotive Lubricants (OECD, 2020). The EPA Mass Balance Inhalation Model estimates the amount of chemical inhaled by a worker during a vapor-generating activity. EPA estimated the inhalation exposure for the first exposure point using a vapor generation rate (*G*) and exposure duration based on the OECD *ESD on Chemical Additives Used in Automotive Lubricants* (OECD, 2020). EPA calculated vapor generation rates for these exposure points with possible vapor generation rate models and default values presented in the OECD ESD on Chemical Additives used in Automotive Lubricants (OECD, 2020). The Monte Carlo simulation varies the following parameters: ventilation rate, mixing factor, working years, operating days, unloading saturation factor, and air speed.

EPA used the vapor generation rate, exposure duration parameters, and the EPA Mass Balance Inhalation Model to determine a time-weighted average (TWA) exposure for each exposure point. EPA assumed the same worker performed each activity throughout their work shift and estimated the 8-hour TWA by combining the exposures from each exposure point and averaging over 8-hours within the Monte Carlo simulation. EPA assumed workers had no exposure outside each exposure activity. Table 4-37 summarizes the estimated 8-hour TWA exposures for use of formulations containing formaldehyde in industrial use of lubricants based on the two approaches to the second exposure point described above. The high-end values represent the 95th percentile and the central tendency values represent the 50th percentile of the simulation outputs. Methods for calculating 8-hour TWA, AC, ADC, and LADC.

Table 4-37. Summary of Inhalation Exposure Modeling Data for the Industrial Use of Lubricants

Exposure Concentration Type	Central Tendency (ppm)	High-End (ppm)	Data Quality Rating of Air Concentration Data
Inhalation Exposure during container unloading or transferring	4.21E−01	1.49E00	N/A – Modeled data
Container Cleaning Exposure	2.71E−02	9.85E−02	
8-hour TWA (Total Exposure)	7.92E−03	2.78E−02	

4.15.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

8-hour TWA inhalation exposure estimates are assessed using Monte Carlo modeling with information from the OECD ESD on Chemical Additives used in Automotive Lubricants, and EPA/OPPT models. Factors that increase the strength of evidence for this OES are that the ESD and has high overall data quality, high number of data points (simulation runs), and full distributions of input parameters (OECD, 2020). The Monte Carlo modeling accounts for the entire distribution of input parameters, calculating a distribution of potential exposure values that represents a larger proportion of sites than a discrete value. Factors that decrease the strength of the evidence for this OES include that the ESD is not directly applicable to industrial use of lubricants, uncertainty in the representativeness of evidence to all sites, and uncertainty in the use of generic default values from the ESD for sites that specifically use formaldehyde. Based on this information, EPA has concluded that the weight of scientific evidence for this assessment is moderate and provides a plausible estimate of exposures.

4.15.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. Both the high-end and central tendency dermal exposures were assessed at a concentration of 0.2 percent based on data from the 2006 formaldehyde report from the NICNAS (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 2.8 µg/cm^2 as the central tendency value and 4.2 µg/cm^2 as the high-end value.

4.15.2 Foundries

4.15.2.1 Process Description

Formaldehyde-based phenol resins are used as liquid binding agents to coat sand that is then used in the core making in the foundry industry (Löfstedt et al., 2011b; NTP, 2010; Oliva-Teles et al., 2009; NICNAS, 2006; RTI, 1980; Kominsky and Stroman, 1977). The resins generally contain 2 to 6 percent free formaldehyde (NICNAS, 2006). This condition of use was not reported in the 2016 or 2020 CDR.

The formaldehyde resin arrives at sand coating sites in large drums (NICNAS, 2006). The resin is pumped into a mixer and typically mixed with silica sand for 5 minutes (Oliva-Teles et al., 2009; NICNAS, 2006). Some sites may decant the resin manually from drums into a measuring cup, then pour it into the mixer. After mixing, the coated sands are decanted into bags for core-making at foundry sites. The sand coating is a batch operation, and the frequency may vary depending on the site (NICNAS, 2006).

At foundry sites, iron castings are produced for the manufacture of metal products (Löfstedt et al., 2011b; NICNAS, 2006). The coated sand arrives in bags from the sand coating sites and is used to make solid shape “cores,” via a binding system. The cores determine the internal cavities of the casting. Cores are primarily produced by hot or warm box technology using urea formaldehyde resin. The hot box system generally contains 5 to 6 percent formaldehyde in the resin, while the warm box system may contain 2 to 3 percent formaldehyde. The sand coated with resin is blown into a hot mold, where the formaldehyde resin melts and acts as a binding agent to form the core. At larger operations, sand coating and core making may take place in an enclosed system, where a set dosage of formaldehyde resin is automatically supplied to core-making machines (Löfstedt et al., 2011b; Löfstedt et al., 2011a; Löfstedt et al., 2009; NICNAS, 2006; NIOSH, 1993).

4.15.2.2 Worker Activities

Workers are potentially exposed to formaldehyde during foundry processes during loading/unloading of transport containers, container and equipment cleaning, during decanting of resin into mixers, and during core making (NICNAS, 2006). Literature sources stated common engineering controls are exhaust ventilation systems (McCammon, 1998). EPA did not identify the extent to which workers used PPE at foundry facilities.

ONUs include employees (*e.g.*, supervisors, managers) at foundry sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.15.2.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during the use of formaldehyde in foundries is listed in Table 4-38 and described in detail below. Table 4-39 summarizes the 8-hour TWA and short-term monitoring data for foundries.

Table 4-38. Foundries Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Core unloading and subassembly, core racking	PBZ monitoring data	6	Medium	(NICNAS, 2006)
Operating sand mixer	PBZ monitoring data	1	High	(McCammon, 1998)
Unknown	PBZ monitoring data	637	Medium	(OSHA, 2019)

Only one short-term PBZ sample was available, therefore EPA used it for both the high and central tendency as stated in Section 2.5.1 (McCammon, 1998). Of the 395 8-hour TWA samples available, 388 of them came from the OSHA's CEHD in the primary metal and fabricated metal product manufacturing sectors. The worker activities conducted during the sampling period is unknown. The other six samples come from sampling of workers core making (NICNAS, 2006).

It should be noted that 6 percent of the 8-hour TWA PBZ and 87 percent of the 15-minute TWA samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-39.

Table 4-39. Summary of Inhalation Exposure Monitoring Data for Foundries

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hour TWA	0.09	0.48	476	0.09		0	Medium
15-minute TWA	0.08	0.63	169	EPA did not identify 15-minute data for ONUs			Medium
Short-term TWA	2.36	2.36	1	EPA did not identify short-term data for ONUs			High

EPA identified additional studies with PBZ monitoring data for the use of formaldehyde in foundries that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the estimates listed above. In the 2006 formaldehyde NICNAS report, monitoring data from two Australian foundries ranged from 0.007 to 2.0 ppm for workers involved in foundry core making (NICNAS, 2006). Three studies measured at facilities in Sweden reported worker exposures at foundries which use formaldehyde-based resins in core-making (Löfstedt et al., 2011a; Löfstedt et al., 2009; Westberg et al., 2005). The monitoring data ranged from 0.0065 to 1.3 ppm for various worker activities such as core making, die-casting, and molding. Armstrong (2001) measured worker exposures at a foundry in Malaysia, the arithmetic mean was 0.16 ppm (n = 51).

4.15.2.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour inhalation exposures, which have a medium to high data quality rating from the systematic review process. Only one data point was available for short-term exposure, which increases the uncertainty in the exposure value. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, and lack of worker job descriptions. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. For 15-minute data, an additional limitation is that 87 percent of the data points were below the detection limit. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate to robust for both 8-hour and moderate for 15-minute exposure estimate and provides a plausible estimate of exposures.

4.15.2.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 6 percent and the minimum concentration assessed for this OES was 2 percent based on data from the 2006 formaldehyde report from the NICNAS (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 84 $\mu g/cm^2$ as the central tendency value and 126 $\mu g/cm^2$ as the high-end value.

4.16 Commercial Use – Chemical Substances in Furnishings Treatment/Care Products – Floor Coverings; Foam Seating and Bedding Products; Furniture and Furnishings Including Stone, Plaster, Cement, Glass and Ceramic Articles; Metal Articles; or Rubber Articles; Cleaning and Furniture Care Products; Leather Conditioner; Leather Tanning, Dye, Finishing Impregnation and Care Products; Textile (Fabric) Dyes; Textile Finishing and Impregnating/Surface Treatment Products

EPA evaluated the following OESs for this COU:

- Textile Finishing, see Section 4.4.1;
- Leather Tanning, see Section 4.4.2; and
- Installation and demolition of formaldehyde-based furnishings and building/construction materials in residential, public and commercial buildings, and other structures

4.16.1 Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public and Commercial Buildings, and Other Structures

4.16.1.1 Process Description

Furnishings and Construction/Building Materials

Formaldehyde-based resins are used as adhesives in the production of wood-based and composite panels including particleboards, medium-density fiberboard (MDF), oriented strand board (OSB), plywood, and blockboards (FWIC, 2020; Solenis, 2020; Offermann, 2017; Kim, 2010; NICNAS, 2006). Concentrations of formaldehyde in the resins used range from < 0.2 to 0.5 percent (NICNAS, 2006). Wood panel products may be used for shelving, furniture, doors, cabinets, and flooring. Plywood is used in several commercial applications, such as the construction of residential, commercial, or industrial structures, building components for homes or other structures, material handling such as pallets, and so-it-yourself (DIY) structures (NICNAS, 2006).

Wooden boards are cut to size on-site using a circular saw, then fitted and sanded before installation (NICNAS, 2006; NZ DOH, 1981). The lifespan of plywood, veneers, and wood paneling typically ranges from 20-100 years before demolition is required (U.S. EPA, 2003).

Foam and Fiberglass Insulation

Formaldehyde resins may also be present in fiberglass insulation and urea-formaldehyde foam insulation (NAIMA, 2019; Rossiter and Mathey, 1985; Enviro Control Inc., 1983; NIOSH, 1982c, 1980). According to public comment, final concentrations of formaldehyde in fiberglass insulation are negligible (NAIMA, 2019). EPA believes the use of formaldehyde in foam has significantly reduced; therefore, it is unlikely to be included in this assessment.

Phenol-formaldehyde resins are present in fibrous glass insulation used to seal annealing furnace doors (Price, 1978). Annealing furnaces may be used to relieve stress during the fabrication of steel tank cars (Price, 1978). Shell plates of stainless steel or carbon steel arrive at the facility in flat form. The plates are cut, rolled into cylinders, welded, then assembled to form a tank shell. Submerged arc welding is performed on the seams of the shell. Various fittings, fixtures, and pads are added to the shell via tack welding, flux-cored arc welding, or stick/wire electrode welding. After the welds are inspected, the tank car is stress relieved in an annealing furnace. The tank cars may be insulated with fibrous glass by manually wrapping rolls of the material around the outer wall of the tank and then welding an outer metal shell over the insulation. Valves, walkways, ladders, rails, and pipes are applied to the tank car. The car undergoes a final inspection after painting (Price, 1978).

4.16.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during installation and demolition of formaldehyde-based furnishings and building/construction materials during loading and unloading of transport containers, cleaning of transport containers, spray application of SPF, foam thickness verification, and SPF trimming activities (U.S. EPA, 2021a). EPA did not find information that indicates the extent of engineering controls and PPE used by workers at facilities that perform installation and demolition of formaldehyde-based furnishings and building/construction materials.

ONUs include employees (*e.g.*, supervisors, managers) at installation and demolition of formaldehyde-based furnishings and building/construction materials sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure

4.16.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during installation and demolition is listed in Table 4-40 and described in detail below. Table 4-41 summarizes the 8-hour TWA monitoring data for installation and demolition of formaldehyde-based furnishings.

Table 4-40. Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public and Commercial Buildings, and Other Structures Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	47	Medium	(OSHA, 2019)

Short-term and 15-minute samples were not available to estimate worker exposures. All 8-hour TWA samples were from OSHA's CEHD in the construction sector. The worker activities conducted during the sampling period is unknown. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

PBZ data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. Several area samples were provided by sources; however, some of the locations include office buildings and schools (Almaguer et al., 1995; Burr et al., 1993). In these locations EPA does not expect the ONUs to be installing or demolishing or be in the vicinity immediately after such an activity. Therefore, EPA has not included these sources in the exposure estimates. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.
It should be noted that 14 percent of the 8-hour TWA PBZ and 79 percent of the 15-minute TWA samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-41.

Table 4-41. Summary of Inhalation Exposure Monitoring Data for Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public and Commercial Buildings, and Other Structures

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.13	0.37	28	0.13	N/A	Medium
15-minute TWA	0.58	0.88	19	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		

EPA identified one additional study with PBZ monitoring data for the installation/demolition of formaldehyde-based furnishings and building/construction materials that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the estimates listed above. Scarselli et al. (2017) compiled monitoring data from the Italian information system on occupational exposure to carcinogens (SIREP). The woodworking machine setters and setter-operators occupational group had an arithmetic and geometric means of 0.12 ppm and 0.016 ppm, respectively.

In addition, Harley et al. (2021) measured short-term exposures to formaldehyde during the use of surface cleaners in domestic kitchens and bathrooms. The use of standard surface cleaners resulted in a geometric mean of 0.013 ppm (n = 50), and the use of "green" surface cleaners resulted in a geometric mean of 0.011 ppm (n = 50).

4.16.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour inhalation exposures, which have a medium data quality rating from the systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, and lack of PBZ and ONU data. For 15-min peak exposure estimates, 79 percent of the samples were below the LOD. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for 8-hour TWA and slight to moderate for peak (15-minute) exposure estimates and provides a plausible estimate of exposures.

4.16.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 24 percent, and the minimum concentration identified was 0.004 percent, both based on formaldehyde concentration data in construction and building material (Schwensen et al., 2017). The calculated occupational dermal exposures for this OES are 336 μg/cm^2 as the central tendency value and 504 μg/cm^2 as the high-end value.

4.17 Commercial Use – Chemical Substances in Treatment Products – Water Treatment Products

4.17.1 Use of Formulations containing Formaldehyde for Water Treatment

COU: Commercial uses – chemical substances in treatment products – water treatment products.

4.17.1.1 Process Description

In the 2016 CDR, two reporters indicated the commercial use of formaldehyde as a liquid in water treatment products (U.S. EPA, 2016). One facility reported 6 percent of its PV towards this use with a formaldehyde concentration of less than 1 percent by weight. The other facility reported 28 percent of its PV with a concentration of 1 to less than 30 percent by weight (U.S. EPA, 2016). This condition of use was not reported in the 2020 CDR. A safety data sheet (SDS) by CHEMetrics indicates the use of formaldehyde in water testing kits with a concentration of 0.1 to 0.2 percent by weight (CHEMetrics, 2018). Another safety data sheet by CHEMTREC indicates the use of formaldehyde as a waste treatment liquid chemical, although a concentration was not provided (Koch Turf, 2016). Water treatment facilities may use formulations containing 37 to 40 percent formaldehyde as an additive to sanitize the facility, although that use would be a non-TSCA use (NICNAS, 2006).

EPA did not find any container-specific information on formaldehyde in water treatment products. According to the GS on Water Treatment Disinfectants, other disinfectant chemicals arrive at water treatment sites in a tank car or tank truck (U.S. EPA, 1994c). EPA assumes the formaldehyde for non-pesticidal water treatment to arrive similarly. EPA expects that formaldehyde formulation will arrive, be unloaded then distributed for use in water systems.

4.17.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of formulations containing formaldehyde for water treatment during equipment cleaning, loading/unloading of containers, and process activities such as pulling solids from the bar screener (Dow Chemical, 2017b). EPA did not identify any information to indicate the extent to which workers used PPE in water treatment.

ONUs include employees (*e.g.*, supervisors, managers) at water treatment sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.17.1.3 Inhalation Exposure Estimates

EPA did not identify inhalation monitoring data to assess exposures during use of formulations containing formaldehyde for water treatment. Therefore, EPA estimated inhalation exposures during water treatment products using the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model. A detailed discussion of this model can be found in Appendix C.7

Table 4-42 summarizes the estimated full-shift TWA exposures for use of formulations containing formaldehyde in for water treatment based on the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model. The high-end values represent the 95th percentile and the central tendency values represent the 50th percentile of the model outputs.

Table 4-42. Summary of Inhalation Exposure Modeling Data for the Use of Formulations Containing Formaldehyde for Water Treatment

Exposure Concentration Type	Central Tendency (ppm)	High-End (ppm)	Data Quality Rating of Air Concentration Data
8-hour TWA	3.83E−02	1.55E−01	N/A – Modeled data

4.17.1.1 Weight of Scientific Evidence in Inhalation Exposure Estimates

8-hour TWA inhalation exposure estimates are assessed using EPA/OPPT models. Factor that increase the strength of evidence for this OES is that the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model is more robust than other EPA/OPPT standard models for assessing inhalation exposure. Factors that decrease the strength of the evidence for this OES are that: After each loading event, the model assumes saturated air containing formaldehyde that remains in the transfer hose and/or loading arm is released to air. The model calculates the quantity of saturated air using design dimensions of loading systems published in the OPW Engineered Systems catalog and engineering judgment. These dimensions may not be representative of the whole range of loading equipment used at industrial facilities.

The model estimates fugitive emissions from equipment leaks using total organic compound emission factors from EPA's Protocol for Equipment Leak Emission Estimates (U.S. EPA, 1995), and engineering judgement on the likely equipment type used for transfer (*e.g.*, number of valves, seals, lines, connections). The applicability of these emission factors to formaldehyde, and the accuracy of EPA's assumption on equipment type are not known.

The model assumes the use of a vapor balance system to minimize fugitive emissions. Although most industrial facilities are likely to use a vapor balance system when loading/unloading volatile chemicals, EPA does not know whether these systems are used by all facilities that potentially handle formaldehyde.

The model does not account for other potential sources of exposure at industrial facilities, such as sampling, equipment cleaning, and other process activities that can contribute to a worker's overall 8-hour daily exposure. These model uncertainties could result in an underestimate of the worker 8-hour exposure.

Based on this information, EPA has concluded that the weight of scientific evidence for this assessment is slight to moderate and provides a plausible estimate of exposures.

4.17.1.2 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 40 percent with the assumption of a concentrated formaldehyde solution used and diluted for water treatment purposes. The calculated occupational dermal exposures for this OES are 560 $\mu g/cm^2$ as the central tendency value and 840 $\mu g/cm^2$ as the high-end value.

4.18 Commercial Use – Chemical Substances in Treatment/Care Products – Laundry and Dishwashing Products

4.18.1 Use of Formulations Containing Formaldehyde in Laundry and Dishwashing Products

COU: Commercial uses – chemical substances in treatment products – water treatment products.

4.18.1.1 Process Description

Laundry Products

Safety data sheets have identified the use of formaldehyde in liquid laundry detergent and fabric softener (Colgate-Palmolive Company, 2016b; Phoenix Brands, 2007). The concentration of formaldehyde was not indicated in these SDSs. This COU was not reported in the 2020 or 2016 CDR. In the U.S., laundry facilities can be classified into two main categories: industrial and institutional (OECD, 2011c). Industrial laundries wash soiled laundry received from hospitals, repair shops, doctor's offices, and other customers. Institutional laundries are located within a hospital, nursing home, hotel, or other institutional facilities (OECD, 2011c).

EPA did not find container-specific information for formaldehyde in industrial or institutional laundry detergents. The ESD on Water Based Washing Operations at Industrial and Institutional Laundries indicates that industrial laundry detergents typically arrive as a liquid or powder in drums, totes, or bulk tanker trucks (OECD, 2011c). The ESD also indicates that institutional laundry detergents typically arrive as a liquid or powder in 5-gallon pails (OECD, 2011c). For both types of laundries, the soiled laundry is loaded into mechanical washers, and the laundry is washed using water and a detergent appropriate for the item type and soil loading (OECD, 2011c). Washing may be completed in cycles or a continuous process (OECD, 2011c). The washing machine generally rinses the laundry after washing to remove most of the wash chemicals (OECD, 2011c). Wastewater is transferred down drains to a POTW (OECD, 2011c).

Dishwashing Products

Am SDS identified formaldehyde in consumer liquid hand soap in concentrations ranging from 0 to 0.1 percent (Colgate-Palmolive Company, 2016a). EPA did not find any container-specific information on formaldehyde in hand soaps or other dishwashing products; however, EPA expects formulation to arrive as a liquid in small containers of various sizes. EPA did not identify any process-specific information for formaldehyde in dishwashing products. In an occupational setting, EPA expects hand soaps to be used when a worker washes their hands. Dirty water containing the used hand soap is expected to be rinsed down sink drains to POTWs. Similarly, EPA expects dishwashing soap to be used when a worker washes dishes. Water containing the used dishwashing soap is expected to be rinsed down sink drains to POTWs. The number and location of sites that use dishwashing products containing formaldehyde are unknown. EPA expects facilities using dish washing products to operate up to seven days per week, although it is uncertain that formaldehyde is used every day.

4.18.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of formulations containing formaldehyde in laundry and dishwashing products during loading\unloading activities, spot cleaning, and fabric pressing activities (Ceballos et al., 2016). EPA did not identify any information to indicate the extent to which workers used PPE in laundry and dishwashing sites.

ONUs include employees (*e.g.*, supervisors, managers) at laundry and dishwashing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.18.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of laundry and dishwashing products is listed in Table 4-43 and described in detail below. Table 4-44 summarizes the 8-hour TWA and short-term monitoring data for use of formulations containing formaldehyde in laundry and dishwashing products.

Table 4-43. Use of Formulations Containing Formaldehyde in Laundry and Dishwashing Products

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source(s)
Pressing fabrics, unloading and loading fabrics from dry cleaning machine	PBZ monitoring data	12	High	(Ceballos et al., 2016)
Dry cleaning area	Area Monitoring Data[a]	1	High	(Ceballos et al., 2016)
[a] Discrete short-term PBZ samples were not available; therefore, EPA used a discrete area sample for the short-term exposure estimate.				

Data for 15-minute was not available to estimate worker exposures. Discrete short-term PBZ samples were not available therefore EPA used a discrete area sample from a dry-cleaning shop. The area sample taken, using OSHA Method 52, had a concentration between the minimum detectable (0.008 ppm) and minimum quantifiable concentration (0.04 to 0.2 ppm), leading to higher uncertainty (Ceballos et al., 2016). All 8-hour TWA samples came from two papers that investigated fabric cleaning and dry-cleaning shops (Ceballos et al., 2016; Ceballos et al., 2015).

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

It should be noted that 12 of the 8-hour TWA PBZ and one of the short-term samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-44.

Table 4-44. Summary of Inhalation Exposure Monitoring Data for Use of Formulations Containing Formaldehyde in Laundry and Dishwashing Products

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.01	0.01	12	0.01	0	High
15-minute TWA	EPA did not identify 15-minute data for workers			EPA did not identify 15-minute data for ONUs		
Short-term TWA	0.04	0.04	1	EPA did not identify short-term data for ONUs		

4.18.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour inhalation exposures, which has a high data quality rating from the systematic review process. EPA used an area source for the short-term exposure as it was the only value available, however the source states that the sample is between the minimum detectable and minimum quantifiable concentration. This leads to more uncertainty associated with the short-term exposure value. The primary limitation of this data includes the uncertainty of whether the scenario covers industrial use of the type of laundry products identified, limited use information, and that over 50 percent of the 8-hour TWA data for workers were reported as below the LOD. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight, but still provides a plausible estimate.

4.18.1.5 Occupational Dermal Exposure Results

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The high-end and central tendency dermal exposures were both assessed using a concentration of 4 percent based on the Emission Scenario Document on the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries (OECD, 2011c). The calculated occupational dermal exposures for this OES are 56 µg/cm^2 as the central tendency value and 84 µg/cm^2 as the high-end value.

4.19 Commercial Use – Chemical Substances in Construction, Paint, Electrical, and Metal Products – Adhesives and Sealants; Paints and Coatings

EPA has evaluated two OESs:

- Use of coatings, paints, adhesives, or sealants (non-spray applications), see Section 4.5.1
- Use of coatings, paints, adhesives, or sealants (spray applications), see Section 4.5.1

4.20 Commercial Use – Chemical Substances in Furnishing Treatment/Care Products – Construction and Building Materials Covering Large Surface Areas, Including Wood Articles; Construction and Building Materials Covering Large Surface Areas, Including Paper Articles; Metal Articles; Stone, Plaster, Cement, Glass and Ceramic Articles

EPA has evaluated one OES:

- Installation and demolition of formaldehyde-based furnishings and building/construction materials in residential, public and commercial buildings, and other structures, see Section 4.16.1

4.21 Commercial Use – Chemical Substances in Electrical Products – Machinery, Mechanical Appliances, Electrical/Electronic Articles; Other Machinery, Mechanical Appliances, Electronic/Electronic Articles

4.21.1 Use of Electronic and Metal Products

4.21.1.1 Process Description

Formaldehyde is used to manufacture printed circuit boards, which are found in virtually all electronic products, including televisions, computers, printers, phones, weapons systems, and aerospace hardware (Schripp and Wensing, 2009; LaDou, 2006). The 2020 CDR cites use of formaldehyde as an intermediate in electronics (U.S. EPA, 2020a). Electrical and electronic products may be used in a variety of occupational settings, such as repair shops, office buildings, copy centers, and electronic waste recycling centers (Vicente et al., 2017; Schripp and Wensing, 2009; Klincewicz and Reh, 1989). The concentration of formaldehyde in electronic products is unknown; although, public comments report a negligible amount of formaldehyde in electronics (IPC International, 2020; SIA, 2020). EPA did not identify any process information related to the use of metal products containing formaldehyde.

4.21.1.2 Worker Activities

Workers may potentially be exposed to formaldehyde during use of electronic and metal products during equipment cleaning. EPA did not identify information that indicates the extent of engineering controls and PPE used by workers at facilities that perform use of electronic and metal product operations.

ONUs include employees (*e.g.*, supervisors, managers) at use of electronic and metal products sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.21.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of electronic and metal products is listed in Table 4-45 and described in detail below. Table 4-46 summarizes the 8-hour TWA monitoring data for the use of electronic and metal products containing formaldehyde.

Table 4-45. Use of Electronic and Metal Products Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	46	Medium	(OSHA, 2019)
Electronic Technician	PBZ monitoring data	1[a]	Medium	(Akinyemi et al., 2019)

[a] EPA used the median value for high-end and central tendency calculations.

Short-term discrete data was not available to estimate worker exposures; however, EPA identified a median value to use for the high-end and central tendency exposure estimates. The study sampled electronic technicians conducting their routine repair activities in their workshops (Akinyemi et al., 2019). The 8-hour TWA samples were from OSHA's CEHD. OSHA sampled companies within the professional, scientific, and technical services sector as well as the electrical equipment, appliance and component manufacturing sector. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

It should be noted that 4 percent of the 8-hour TWA PBZ and 18 percent of the 15-minute TWA samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs for the 8-hour TWA estimates.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-46.

Table 4-46. Summary of Inhalation Exposure Monitoring Data for Use of Electronic and Metal Products

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.05	0.51	29	0.05	N/A	Medium
15-minute TWA	0.38	1.14	17	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	0.06		1	EPA did not identify short-term data for ONUs		Medium

EPA did not identify any non-discrete PBZ monitoring data for workers or ONUs during the use of electronic and metal products.

4.21.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which has a medium data quality rating from the systematic review process. The OSHA CEHD monitoring data does not include process information or worker activities; therefore, there is uncertainty as to which worker activities these data cover and whether all potential worker activities are included in this data. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate and provides a plausible estimate of exposures.

4.21.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 40 percent, and the minimum concentration assessed was 20 percent, both based on data from the Emission Scenario Document on Photoresist Use in Semiconductor Manufacturing (OECD, 2010). The calculated occupational dermal exposures for this OES are 560 µg/cm^2 as the central tendency value and 840 µg/cm^2 as the high-end value.

4.22 Commercial Use – Chemical Substances in Metal Products – Construction and Building Materials Covering Large Surface Areas, Including Metal Articles

EPA has evaluated one OES:

- Use of electronic and metal products, see Section 4.21.1

4.23 Commercial Use – Chemical Substances in Automotive and Fuel Products – Automotive Care Products; Lubricants and Greases; Fuels and Related Products

EPA has evaluated three OESs:

- Use of formulations containing formaldehyde in automotive care products;
- Use of automotive lubricants; and
- Use of formulation containing formaldehyde in fuels.

4.23.1 Use of Formulations Containing Formaldehyde in Automotive Care Products

COU: Commercial uses – chemical substances in automotive and fuel products - automotive care products; lubricants and greases; fuels and related products.

4.23.1.1 Process Descriptions

EPA did not identify formaldehyde-specific process information on automotive care products. According to the Automotive Detailing Methodology Review Draft (MRD), automotive detailing products arrive at facilities in small containers ranging from four ounces to 15 gallons (U.S. EPA, 2022b). Products may be applied directly onto the car or application equipment (*e.g.,* cloths, buffer pads) or diluted with water in a bucket before use. Before polishing and other detailing processes, the exterior of the vehicle to be detailed is washed, typically with a hose, bucket, and sponge. The interior of the vehicle may also be cleaned using compressed air to loosen dirt and then vacuum. Detailers may apply a protective coating to vinyl or leather surfaces by wiping the coating onto surfaces and removing excess coating with cloths. Carpet and upholstery are cleaned by pre-treating stains, then using portable carpet cleaning machines. Upon completion of the detailing process, the vehicle is returned to the customer (U.S. EPA, 2022b).

4.23.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of formulations containing formaldehyde in automotive care products during unloading chemicals from transport containers and the application and use of automotive detailing products (U.S. EPA, 2022b). EPA did not identify any information to indicate the extent to which worker PPE is used in automotive care sites.

ONUs include employees (*e.g.*, supervisors, managers) at automotive care sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.23.1.3 Inhalation Exposure Estimates

EPA did not identify inhalation monitoring data to assess exposures during use of formulations containing formaldehyde in automotive care products. Therefore, EPA estimated inhalation exposures using a Monte Carlo simulation of models based on the OES. EPA estimated inhalation exposures of formaldehyde by simulating two possible scenarios. EPA assumed that the formaldehyde-containing product arrives at the site in its final formulation and is used with no engineering controls present. Actual exposures may differ based on worker activities, formaldehyde throughputs, and facility processes.

For this scenario, EPA applied the EPA Mass Balance Inhalation Model to the first exposure point (Transfer Operation Exposures from Unloading Transport Containers) described in the *Draft GS on Commercial Use of Automotive Detailing Products* (U.S. EPA, 2022b). The EPA Mass Balance Inhalation Model estimates the amount of chemical inhaled by a worker during a vapor-generating activity. EPA estimated the inhalation exposure for the first exposure point using a vapor generation rate (*G*) and exposure duration based on the *Draft GS on Commercial Use of Automotive Detailing Products* (U.S. EPA, 2022b). EPA calculated vapor generation rates for the first exposure point with possible vapor generation rate models and default values presented in the draft GS. For the second exposure point (Application and Use of Automotive Detailing Products), EPA applied two approaches. The first was using industry monitoring data for total volatile organic compounds (TVOCs) cited in the draft GS. The second was assuming that all of the formaldehyde in the applied detailing product evaporates over the duration of the activity, and thus a vapor generation rate could be calculated and applied in the EPA Mass Balance Inhalation Model. The Monte Carlo simulation varies the following parameters: ventilation rate, mixing factor, saturation factor, loss factor, container sizes, working years, operating and exposure days, formaldehyde concentration in the auto detailing product, annual number of cars detailed per site, use rate of automotive detailing product per car, and mass concentration of formaldehyde in air for the second exposure point based on industry data cited in the draft GS.

EPA used the vapor generation rate, exposure duration parameters, and mass concentration of formaldehyde in air for the second exposure point from the *Draft GS on Commercial Use of Automotive Detailing Products* (U.S. EPA, 2022b) and the EPA Mass Balance Inhalation Model to determine a TWA exposure for each exposure point. EPA assumed the same worker performed each activity throughout their work shift and estimated the 8-hour TWA by combining the exposures from each exposure point and averaging over 8 hours within the Monte Carlo simulation. EPA assumed workers had no exposure outside each exposure activity. Table 4-47 summarizes the estimated full-shift TWA exposures for use of formulations containing formaldehyde in automotive care products based on the two approaches to the second exposure point described above. The high-end values represent the 95th percentile and the central tendency values represent the 50th percentile of the simulation outputs.

Table 4-47. Summary of Inhalation Exposure Modeling Data for the Use of Formulations Containing Formaldehyde in Automotive Care Products

Modeled Scenario	Exposure Concentration Type	Central Tendency (ppm)	High-End (ppm)	Data Quality Rating of Air Concentration Data
Scenario 1: Industry Data for Exposure Point 2	Transfer Operation Exposures from Unloading Transport Containers	3.26E−02	1.3E00	N/A – Modeled data
	Application and Use of Automotive Detailing Products	4.72E−01	3.01E00	
	Full-shift TWA exposure concentration (Total Exposure)	**2.97E−01**	**1.51E00**	
Scenario 2: Complete Evaporation for Exposure Point 2	Transfer Operation Exposures from Unloading Transport Containers	3.22E−02	1.3E00	
	Application and Use of Automotive Detailing Products	8.62E−01	2.81E01	
	Full-shift TWA exposure concentration (Total Exposure)	**4.38E−01**	**1.41E01**	

4.23.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

Inhalation exposure estimates are assessed using Monte Carlo modeling with information from the *Draft GS on Commercial Use of Automotive Detailing Products* (U.S. EPA, 2022b). Factors that increase the strength of evidence for this OES are that the draft GS has high overall data quality, high number of data points (simulation runs), and full distributions of input parameters (U.S. EPA, 2022b). The Monte Carlo modeling accounts for the entire distribution of input parameters, calculating a distribution of potential exposure values that represents a larger proportion of sites than a discrete value. Factors that decrease the strength of the evidence for this OES include uncertainty in the representativeness of evidence to all sites and uncertainty in the use of generic default values from the draft GS for sites that specifically use formaldehyde. Based on this information, EPA concluded that the weight of scientific evidence for this assessment is moderate and provides a plausible estimate of exposures.

4.23.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 30 percent, and the minimum concentration assessed was 1 percent based on reporting data for this OES in the 2020 CDR (U.S. EPA, 2020a). While there were reporters which reported in ranges up to 60 percent in the 2016 CDR, formaldehyde is not expected to be present in this concentration in automotive care products based on the 2020 reporting data (U.S. EPA, 2016). High-end dermal exposures are calculated based on a higher amount of formaldehyde remaining on skin upon immersion (10.3 mg/cm^2 per event), and the central tendencies are based on a lower amount of formaldehyde remaining on skin upon immersion (3.8 mg/cm^2 per event). The maximum concentration was used for both high-end and central tendency calculations. The calculated occupational dermal exposures for this OES are 420 µg/cm^2 as the central tendency value and 3,090 µg/cm^2 as the high-end value.

4.23.2 Use of Automotive Lubricants

COU: Commercial Uses – chemical substances in automotive and fuel products – automotive care products; lubricants and greases; fuels and related products.

4.23.2.1 Process Description

Formaldehyde is present in lubricants that may be used in the automotive industry (NICNAS, 2006). A lubricant is defined as a material used to reduce friction between surfaces in relative motion with each other (OECD, 2020). In the automotive industry, lubricants are used in gasoline and diesel engines. This COU was not reported in the 2016 or 2020 CDR. The formaldehyde concentration in automotive greases and lubricants is unknown. Based on the ESD on Chemical Additives Used in Automotive Lubricants, default concentration values for lubricant additives range from 0.1 to 20 percent (OECD, 2020).

EPA did not find any container-specific information on formaldehyde in automotive lubricants; however, EPA expects lubricants to arrive at automotive service facilities in 5-gallon or smaller containers. EPA did not identify process-specific information for formaldehyde in automotive lubricants. According to the ESD on Automotive Lubricants, the lubricant is directly injected into the engine of the vehicle (OECD, 2020). It is estimated that 25 percent of the lubricants in passenger cars and commercial vehicles are consumed during use. Most of the used lubricant is present in the exhaust gases as either combustion products or particulates. The remaining spent lubricant is either recycled for the use of in-house heating, reused for fuel oil after further treatment, or disposed of as municipal waste. The frequency of oil changes is specified by the vehicle manufacturer, typically depending on factors such as vehicle mileage and extent of use.

4.23.2.2 Worker Activities

Workers are potentially exposed to formaldehyde during use of automotive lubricants during loading/unloading of transport containers, equipment cleaning, and direct injection of lubricant into the engine (OECD, 2020). EPA did not identify information that indicates the extent of engineering controls and PPE used by workers at facilities that perform use of automotive lubricant operations.

ONUs include employees (*e.g.*, supervisors, managers) at use of automotive lubricant sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.23.2.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of automotive lubricants is listed in Table 4-48 and described in detail below. Table 4-49 summarizes the 8-hour TWA monitoring data for use of automotive lubricants containing formaldehyde.

Table 4-48. Use of Automotive Lubricants Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	13	Medium	(OSHA, 2019)

Short-term was not available to estimate worker exposures. All worker samples available were from OSHA's CEHD. OSHA sampled companies within the transportation equipment manufacturing, fabricated metal product manufacturing, and repair and maintenance sector. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

It should be noted that 18 percent of 8-hour TWA samples and 50 percent of the 15-minute samples were below the detection limit.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-49.

Table 4-49. Summary of Inhalation Exposure Monitoring Data for the Use of Automotive Lubricants

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.02	0.16	11	0.02	N/A	Medium
15-minute TWA	0.40	0.74	2	EPA did not identify 15-minute data for ONUs		N/A
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		N/A

EPA did not identify any non-discrete PBZ data for workers or ONUs during the use of automotive lubricants.

4.23.2.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which has a medium data quality rating from the systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for 8-hour and slight to moderate for 15-minute and provides a plausible estimate of exposures.

4.23.2.5 Dermal Exposure Results

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. EPA did identify concentration specific to formaldehyde use for these COUs. EPA assessed at a concentration of 20 percent based on data from the Emission Scenario Document on Chemical Additives Used in Automotive Lubricants (OECD, 2020). The calculated occupational dermal exposures for this OES are 280 $\mu g/cm^2$ as the central tendency value and 420 $\mu g/cm^2$ as the high-end value.

4.23.3 Use of Formulations containing Formaldehyde in Fuels

COU: Commercial uses – chemical substances in automotive and fuel products - automotive care products; lubricants and greases; fuels and related products.

4.23.3.1 Process Description

Formaldehyde may be emitted during the combustion of unleaded gasoline (Geivanidis et al., 2003; EC, 2000). EPA did not identify process-specific information besides scenarios where formaldehyde is produced during the combustion of gasoline.

4.23.3.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of formulations containing formaldehyde in fuels during gas station activities, loading/unloading, and the fueling of vehicles (Shinohara et al., 2019; Majumdar (neé som) et al., 2008; Davis et al., 2007). EPA did not identify any information to indicate the extent to which worker PPE is used in processes using formaldehyde in fuels.

ONUs include employees (*e.g.*, supervisors, managers) at fuel use sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.23.3.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of formulations containing formaldehyde in fuels is listed in Table 4-50 and described in detail below. Table 4-51 summarizes the 8-hour TWA and short-term monitoring data for use of formulations containing formaldehyde in fuels.

Table 4-50. Use of Formulations Containing Formaldehyde in Fuels Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	13	Medium	(OSHA, 2019)

OSHA sampled one company in the petroleum bulk stations and terminals subsector. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

It should be noted that one of the 8-hour TWA and one of the 15-minute samples measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-51.

Table 4-51. Summary of Inhalation Exposure Monitoring Data for the Use of Formulations containing Formaldehyde in Fuels

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.26	0.34	3	0.26	N/A	Medium to High
15-minute TWA	1.63	2.53	8	EPA did not identify 15-minute data for ONUs	N/A	Medium
Short-term TWA	EPA did not identify short-term data					

EPA identified additional studies with PBZ monitoring data for the use of formulations containing formaldehyde in fuels that did not provide the discrete data to be incorporated into the inhalation estimates. These data were not included in the estimates listed above. Overall, these monitoring data were all conducted in sites in other countries but reported lower concentrations during use of fuels. Davis et al. (2007) collected 8-hour TWA monitoring data from truck transport operations in the United States, with arithmetic means ranging between 0.0068 and 0.0078 and medians ranging between 0.0058 and 0.0066 ppm. In 2019, Shinohara et al. (2019) took short-term measurements of gas station employees in Japan during the refueling processing, which resulted in arithmetic means concentrations of 0.0041 and 0.0094 ppm. Another study conducted in Korea measured 8-hour TWA concentrations of gas station workers and resulted in a much higher exposure concentration with an arithmetic mean of 0.75 ppm. A study conducted in Thailand by Kitwattanavong et al. (2013) measured petrol station attendants and resulted in an exposure range between 0.0062 and 0.015 ppm (Kitwattanavong et al., 2013). Sousa et al. (2015) measured short-term exposures for gas station attendants in Brazil between 2009 and 2010, which resulted in an arithmetic mean of 0.011 ppm.

EPA identified non-discrete PBZ data for ONUs working as gas station employees from Shinohara (Shinohara et al., 2019). The short-term data resulted in arithmetic means of 0.0082 and 0.02 ppm. The study stated that the higher indoor formaldehyde concentrations are thought to be from off-gassing of plywood and wallpaper adhesives.

4.23.3.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour and short-term inhalation exposures, which have a medium to high data quality rating from the systematic review process. The primary limitations of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario and the limited data pool. Although, EPA identified non-discrete data specific to the occupational scenarios, which addresses use of fuel at gas stations. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA concluded that the weight of scientific evidence for this assessment is slight to moderate for both 15-minute and 8-hour TWAs, yet provides a plausible estimate of exposures.

4.23.3.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 0.15 percent, based on the 2016 CDR for fuels and related products (<1%) and the MRD on the Use of Fuels (U.S. EPA, 2021c, 2016). The calculated occupational dermal exposures for this OES are 2.1 µg/cm^2 as the central tendency value and 3.15 µg/cm^2 as the high-end value.

4.24 Commercial Use – Chemical Substances in Agriculture Use Products – Lawn and Garden Products

4.24.1 Use of Fertilizers Containing Formaldehyde in Outdoors Including Lawns

4.24.1.1 Process Description

Urea-formaldehyde is used in the manufacture of controlled-release fertilizers, which release nutrients at a constant rate over time (ECHA, 2019). End users of controlled-release fertilizers include agricultural, horticultural, landscaping, and consumer markets (ECHA, 2019). The 2020 CDR indicates a formaldehyde concentration of less than 1 percent (U.S. EPA, 2020a).

Fertilizers can arrive as a liquid or dry granulated material (Koch Turf, 2016). EPA assumes commercial containers for fertilizer may be similar to those of agricultural pesticides. According to the GS on Application of Agricultural Pesticides, liquid formulations may arrive in reusable plastic or metal containers of several gallons (U.S. EPA, 1993). Solid products may arrive in paper, plastic, or cardstock containers (U.S. EPA, 1993). The application depends on a variety of factors including crop type, soil type, and climate. Common application techniques include surface broadcasting, incorporation into the soil using attachments to plow, and injection of liquid/gaseous formulations by pumping through cultivator knives (Taylor, 2004). Dry granulated formaldehyde fertilizers are either broadcast or suspended in water and root-zone injected or spray-applied (Koch Turf, 2016).

4.24.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during use of fertilizers containing formaldehyde during unloading of transport containers, application of fertilizer to lawn, and equipment cleaning. EPA did not identify information that indicates the extent of engineering controls and PPE used by workers at facilities that perform use of formulations containing formaldehyde in outdoors including lawn operations.

ONUs include employees (*e.g.*, supervisors, managers) at use of formulations containing formaldehyde in outdoors including lawn sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.24.1.3 Inhalation Exposure Estimates

EPA did not identify inhalation monitoring data to assess exposures during use of fertilizers containing formaldehyde in outdoors including lawns. Therefore, EPA estimated inhalation exposures using Monte Carlo simulation of models based on the OES. EPA assumed that the formaldehydE–containing product arrives at the site in its final formulation and is used with no engineering controls present. Actual exposures may differ based on worker activities, formaldehyde throughputs, and facility processes.

For this scenario, EPA applied the EPA Mass Balance Inhalation Model to the exposure points assumed using engineering judgement. That model estimates the amount of chemical inhaled by a worker during a vapor-generating activity. EPA estimated the inhalation exposure for the exposure points using a vapor generation rate (G) and exposure duration based on the *ChemSTEER User Guide* for the EPA/OPPT Mass Balance Inhalation Model (U.S. EPA, 2015b) and *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments, Volume 1* (U.S. EPA, 1991a). EPA calculated vapor generation rates for the exposure points with possible vapor generation rate models and default values presented in the aforementioned reports. The Monte Carlo simulation varies the following parameters: ventilation rate, mixing factor, saturation factor, working years, formaldehyde mass fraction in the urea-formaldehyde product, hours exposed for exposure point B, and production volume.

EPA used the vapor generation rate, exposure duration parameters, and the EPA Mass Balance Inhalation Model to determine a TWA exposure for each exposure point. EPA assumed the same worker performed each activity throughout their work shift and estimated the 8-hour TWA by combining the exposures from each exposure point and averaging over 8 hours within the Monte Carlo simulation. EPA assumed workers had no exposure outside each exposure activity. Table 4-52 summarizes the estimated full-shift TWA exposures for use of fertilizer containing formaldehyde. The high-end values represent the 95th percentile and the central tendency values represent the 50th percentile of the simulation outputs.

Table 4-52. Summary of Inhalation Exposure Modeling Data for the Use of Fertilizers Containing Formaldehyde in Outdoors Including Lawns

Exposure Concentration Type	Central Tendency (ppm)	High-End (ppm)	Data Quality Rating of Air Concentration Data
Inhalation exposure during container unloading	2.45E−03	5.86E−03	N/A – Modeled data
Equipment cleaning exposure	7.34E−02	1.28E−01	
8-hour TWA (Total exposure)	3.24E−02	6.12E−02	

4.24.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

Inhalation exposure estimates are assessed using Monte Carlo modeling with information from the *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b) and *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments, Volume 1* (U.S. EPA, 1991a) and EPA/OPPT models. Factors that increase the strength of evidence for this OES are the high number of data points (simulation runs), and full distributions of input parameters. The Monte Carlo modeling accounts for the entire distribution of input parameters, calculating a distribution of potential exposure values that represents a larger proportion of sites than a discrete value. Factors that decrease the strength of the evidence for this OES include that the exposure points were not identified using a GS/ESD, uncertainty in the representativeness of evidence to all sites, and uncertainty in the use of generic default values from the aforementioned reports for sites that specifically use formaldehyde. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on this information, EPA has concluded that the weight of scientific evidence for this assessment is moderate and provides a plausible estimate of exposures.

4.24.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 1 percent based on reporting data for the agricultural non-pesticidal products in the 2020 CDR (U.S. EPA, 2020a). One submitter reported 30 to 60 percent and the other reported less than 1 percent for the agricultural non-pesticidal products. The high concentration reported may refer to the intermediate product sold as urea formaldehyde concentrate (UFC), which contains 60 percent formaldehyde. This product is then used in the production of solid urea and ureaform fertilizers (U.S. EPA, 1991b). The minimum concentration identified was 0.01 percent based on formaldehyde report data from the Tennessee Valley Authority (TVA) (TVA, 1991). The calculated occupational dermal exposures for this OES are 14 µg/cm^2 as the central tendency value and 21 µg/cm^2 as the high-end value.

4.25 Commercial Use – Chemical Substances in Outdoor Use Products – Explosive Materials

4.25.1 Use of Explosive Materials

4.25.1.1 Process Description

Formaldehyde is emitted in explosive materials such as ground-level pyrotechnics and firearms (Quémerais, 2013; Croteau et al., 2010). Information from the 2020 CDR indicates that formaldehyde is used as a chemical ingredient for propellant composition, although the concentrations are unknown (U.S. EPA, 2020a). In an occupational setting, EPA expects explosive materials to be used when a worker conducts outdoor pyrotechnic performances or in commercial or military firing ranges. EPA did not identify container-specific information on formaldehyde in explosive materials; however, the Agency expects products to arrive in packages of assorted sizes. The explosive material is ignited, undergoes a combustion reaction, and explodes (Croteau et al., 2010).

4.25.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during loading/unloading of explosives containing formaldehyde, use of the explosive material and possibly through cleaning of equipment. EPA did not identify any information to indicate the extent of use of PPE by the workers in processes using formaldehyde in explosive materials.

ONUs include employees (*e.g.*, supervisors, managers) at explosive materials sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.25.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of explosive materials is listed in Table 4-53 and described in detail below. Table 4-54 summarizes the 8-hour TWA and short-term monitoring data for use of explosive materials containing formaldehyde.

Table 4-53. Use of Explosive Materials Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	18	Medium	(OSHA, 2019)
Performer	PBZ monitoring data	1	High	(Croteau et al., 2010)

The other short-term sample was taken at a firework show (Croteau et al., 2010). All personal and area samples provided through Croteau; were at or below the LOD of 0.016 ppm (Croteau et al., 2010). The only 8-hour TWA PBZ samples available were from OSHA's CEHD. OSHA sampled military and air force bases as well as companies within the fabricated metal production manufacturing sector. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

Four of the 10 15-minute exposure samples were measured below the LOD. To estimate exposure concentrations for this data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-54.

Table 4-54. Summary of Inhalation Exposure Monitoring Data for the Use of Explosive Materials

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.04	0.08	7	0.04	N/A	Medium
15-minute TWA	0.09	0.26	9	EPA did not identify 15-minute data for ONUs		Medium
Short-term	0.016		1	EPA did not identify short-term data for ONUs		High

4.25.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 8-hour and 15-minute (peak) inhalation exposures, which have a medium data quality rating from the systematic review process. The primary limitations of this data includes on whether the formaldehyde exposure measured at the military sites were from explosives or other sources of formaldehyde as well as the limited data pool. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight for 8-hour and 15-minute exposure estimates yet provides a plausible estimate of exposures.

4.25.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 1 percent. Explosive materials were not reported in 2020 CDR (U.S. EPA, 2020a) and were reported by one submitter at less than 1 percent concentration in the 2016 CDR. EPA did not identify additional concentration information on explosive materials. The calculated occupational dermal exposures for this OES are 14 $\mu g/cm^2$ as the central tendency value and 21 $\mu g/cm^2$ as the high-end value.

4.26 Commercial Use – Chemical Substances in Packaging, Paper, Plastic, Hobby Products – Paper Products; Plastic and Rubber Products; Toys, Playground, and Sporting Equipment

4.26.1 Use of Packaging, Paper, Plastics, and Hobby Products

4.26.1.1 Process Description

A public comment submitted by ACC indicates the use of formaldehyde in paper products (ACC, 2019). Urea and melamine resins, containing up to 1.5 percent free formaldehyde, are used in paper treating and coating (NICNAS, 2006). In the 2020 CDR, one facility reported 5 percent of its PV for downstream use of formaldehyde in paper articles with a maximum concentration of 1 to less than 30 percent (U.S. EPA, 2020a). Packaging and other hobby products were not in the 2020 CDR. Formaldehyde has been identified in carbonless copy paper (CCP) which may be used in office settings, educational supply stores, and printing shops (NIOSH, 2000; Zimmer and Hadwen, 1993; NIOSH, 1984b). Sources indicate concentrations of formaldehyde in CCP ranging from 33.6 to 800,000 µg/kg (Chrostek, 1985; NIOSH, 1984b; Gockel et al., 1981). EPA did not find container-specific information on formaldehyde in CCP; however, EPA expects paper products to arrive ready for use in large boxes containing various amounts of paper. Workers may use CCP for several activities, such as writing, copying, archiving records, and sorting. According to one NIOSH report, the spent paper is either filed away for future use or disposed of landfill or recycling (NIOSH, 2000). In general, site trash could be collected for disposal as solid wastes that are recycled, incinerated, or landfilled. EPA did not identify process-specific information for formaldehyde in packaging or other hobby products.

4.26.1.2 Worker Activities

Workers may potentially be exposed to formaldehyde during use of packaging, paper, and hobby products during handling of packaging, paper, or other similar products. EPA identified one literature source describing ventilation as the only engineering control in place (Hall et al., 2002). EPA did not identify the extent of use of PPE by the workers at sites with use of packaging, paper, and hobby products.

ONUs include employees (*e.g.*, supervisors, managers) at use of packaging, paper, and hobby product sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.26.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during use of packaging, paper, and hobby products is listed in Table 4-55 and described in detail below. Table 4-56 summarizes the 8-hour TWA and short-term monitoring data for use of packaging, paper, and hobby products containing formaldehyde.

Table 4-55. Use of Packaging, Paper, and Hobby Products Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	4	Medium	(OSHA, 2019)
Mail Handling	Area	36	High	(Hall et al., 2002)

No short-term PBZ monitoring data was available therefore EPA used two area samples from Hall taken in 2002. The study sampled mail handlers that dealt with irradiated mail at the United States Senate and House office buildings in Washington, D.C. The only 8-hour TWA PBZ samples available were from OSHA's CEHD. OSHA sampled companies within the retail trade and transportation and warehousing sectors. The 15-minute data were from OSHA sampling of a mail delivery service. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

It should be noted that one of the two 15-minute data samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 15-minute and 8-hour TWA data represent the maximum and 50th percentile, respectively. The calculated values are summarized in Table 4-56.

Table 4-56. Summary of Inhalation Exposure Monitoring Data for the Use of Packaging, Paper, and Hobby Products

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.01	0.02	2	0.01	N/A	Medium
15-minute TWA	0.23	0.28	2	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	0.014	0.008	36	EPA did not identify short-term data for ONUs		High

EPA did not identify any non-discrete PBZ data for workers or ONUs during the use of packaging, paper and hobby products.

4.26.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess 15-minute and 8-hour inhalation exposures, which has a medium data quality rating from the systematic review process. For these exposures, EPA only used two samples to estimate 8-hour and 15-minute exposures. For short-term exposures, EPA used area samples that have a high data quality rating from the systematic review process. The primary limitation of this data includes the limited data pool as most monitoring samples are area samples from one source published in 2002. In addition, there is uncertainty on whether the primary source of formaldehyde in these mail delivery services is from the packaging and paper. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight for both the full-shift and short-term exposure estimates, yet provides a plausible estimate of exposures.

4.26.1.5 Dermal Exposure Estimates

The maximum concentration identified for this OES was 1 to 30 percent, based on reporting data for the other articles with routine direct contact during normal use, including paper articles in the 2020 CDR (U.S. EPA, 2020a). Other sources indicate the percentage of formaldehyde in paper products at below 1 percent (Chrostek, 1985; NIOSH, 1984b; Gockel et al., 1981). Since paper products are solid articles, EPA did not estimate dermal exposure using the dermal loading calculation as loading values are based on liquid loading. EPA notes that dermal exposure to formaldehyde may still be possible but it is not quantified.

4.27 Commercial Use – Chemical Substances in Packaging, Paper, Plastic, and Hobby Products – Arts, Crafts, and Hobby Materials

4.27.1 Use of Craft Materials

4.27.1.1 Process Description

A Safety data sheet identified formaldehyde in craft consumer glue in concentrations less than 0.1 percent (U.S. EPA, 2020b; Elmer's, 2012). According to the 2020 CDR, one manufacturer/importer reported downstream use of formaldehyde as an intermediate in solvent-based paint with a concentration ranging from 30 to 60 percent (U.S. EPA, 2020a). EPA did not identify process-specific information for formaldehyde in paints, coatings, and adhesives marketed as craft and hobby materials. The formaldehyde use report indicated up to 10 percent in consumer craft materials, EPA assumes that commercial users may be using these consumer products. EPA expects paints, coatings, and adhesives marketed as craft and hobby products to be used in its final formulation and to be applied manually by brush, roller, or spray onto the substrate. Following application, EPA expects the substrate to be allowed to cure or dry before use.

4.27.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of craft materials during loading/unloading of craft materials containing formaldehyde as well as the cleaning of equipment which use craft materials containing formaldehyde. EPA did not identify any information to indicate the extent of use of PPE by the workers in processes using formaldehyde in craft materials.

ONUs include employees (*e.g.*, supervisors, managers) at craft materials sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.27.1.3 Inhalation Exposure Estimates

EPA did not identify monitoring data or a NAICS code specific to commercial uses of arts and crafts products. EPA assumes that these products are paints, coatings, and adhesives; therefore, monitoring data considered in the use of paints, coatings, and adhesives was considered.

EPA expects arts and craft products would be applied manually by brush, roller, or spray applications. The exposure estimates for non-spray application were not used because they include application methods not expected with arts and craft products (*e.g.*, curtain and dip painting). EPA used the exposure estimates for spray or unknown applications as surrogate monitoring data. Table 4-57 summarizes the 8-hour TWA monitoring data used for use of craft materials containing formaldehyde.

Short-term data was not available to estimate worker exposures. A full discussion of the supporting data is in Section 4.27.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the maximum and 50th percentile, respectively. The calculated values are summarized in Table 4-57.

Table 4-57. Summary of Inhalation Exposure Monitoring Data for the Use of Craft Materials

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.07	0.55	212	0.07	N/A	Medium to High
15-minute TWA	0.24	1.17	116	N/A	N/A	Medium
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		N/A

For consumer use, EPA modeled an annual-averaged daily concentration (ADC) of 0.026 ppm using CEM. The occupational ADC is 0.047 ppm, this compares well with the surrogate approach, given that workers would be expected to be expose for longer durations and higher frequencies of use.

4.27.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of PBZ air concentration data to assess inhalation exposures, which has a medium to high data quality rating from the systematic review process. The primary limitation of this data is that the monitoring data is not specific to use of craft materials. It includes surrogate monitoring data sampled at industrial sites that may overestimate exposures for use of craft paints and adhesives. Furthermore, EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight to moderate yet provides a plausible estimate of exposures.

4.27.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The concentration assessed for this OES was 10 percent based on the formaldehyde use report. Note that concentrations can be as low as 0.1 percent as reported by the ACA via public comment (ACA, 2019). As these products may include spray products, high-end dermal exposures are calculated based on a higher amount of formaldehyde remaining on skin upon immersion (10.3 mg/cm^2 per event), and the central tendencies are based on a lower amount of formaldehyde remaining on skin upon immersion (3.8 mg/cm^2 per event). The calculated occupational dermal exposures for this OES are 380 µg/cm^2 as the central tendency value and 1,030 µg/cm^2 as the high-end value.

4.28 Commercial Use – Chemical Substances in Packaging, Paper, Plastic, Hobby Products – Ink, Toner, and Colorant Products; Photographic Supplies

For Commercial use – chemical substances in packaging, paper, plastics, and hobby products – ink, toner, and colorant products, EPA assessed two OESs:

- Use of printing ink, toner, and colorant products containing formaldehyde; and
- Photo processing using formulations containing formaldehyde.

4.28.1 Use of Printing Ink, Toner, and Colorant Products Containing Formaldehyde

COU: Commercial uses – chemical substances in packaging, paper, plastic, hobby products – ink, toner, and colorant products; photographic supplies.

4.28.1.1 Process Description

Formaldehyde is a component of printing inks, which may include letterpress, offset, lithographic, inkjet, and flexographic inks (U.S. EPA, 2020b, 2010; Tuomi et al., 2000). The inks may be used for newspapers, books, labeling, and packaging. Printing activities may be categorized by the following processes: lithography, gravure, flexography, letterpress, digital, and screen-printing, with lithography being the most used (U.S. EPA, 2010).

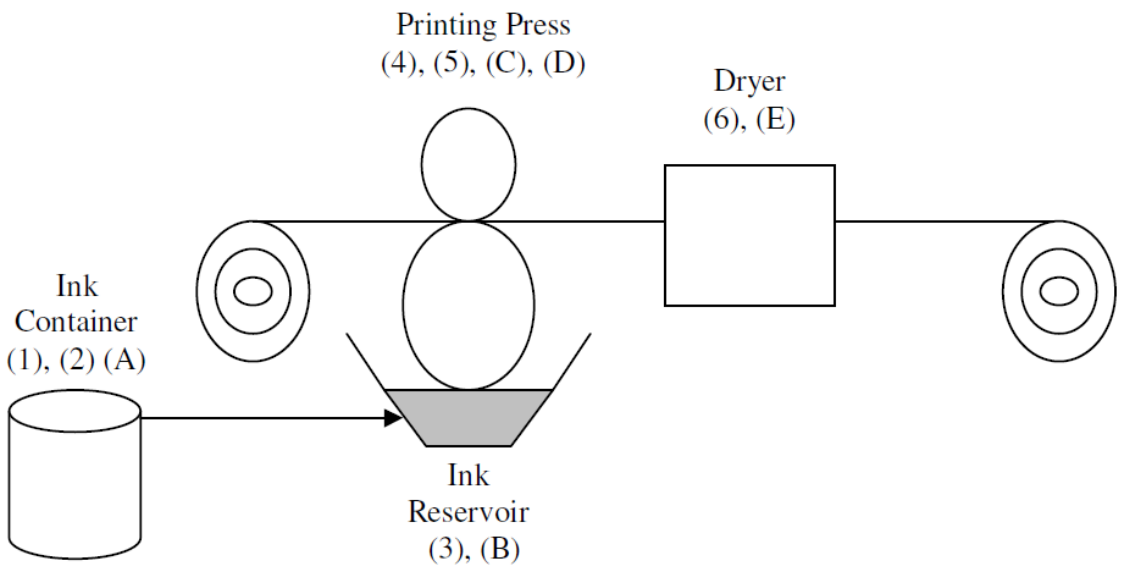
EPA identified one source that indicated formaldehyde contained in ink used for printing labels onto aluminum cans (Rodriguez et al., 2012). There are many different printing processes. Inks typically arrive at the facility in large drums and may be pumped into smaller containers for storage (U.S. EPA, 2002). The formulation may require mixing before loading into the printing machine (U.S. EPA, 2002). The printing process may be web-fed, in which a continuous roll of paper is fed through the machine, or sheet-fed, in which printing occurs on individual pieces of paper or substrate (U.S. EPA, 2010). In the case of web-fed, the paper must be cut to size after printing. Most commercial printing processes are sheet-fed while newspapers, magazines, and books are web-fed. The printing press is cleaned either at the end of the working day or when the plates are changed. See Figure 4-8 for typical release and exposure points during the use of printing inks (U.S. EPA, 2010).

During lithography, the ink is unloaded from a container to an ink tank on the printing machine (U.S. EPA, 2010). The ink is transferred to the ink rollers, then to the printing cylinder, then to the intermediate blanket roll, and finally to the paper. Lithography processes may be sheet-fed, non-heat-set-fed, or heat-set-fed. Web-fed lithography may be used in the production of periodicals, newspapers, and books (U.S. EPA, 2010). After printing and coating, the ink is dried via gas-fired ovens at 350 °F (Cook and Page, 2000). Press equipment is routinely cleaned during printing operations with blanket wash solutions and wetting agents. Some machines are manually cleaned using shop rags, while other machines have auto-blanket wash systems (Cook and Page, 2000).

Gravure printing is a process in which an image is etched with millions of minute cells below the surface of a plate or cylinder. Gravure is typically used for currency. Ink flows from the cells to the substrate at high speeds. As the substrate passes through air dryers, the ink dries through evaporation. Gravure is generally used for long printing jobs where engraving new images is not frequently required (U.S. EPA, 2010).

Flexography is a type of relief printing in which the image area is raised relative to the non-image area (U.S. EPA, 2010). Flexographic printing may be sheet-fed or web-fed, and is typically used for flexible and rigid packaging, newspapers, magazines, and consumer paper products (U.S. EPA, 2010). The three primary flexographic ink systems are solvent-based, water-based, and UV-cured inks. Solvent-based and water-based inks dry via evaporation, while UV-cured inks are cured by chemical reactions (U.S. EPA, 2002). The liquid ink typically arrives at the facility in 55-gallon drums and is pumped into a dispensing system or poured into 5-gallon cans (U.S. EPA, 1999). The ink is poured into an enclosed ink sump where it is pumped to an enclosed chamber. The substrate is run through the press, and the unused ink is pumped back out of the chamber into the sump.

Letterpress printing uses a relief plate or cylinder with a raised metal image (U.S. EPA, 2010). Sheet-fed, heat-set web and non-heat-set web pressed may be used. Letterpress is typically used to print newspapers, magazines, books, stationary, and advertising; however, it is difficult to print high-quality shaded images using this process. Digital printing encompasses any printing that may be completed via digital files and can incorporate data directly for compact database and printing to a digital press not using traditional methods of film or printing plates (U.S. EPA, 2010). During screen printing, ink is transferred to the substrate through a porous screen marked with a stencil. Both sheet-fed and web-fed processes may be used. The substrate can either be dried after each color application or after all colors have been printed. Screen printing is typically used for signs, electronics, displays, decals, and textiles (U.S. EPA, 2010; NIOSH, 1981b).



Occupational Exposure:
A. Dermal exposure to ink and inhalation exposure to volatilized formaldehyde during unloading
B. Inhalation exposure to fugitive air releases from ink reservoir
C. Inhalation exposure to ink mist generated from printing press
D. Dermal and inhalation exposure to formaldehyde during equipment cleaning
E. Inhalation exposure to fugitive air releases from drying

Figure 4-8. Typical Release and Exposure Points During the Use of Formaldehyde in Printing Inks (U.S. EPA, 2010)

4.28.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during the use of printing ink, toner, and colorant products containing formaldehyde during loading/unloading activities, equipment cleaning, and spray activities (Rodriguez et al., 2012). EPA did not identify any information to indicate the extent of use of PPE by the workers in processes using formaldehyde in ink, toner, and colorant products.

ONUs include employees (*e.g.*, supervisors, managers) at printing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.28.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during photo processing using formulations containing formaldehyde is listed in Table 4-58 and described in detail below. Table 4-59 summarizes the 8-hour TWA monitoring data for use of printing ink, toner, and colorant products containing formaldehyde.

Table 4-58. Use of Printing Ink, Toner, and Colorant Products Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	15	Medium	(OSHA, 2019)
Front end, printer, chemical process operator, millwright, forklift operator, lacquer spray	PBZ monitoring data	21	High	(Rodriguez et al., 2012)
Operating a color press	PBZ monitoring data	12	High	(Cook and Page, 2000)

Rodriguez sampled at aluminum beverage can manufacturing plants in the United States. The study sampled various workers and locations for formaldehyde over two days as it was used as a component of printing ink for the printing press equipment. Cook conducted a similar study and sampled color press operators. OSHA sampled companies within the commercial printing sectors. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

It should be noted that all of the 15-minute data samples measured below the LOD, and therefore the 15-minute peak estimate is highly biased. To estimate exposure concentrations for that data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs for 8-hour TWA.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-59.

Table 4-59. Summary of Inhalation Exposure Monitoring Data for the Use of Printing Ink, Toner, and Colorant Products Containing Formaldehyde

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.04	0.12	39	0.04	N/A	Medium to High
15-minute TWA	0.11	0.21	9	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		N/A

EPA did not identify any non-discrete PBZ data for workers or ONUs during the use of printing ink, toner, and colorant products.

4.28.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which has a medium to high data quality rating from the systematic review process. The primary limitation of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is moderate for the 8-hour TWA exposure estimate, which provides a plausible estimate of exposures. All of the 15 min data was below the detection limit, and therefore the peak exposure estimate is highly skewed. EPA has concluded that the weight of scientific evidence for the 15-minute exposure estimate is slight to moderate, but still provides a plausible estimate of exposures.

4.28.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed was 2 percent based on data from the 2006 formaldehyde report from the NICNAS (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 28 $\mu g/cm^2$ as the central tendency value and 42 $\mu g/cm^2$ as the high-end value.

4.28.2 Photo Processing Using Formulations Containing Formaldehyde

4.28.2.1 Process Description

Formaldehyde has been identified as a component in photographic film processing (Eastman Kodak, 2009; NICNAS, 2006; NIOSH, 1982a, 1974a). Formaldehyde is used as a preservative, stabilizer, replenisher, and hardener in final baths to prevent deterioration of image quality and damage to film coatings (NICNAS, 2006). A safety data sheet indicates formaldehyde is present in photographic processing with weight fractions ranging from 5 to 15 percent (Eastman Kodak, 2009). This condition of use was not reported in the 2016 or 2020 CDR.

According to NICNAS, commercial film processing sites typically use enclosed machines with a final bath tank specifically for formaldehyde solutions (NICNAS, 2006). EPA did not identify specific container information on formaldehyde used in film processing. The formaldehyde is received, poured into the final bath tank, and diluted with water to achieve a concentration ranging from 0.1 to 15 percent. The final bath is replenished one to two times per week (NICNAS, 2006). This process may be automated or manual. For manual operations, the diluted solution is poured into a tray in a dark room where negative or film paper is submerged to develop (NICNAS, 2006).

During specialized film processing, such as aerial film processing, formaldehyde is used in concentrations ranging from 20 to 35 percent (NICNAS, 2006). Formaldehyde solutions are received in 9-L or 19-L plastic drums. A tube is inserted into the drum and the solution is pumped into an enclosed final bath and diluted to 1 percent in a film processing machine (NICNAS, 2006).

Film development is typically done via a batch process (NICNAS, 2006). The final product is transferred to containers and dispatched to customers. The concentration of formaldehyde in the end product is typically 10.4 percent (NICNAS, 2006).

4.28.2.2 Worker Activities

Workers are potentially exposed to formaldehyde during photo processing during photo development activities, printing, loading/unloading activities, and equipment cleaning (Salisbury, 1996). Possible engineering controls utilized by photo processing sites include general ventilation such as HVAC units (Salisbury, 1996).

ONUs include employees (*e.g.*, supervisors, managers) at photo processing sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.28.2.3 Inhalation Exposure Estimates

The information and data quality evaluation to assess occupational exposures during photo processing using formulations containing formaldehyde is summarized in Table 4-60 and described in detail below. The 8-hour and 15-minute TWA monitoring data for photo processing using formulations containing formaldehyde are summarized in Table 4-61.

Table 4-60. Photo Processing Using Formulations Containing Formaldehyde Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	10	Medium	(OSHA, 2019)

Short-term data was not available to estimate worker exposures. All samples available came directly from OSHA's CEHD. OSHA sampled eight companies within the other services, except public administration sector. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

It should be noted that 75 percent of the 15-minute data samples were measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

The high-end and central tendency values for the 8-hour TWA data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-61.

Table 4-61. Photo Processing Using Formulations Containing Formaldehyde

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.03	0.04	6	0.03	N/A	Medium
15-minute TWA	0.09	0.09	4	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	EPA did not identify short-term data for workers			EPA did not identify short-term data for ONUs		N/A

4.28.2.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which has a medium data quality rating from the systematic review process. The primary limitation of this data includes the limited data pool and the sample dates, with a majority being between 1993 and 1999. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. For 15-minute exposure estimates, more than 50 percent of the sample data were non-detects, which introduces an uncertainty on the values estimated. Based on these strengths and limitations, EPA has concluded that the weight of scientific evidence for this assessment is slight to moderate for 8-hour TWA and 15-minute exposure estimates yet provides a plausible estimate of exposures.

4.28.2.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 35 percent, based on data from the 2006 formaldehyde report from the NICNAS (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 490 µg/cm^2 as the central tendency value and 735 µg/cm^2 as the high-end value.

4.29 Commercial Use – Chemical Substances in Products Not Described by Other Codes – Laboratory Chemicals

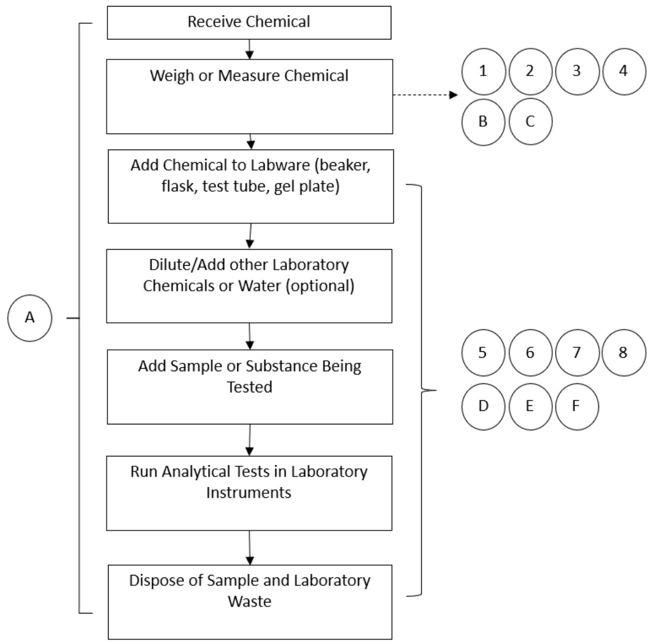
4.29.1 General Laboratory Use

4.29.1.1 Process Description

Formaldehyde may be used as a fixative in forensic/hospital mortuaries, pathology laboratories, and other medical-related laboratories (Bruno et al., 2018; NICNAS, 2006). Formaldehyde used in laboratories is often a neutral buffered formalin which can contain 4 up to 40 percent formaldehyde (Bruno et al., 2018; Xu and Stewart, 2016; Sancini et al., 2014; Viegas and Prista, 2010; NICNAS, 2006; Roy, 1999). EPA expects labs likely purchase at higher concentrations and dilute to the desired concentrations for specific applications. These dilutions can be automated using enclosed mixing systems or manually completed by the lab worker (NICNAS, 2006).

Gross dissection and examination of the tissue typically take place in pathology or other medical laboratories after the specimen has been in full contact with a formalin solution containing 3.7 percent formaldehyde for several hours or longer (Xu and Stewart, 2016; NIOSH, 1983a). The tissue is placed into plastic cassettes and the cassettes are immersed in trays of formalin during grossing (Xu and Stewart, 2016). The cassettes are processed into paraffin blocks, sliced extremely thin, and mounted on a slide (Xu and Stewart, 2016; Kilburn et al., 1985; NIOSH, 1982b). The slide goes through a series of solutions where stains are applied, and the slides are fixed (NIOSH, 1982b). A pathologist examines the slide via microscopic analysis (Xu and Stewart, 2016; NIOSH, 1982b). One source indicates that specimens no longer needed are disposed of once a week. The specimen is rinsed with water and the formaldehyde is washed down the sink (NIOSH, 1982b). Loading tissue cassettes and tissue processing typically takes 1.5 hours and may occur up to several times a week (NIOSH, 2013).

Formaldehyde may also have uses in laboratories as an analytical standard for various applications. Figure 4-9 illustrates a typical process for the use of laboratory chemicals primarily used as analytical standards, as well as the relevant environmental release and occupational exposure points (U.S. EPA, 2023d).



Occupational Exposures:

a) Full-shift inhalation and dermal exposure from all activities.
b) Inhalation and dermal exposure from unloading formaldehyde from transport containers (if full-shift estimates are not used).
c) Inhalation and dermal exposure to formaldehyde during container cleaning throughout sample preparation and testing activities (if full-shift estimates are not used).
d) Inhalation exposure to volatilized formaldehyde and dermal exposure to solids and liquids during equipment cleaning (if full-shift estimates are not used).
e) Inhalation exposure to volatilized formaldehyde and dermal exposure to solids and liquids during laboratory analyses (if full-shift estimates are not used).
f) Dermal exposure during disposal of formaldehyde (if full-shift estimates are not used).

Figure 4-9. Typical Exposure Points During the Use of Formaldehyde in Laboratory Chemicals (U.S. EPA, 2023d)

4.29.1.2 Worker Activities

Workers are potentially exposed to formaldehyde during general laboratory use for activities within the laboratory, unloading transport containers, container and equipment cleaning, sample preparation and testing, laboratory analyses, and disposal (U.S. EPA, 2023d). EPA identified one source describing mechanical ventilation as the only engineering control set in place (Ho et al., 2014). EPA did not identify the extent of use of PPE by the workers in laboratories.

ONUs include employees (*e.g.*, supervisors, managers) at laboratory sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.29.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during general laboratory use is listed in Table 4-62 and described in detail below. Table 4-63 summarizes the 8-hour TWA, short-term and 15-minute monitoring data for general laboratory use.

Table 4-62. General Laboratory Use Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	429	Medium	(OSHA, 2019)
Quality Control Lab	PBZ monitoring data	2	Medium	(NICNAS, 2006)
Surveillance Necropsy	PBZ monitoring data	1	Medium	(Diberardinis et al., 2001)
Lab Personnel	PBZ monitoring data	1	Medium	(Diberardinis et al., 2001)
Pathologist, Forensic Assistant	PBZ monitoring data	10	High	(NIOSH, 2013)
Pathologist, Technician, Assistant	PBZ monitoring data	29	High	(Viegas and Prista, 2010)

Short-term samples had 11 data points available from two data sources; however, one source did not describe engineering controls or the activities of the worker during the sampling (Diberardinis et al., 2001). The other reported that air from the laboratory was exhausted outdoors. (NIOSH, 2013). All but one of the 291 15-minute samples were from OSHA's CEHD, and the other had no engineering controls or worker activities to report (Diberardinis et al., 2001). Out of the 170 8-hour TWA samples available, 138 were from OSHA's CEHD. OSHA sampled the following sectors: professional, scientific, and technical services, educational services, veterinary care, health care and social assistance. The methodology for obtaining and analyzing this data is described in Section 2.5.1.

It should be noted that 11 percent of the worker 8-hour TWA samples and 33 percent of the 15-minute data samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

It should be noted that two of the 8-hour TWA samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

The high-end and central tendency values for the 8-hour TWA and short-term data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-63.

Table 4-63. Summary of Inhalation Exposure Monitoring Data for General Laboratory Use

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)				
8-hour TWA	0.10	0.55	170	0.10	N/A	Medium
15-minute TWA	0.26	2.15	291	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	0.15	0.38	11	EPA did not identify short-term data for ONUs		Medium

In addition, EPA identified additional monitoring studies that provided summary statistics, which are provided in the *Supplemental Formaldehyde Occupational Monitoring Data Summary*. One study measured full-shift exposures to workers in various laboratories in a cancer research institute (Pala et al., 2008). The exposures ranged from 0.004 ppm to 0.22 ppm (n = 36). Another study measured full-shift PBZ exposures to workers in hospital pathology laboratories in Portugal, and this resulted in an arithmetic mean of 0.38 ppm (Costa et al., 2015). In addition, the study measured short-term exposures, which ranged from 0.3 to 3.2 ppm. The short-term tasks included examination of formaldehyde-preserved specimens, and disposal of specimens and waste solutions.

4.29.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which have a medium data quality rating from the systematic review process. The exposure estimates are supported by a large number of workplace sampling data. The primary limitations of this data includes the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations in this scenario, and the limited short-term available. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA concluded that the weight of scientific evidence for this assessment is moderate to robust for both 8-hour TWA and 15-minute exposure estimates, which provides a plausible estimate of exposures.

4.29.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model. The maximum concentration assessed for this OES was 37 percent based on the expected concentration of formaldehyde in solution sold for lab use (NICNAS, 2006). The calculated occupational dermal exposures for this OES are 518 $\mu g/cm^2$ as the central tendency value and 777 $\mu g/cm^2$ as the high-end value.

4.30 Disposal

4.30.1 Worker Handling of Wastes

4.30.1.1 Process Description

Each of the COUs of formaldehyde may generate waste streams of the chemical that are collected and transported to third-party sites for disposal, treatment, or recycling. Industrial sites that treat or dispose of onsite wastes that they generate are assessed in each condition of use assessment in Sections 4.1 through 4.30. Wastes of formaldehyde that are generated during a condition of use and sent to a third-party site for treatment, disposal, or recycling may include the following:

- **Wastewater:** Formaldehyde may be contained in wastewater discharged to POTW or other, non-public treatment works for treatment. Industrial wastewater containing formaldehyde discharged to a POTW may be subject to EPA or authorized NPDES state pretreatment programs. The assessment of workers at on-site wastewater treatment facility of formaldehyde is considered within its respective OES.
- **Solid Wastes:** Solid wastes are defined under RCRA as any material that is discarded by being: abandoned; inherently waste-like; a discarded military munition; or recycled in certain ways (certain instances of the generation and legitimate reclamation of secondary materials are exempted as solid wastes under RCRA). Solid wastes may subsequently meet RCRA's definition of hazardous waste by either being listed as waste at 40 CFR 261.30 to 261.35 or by meeting waste-like characteristics as defined at 40 CFR 261.20 to 261.24. Solid wastes that are hazardous are regulated under the more stringent requirements of Subtitle C of RCRA, whereas non-hazardous solid wastes are regulated under the less stringent requirements of Subtitle D of RCRA. Formaldehyde is a U-listed hazardous waste under code U122 under RCRA; therefore, discarded, unused pure, and commercial grades of formaldehyde are regulated as hazardous waste under RCRA (40 CFR 261.33(f)).
- **Wastes Exempted as Solid Wastes under RCRA:** Certain COUs of formaldehyde may generate wastes of formaldehyde that are exempted as solid wastes under 40 CFR 261.4(a). For example, the generation and legitimate reclamation of hazardous secondary materials of formaldehyde may be exempt as solid waste.

Figure 4-10 shows a typical waste disposal process.

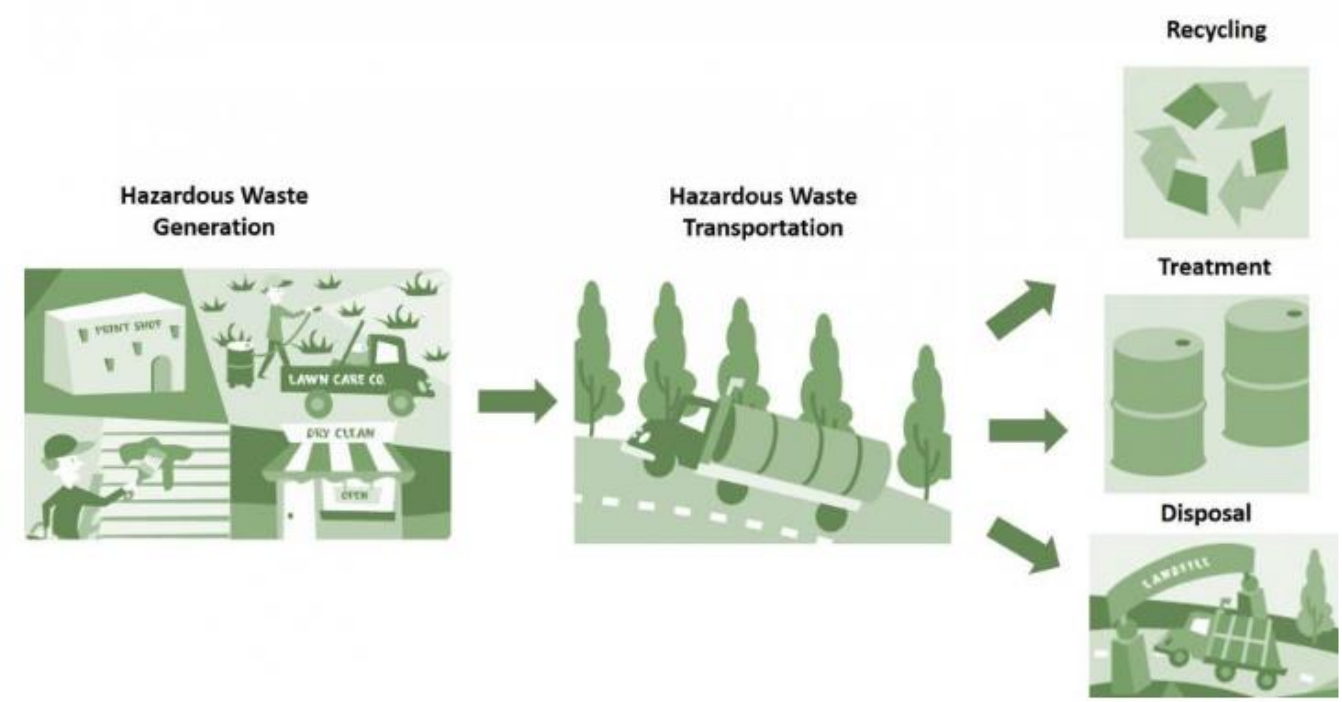


Figure 4-10. Typical Waste Disposal Process (U.S. EPA, 2017a)

4.30.1.2 Worker Activities

For this OES, workers are potentially exposed to formaldehyde during waste handling activities and equipment cleaning activities. EPA did not identify any information to indicate the extent of use of PPE by the workers in processes using formaldehyde in disposal.

ONUs include employees (*e.g.*, supervisors, managers) at disposal sites who do not directly handle formaldehyde. Therefore, the ONUs are expected to have lower inhalation exposures, lower vapor-through-skin uptake, and no expected dermal exposure.

4.30.1.3 Inhalation Exposure Estimates

The information and data quality valuation to assess occupational exposures during worker handling of wastes is listed in Table 4-64 and described in detail below. Table 4-65 summarizes the 8-hour TWA and short-term monitoring data for worker handling of wastes.

Table 4-64. Worker Handling of Wastes Inhalation Exposure Data Evaluation

Worker Activity or Sampling Location	Data Type	Number of Samples	Overall Data Quality Determination	Source
Unknown	PBZ monitoring data	8	Medium	(OSHA, 2019)
Sampling at wastewater treatment plants	PBZ	16	High	(Teixeira et al., 2013)

OSHA sampled four companies in the hazardous waste treatment and disposal, remediation services, and other nonhazardous waste treatment and disposal sectors. Four sampling data points were 15-minute samples and three samples for 8-hour TWA. The methodology for obtaining and analyzing this data is described in Section 2.5.1. Discrete short-term samples were not available; therefore, EPA exposures are based on the range of the monitoring sample from (Teixeira et al., 2013). The short-term data came from an assessment of indoor airborne contamination at a wastewater treatment plant in Portugal. The study sampled bar rack chambers, sedimentation tank, sludge thickeners, sludge dehydration chambers, sludge disposal areas, and an outdoor control sampling point (Teixeira et al., 2013). The study recorded 24 different data points, with 8 being reported as not determined. Of note, formaldehyde does not persist in water, so exposures are expected to be lower than other waste treatment and disposal methods.

It should be noted that 33 percent of the worker 8-hour TWA samples and 25 percent of the 15-minute data samples measured below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994a), as discussed in Section 2.5.1.

Data is not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle chemicals.

The high-end and central tendency values for the 8-hour TWA and short-term data represent the 95th and 50th percentile, respectively. The calculated values are summarized in Table 4-65.

Table 4-65. Summary of Inhalation Exposure Monitoring Data for Worker Handling of Wastes

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	ONU Exposures	Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)		
8-hour TWA	0.041	0.05	3	0.041	0.041	Medium
15-minute TWA	0.38	0.44	4	EPA did not identify 15-minute data for ONUs		Medium
Short-term TWA	0.005	0.01	16	EPA did not identify short-term data for ONUs		High

4.30.1.4 Weight of Scientific Evidence in Inhalation Exposure Estimates

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a weight of scientific evidence conclusion for the inhalation exposure estimates. The primary strength is the use of directly applicable monitoring data, which is preferrable to other assessment approaches such as modeling or the use of OELs/PELs. EPA used PBZ air concentration data to assess inhalation exposures, which have a medium to high data quality rating from the systematic review process. The primary limitation of this data includes the limited data pool, as well as the limited geographical representativeness. EPA also assumed 8-hour exposure hours per day 250 exposure days per year based on continuous formaldehyde exposure each working day for a typical worker schedule; it is uncertain whether this captures actual worker schedules and exposures. Based on these strengths and limitations, EPA concluded that the weight of scientific evidence for full-shift and short-term inhalation assessment is slight to moderate, but still provides a plausible estimate of exposures.

4.30.1.5 Dermal Exposure Estimates

EPA modeled dermal loading using a modified version of the EPA Dermal Exposure to Volatile Liquids Model, as discussed in Section 2.6. The maximum concentration assessed for this OES was 1.3 percent, based on data from a study on formaldehyde in waste effluent (Łebkowska et al., 2013). Of note, formaldehyde does not persist in water, so concentration is expected to decline through the process. The calculated occupational dermal exposures for this OES are 18.2 µg/cm^2 as the central tendency value and 27.3 µg/cm^2 as the high-end value.

REFERENCES

ACA. (2019). Comment submitted by Raleigh Davis, Assistant Director and Riaz Zaman, Counsel, Government Affairs, American Coatings Association (ACA) regarding the proposed 20 high priority candidates for chemical risk evaluation. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0004

ACC. (2019). Comment submitted by Kimberly Wise White, American Chemistry Council (ACC) Formaldehyde Toxic Substances Control Act (TSCA) Risk Evaluation Consortium regarding completion of surveillance testing of consumer products for formaldehyde emissions. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0018

AECOM. (2019). [Redacted] Industrial hygiene air sampling XXX, formaldehyde, XXX.

AIA. (2019). Comment submitted by David Hyde, Director, Environmental Policy, Aerospace Industries Association (AIA) regarding formaldehyde uses in aerospace. (EPA-HQ-OPPT-2018-0438-0006). Arlington, VA. https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0006

Akinyemi, PA; Adegbenro, CA; Ojo, TO; Elugbaju, O. (2019). Neurobehavioral Effects of Organic Solvents Exposure Among Wood Furniture Makers in Ile-Ife, Osun State, Southwestern Nigeria. Journal of Health & Pollution 9: 190604. http://dx.doi.org/10.5696/2156-9614-9.22.190604

Almaguer, D; Alterman, T; Blade, LM; Hurrell, JJ. (1995). Health hazard evaluation report HETA 93-0154-2527, Truman State Office Building, Jefferson City, Missouri. (HETA 93-0154-2527). Cincinnatti, OH: National Institute of Occupational Safety and Health.

Almaguer, D; Boiano, JM. (1986). Health Hazard Evaluation Report HETA-1985-0018-1759 American Crystal Sugar Company, Moorhead, Minnesota. (HETA 1985-0018-1759). Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/85-18-1759.pdf

Analytica. (2015). Choosing an appropriate distribution. Available online at http://wiki.analytica.com/Choosing_an_appropriate_distribution (accessed November 9, 2022).

Analytics Corporation. (2016a). [Redacted] Formaldehyde monitoring results - Fall 2016 (memo dated 11/17/16). (FALL 2016 FA MONITOR). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2016b). [Redacted] Formaldehyde monitoring results - Spring 2016 (memo dated 05/27/16). (SPRING 2016 FA MONIT). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2017a). [Redacted] Formaldehyde monitoring results - Fall 2017 (memo dated 11/13/17). (FA MONITORING). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2017b). [Redacted] Formaldehyde monitoring results - Spring 2017 (memo dated 08/23/2017). (Spring 2017 - FA MONI). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2018a). [Redacted] Formaldehyde monitoring results - Fall 2018 (memo dated 11/06/18). (FA MONITOR FALL 2018). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2018b). [Redacted] Formaldehyde monitoring results - Spring 2018 (memo dated 06/15/18). (FA MON - Spring 2018). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2019a). [Redacted] Formaldehyde monitoring results - Fall 2019 (memo dated 11/11/19). (FA MONITOR FALL19). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2019b). [Redacted] Formaldehyde monitoring results - Spring 2019 (memo dated 06/20/19). (FA MONITOR - Spring 19). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2020a). [Redacted] Formaldehyde monitoring results - Fall 2020 (memo dated 10/30/20). (FALL 2020 FA MONITOR). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2020b). [Redacted] Formaldehyde monitoring results - Spring 2020 (memo dated 06/26/20). (KA MONITORING). Toledo, OH: Perstorp Polyols.

Analytics Corporation. (2021). [Redacted] Formaldehyde monitoring results - Spring 2021 (memo dated 5/28/2021). (SPRING 2021 FA). Toledo, OH: Perstorp Polyols.

Apol, A; Thoburn, TW. (1986). Health Hazard Evaluation Report HETA-1985-462-1748 Boise Cascade, Vancouver, Washington. (HETA 1985-462-1748). Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/85-462-1748.pdf

Apol, AG; Okawa, M. (1977). Health Hazard Evaluation Determination, Report No. HHE-76-55-443, Certain-Teed Products, Inc., Tacoma, Washington (pp. 76-55). (Report No. HHE-76-55-443). Cincinnati, OH: National Institute for Occupational Safety and Health.

ARMA. (2019). Comment submitted by Reed B. Hitchcock, Executive Vice President, Asphalt Roofing Manufacturers Association (ARMA) regarding initiation of prioritization of formaldehyde under the Toxic Substances Control Act. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0005

Armstrong, RW; Rood, MJ; Sani, S; Mohamed, M; Rashid, M; Jab, AT; Landsberger, S. (2001). Aerosol particle and organic vapor concentrations at industrial work sites in Malaysia. Asia Pac J Public Health 13: 24-29. http://dx.doi.org/10.1177/101053950101300106

Arnold, F; Engel, AJ. (2001). Evaporation of pure liquids from open surfaces. In JBHJ Linders (Ed.), Modelling of Environmental Chemical Exposure and Risk (pp. 61-71). The Netherlands: Kluwer Academic Publishers. http://dx.doi.org/10.1007/978-94-010-0884-6_6

Bajaj, P. (2002). Finishing of textile materials. J Appl Polymer Sci 83: 631-659. http://dx.doi.org/10.1002/app.2262

Baldwin, PE; Maynard, AD. (1998). A survey of wind speed in indoor workplaces. Ann Occup Hyg 42: 303-313. http://dx.doi.org/10.1016/S0003-4878(98)00031-3

Barsan, ME. (1994). Health hazard evaluation report No. HETA-92-0117-2388, Rubbermaid, Inc., Reynolds, Indiana (pp. 92-0117). (HETA-92-0117-2388). National Institute for Occupational Safety and Health.

Bassig, BA; Zhang, L; Vermeulen, R; Tang, X; Li, G; Hu, W, ei; Guo, W; Purdue, MP; Yin, S; Rappaport, SM; Shen, M, in; Ji, Z; Qiu, C; Ge, Y; Hosgood, HD; Reiss, B; Wu, B; Xie, Y; Li, L; Yue, F, ei; Freeman, LEB; Blair, A; Hayes, RB; Huang, H; Smith, MT; Rothman, N; Lan, Q. (2016). Comparison of hematological alterations and markers of B-cell activation in workers exposed to benzene, formaldehyde and trichloroethylene. Carcinogenesis 37: 692-700. http://dx.doi.org/10.1093/carcin/bgw053

Bayless Kilgore. (2020). [Redacted] Routine periodic evaluation for air contaminants at Holston Army Ammunitions Plant. (Farnborough, UK). BAE Systems, Inc.

Bendix Corp. (1979). BCME formation and detection in selected work environments. Cincinnati, OH: National Institute for Occupational Safety and Health. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB83174102.xhtml

Blade, LM. (1996). James River Corporation, Packaging Business Greensburg, Indiana HETA 93–0670–2557 January 1996. (HETA #93–0670–2557). Cincinnati, OH: National Institute for Occupational Safety and Health.

BLS, US. (2016). May 2016 Occupational Employment and Wage Estimates: National Industry-Specific Estimates [Website]. http://www.bls.gov/oes/tables.htm

Bono, R; Munnia, A; Romanazzi, V; Bellisario, V; Cellai, F; Peluso, MEM. (2016). Formaldehyde-induced toxicity in the nasal epithelia of workers of a plastic laminate plant. Toxicology Research 5: 752-760. http://dx.doi.org/10.1039/c5tx00478k

Breysse, PA. (1980). Small plants and their medical problems -- the furniture industry: The environmental problems of urea-formaldehyde structures -- formaldehyde exposure in mobile homes. In Occupational safety and health symposia: 1979 (pp. 56-64). (DHHS (NIOSH) Publication No.80-139). Cincinnati, OH: National Institute for Occupational Safety and Health. https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml?searchQuery=PB82150228

Bruno, E; Somma, G; Russo, C; Porozaj, D; Pietroiusti, A; Alessandrini, M; Magrini, A. (2018). Nasal cytology as a screening tool in formaldehyde-exposed workers. Occup Med (Lond) 68: 307-313. http://dx.doi.org/10.1093/occmed/kqy052

Burkhart, JE. (1995). Health hazard evaluation report No. HETA-95-0162-2536, RCA Rubber Company, Akron, Ohio (pp. 95-0162). (HETA-95-0162-2536). National Institute for Occupational Safety and Health.

Burkhart, JE; Jennison, EA. (1994). Health hazard evaluation report no. HETA 92-0297-2396, Exxon Chemical Company, Pottsville Film Plant, Polyethylene Film Department, Mar-Lin, Pennsyvlania. (HETA 92-0297-2396). Cincinnati, OH: National Institute for Occupational Safety and Health.

Burr, GA; Wilcox, TG; Klein, MK; Weber, AM. (1993). Health hazard evaluation report no. HETA 93-011-2309, Tri-county North School, Lewisburg, Ohio (pp. 93-011). (HETA 93-011-2309). Cincinnati, OH: National Institute for Occupational Safety and Health.

Burton, NC; Monestersky, J. (1996). Health hazard evaluation report 96–0135–2612 Eagle Knitting Mills, Inc. Shawano, Wisconsin December 1996. (HETA 96–0135–2612). Cincinnati, OH: U.S. National Institute for Occupational Safety and Health.

Ceballos, D; Burr, GA. (2011). Evaluating a persistent nuisance odor in an office building– maryland. (HETA 2011-0004-3128). Ceballos, D; Burr, GA.

Ceballos, D; Roberts, J; Whittaker, S; Lee, EG; Gong, W. (2015). Evaluation of occupational exposures at drycleaning shops using SolvonK4 and DF 2000. (Report No. 2012-0084-3227). Ceballos, D; Roberts, J; Whittaker, S; Lee, EG; Gong, W.

Ceballos, DM; Whittaker, SG; Lee, E; Roberts, J; Streicher, R; Nourian, F; Gong, W, ei; Broadwater, K. (2016). Occupational exposures to new dry cleaning solvents: High-flashpoint hydrocarbons and butylal. J Occup Environ Hyg 13: 759-769. http://dx.doi.org/10.1080/15459624.2016.1177648

Celanese Corp. (2020). Comment submitted by Stephanie Daigle, Vice President, Government Affairs, Celanese Corporation regarding the draft scope of the risk evaluation for formaldehyde. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0047

Celanese Corp. (2022). Comment submitted by Celanese Corporation regarding characterization of occupational exposures during formaldehyde manufacturing, use as an intermediate, and compounding of formaldehyde-based polymers. Irving, TX. https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0080

CHEMetrics. (2018). Safety Data Sheet (SDS): Chlorine CHEMets and ULR CHEMets refills. (R2505). Midland, VA.

Cherrie, JW; Semple, S; Brouwer, D. (2004). Gloves and Dermal Exposure to Chemicals: Proposals for Evaluating Workplace Effectiveness. Ann Occup Hyg 48: 607-615. http://dx.doi.org/10.1093/annhyg/meh060

Chrostek, WJ. (1985). Health hazard evaluation report: HETA-84-392-1597 - Syntex Dental Products, Inc., Audubon, Pennsylvania. (NIOSH/00153676; HETA-84-392-1597). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/84-392-1597.pdf

Clerc, F; Steinhausen, M; Bertrand, N; Vincent, R; Gabriel, S; Van Gelder, R. (2015). Comparison of formaldehyde exposure measurements stored in French and German databases. Gefahrst Reinhalt Luft 75: 119-126.

Colgate-Palmolive Company. (2016a). Softsoap liquid hand soap aloe vera. Available online at https://www.whatsinproducts.com//brands/show_msds/1/16971 (accessed January 7, 2020).

Colgate-Palmolive Company. (2016b). Suavitel fabric softener liquid morning sun. Available online at https://www.whatsinproducts.com//brands/show_msds/1/16979 (accessed January 7, 2020).

Cook, CK; Page, EH. (2000). Health hazard evaluation report, HETA 99–0137–2810: World Color Press, Effingham, Illinois, September 2000. (HETA 99–0137–2810). Cincinnati, OH: National Institute for Occupational Safety and Health.

Cornwell, R. (1988). Health Hazard Evaluation Report HETA 88-230-1939, Morgan Shirt Company, Morgantown, West Virginia, December 1988. (HETA #88-230-1939). Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/1988-0230-1939.pdf

Costa, S; Carvalho, S; Costa, C; Coelho, P; Silva, S; Santos, LS; Gaspar, JF; Porto, B; Laffon, B; Teixeira, JP. (2015). Increased levels of chromosomal aberrations and DNA damage in a group of workers exposed to formaldehyde. Mutagenesis 30: 463-473. http://dx.doi.org/10.1093/mutage/gev002

Croteau, G; Dills, R; Beaudreau, M; Davis, M. (2010). Emission factors and exposures from ground-level pyrotechnics. Atmos Environ 44: 3295-3303. http://dx.doi.org/10.1016/j.atmosenv.2010.05.048

Cuadros, S; Font, J; Izquierdo, F; Cuadros, R, osa, M.; Olle, L; Marsal, A. (2016). Determination of formaldehyde content in leather: Standard EN ISO 17226 (parts 1 and 2), revision and possible improvements. Journal of the Society of Leather Technologists and Chemists 100: 167-174.

Daftarian, HS; Roegner, KC; Reh, CM. (2000). Health hazard evaluation report 98-0011-2801 Woodbridge Corporation Brodhead, Wisconsin July 2000. (HETA #98-0011-2801). Cincinnati, OH: National Institute for Occupational Safety and Health.

Davis, ME; Blicharz, AP; Hart, JE; Laden, F; Garshick, E; Smith, TJ. (2007). Occupational Exposure to Volatile Organic Compounds and Aldehydes in the U.S. Trucking Industry. Environ Sci Technol 41: 7152-7158. http://dx.doi.org/10.1021/es071041z

Diberardinis, L; Edwards, R; Herrick, R; Julien, R. (2001). Strategy to assess exposure of laboratory personnel to select OSHA-regulated chemicals at Massachusetts Institute of Technology. Chem Health Saf 8: 25-29. http://dx.doi.org/10.1016/S1074-9098(01)00215-5

Dow Chemical. (2016). [Redacted] Industrial hygiene assessment of employee exposures to formaldehyde during manufacturing of Dow Corning® MB40-006 Masterbatch on Line 7 at the Copley, OH Multibase Site. Midland, MI.

Dow Chemical. (2017a). [Redacted] 2016 Exposure monitoring for XXX at Dow Water Solutions Ion Exchange-Anion/SR Facility, 963 Building, Midland, MI USA. (42_552). Midland, MI.

Dow Chemical. (2017b). [Redacted] 2016 Exposure monitoring for XXX formaldehyde, XXX at the Michigan Operations Environmental Operations Facility, Midland, MI, USA. (42_579). Midland, MI.

Dow Chemical. (2017c). [Redacted] 2017 Personal exposure monitoring for XXX formaldehyde, XXX at the Elk Grove Site, Elk Grove Village, Illinois, USA. (312_76). Midland, MI.

Dow Chemical. (2017d). [Redacted] Industrial hygiene assessment of employee exposures to formaldehyde during manufacturing of Dow Corning® IT MQ-1644H Solid Resin in MOD B 2901 Building Dow Corning Midland Plant, Midland MI. (2017-I0000-79734). Midland, MI.

Dow Chemical. (2019a). [Redacted] 2018: Personal monitoring for formaldehyde, XXX at the Anion/SR Plant in Ion Exchange Midland, MI USA. (42_512). Midland, MI.

Dow Chemical. (2019b). [Redacted] 2018: Summary of industrial hygiene monitoring for oxide. (88_630). Midland, MI.

Dow Chemical. (2019c). [Redacted] Personal IH monitoring for XXX formaldehyde, XXX at the HT Facility in Deer Park, Texas from April 25, 2016 to September 19, 2018. (304_135). Midland, MI.

Dunky, M. (2004). Adhesives based on formaldehyde condensation resins. Macromol Symp 217: 417-429. http://dx.doi.org/10.1002/masy.200451338

Dunn, DW; Johnson, ML; Hedley, WH; Pate, JB; Barrett, GJ; Mckinnery, WN. (1983a). Reducing plant pollution exposure - Control practices at formaldehyde production plants. Chemical Engineering Progress 79: 35-38.

Dunn, W; Toy, HD; Wright, AJ; Hedley, WH; Holmes, L; Barrett, GJ. (1983b). Detailed Industrial Hygiene Survey Formaldehyde Production, E. I. DuPont DeNemours and Company, Linden, New Jersey, Report No. CT-114-20b (pp. 068-003). (NIOSH/00133581). Dunn, W; Toy, HD; Wright, AJ; Hedley, WH; Holmes, L; Barrett, GJ.

Eastman Kodak. (2009). Material Safety Data Sheet (MSDS): Kodak Flexicolor Stabilizer III and Replenisher/C-41. Rochester, NY.

EC. (2000). Priority substances list assessment report. Formaldehyde. Ottawa, Canada: Health Canada. http://publications.gc.ca/collections/Collection/En40-215-50E.pdf

ECHA. (2019). Worker exposure to formaldehyde and formaldehyde releasers. Helsinki, Finland.

Echt, A. (1993). Health Hazard Evaluation Report HETA 93-0028-2366, West Helena - Helena Sportswear, Inc., West Helena, Arkansas. (HETA 93-0028-2366). Echt, A. https://www.cdc.gov/niosh/hhe/reports/pdfs/1993-0028-2366.pdf

EDF. (2019). Comment submitted by Robert Stockman, Senior Attorney, Environmental Defense Fund (EDF) regarding proposed high-priority substance designations under the Toxic Substance Control Act (TSCA). (EPA-HQ-OPPT-2018-0438-0017). New Yrok, NY. https://www.regulations.gov/document/EPA-HQ-OPPT-2018-0438-0017

Elmer's. (2012). (M)SDS For: Elmer's CraftBond Acid-Free Multi-Purpose Spray Adhesive, Aerosol. Available online at https://www.whatsinproducts.com//brands/show_msds/1/15107 (accessed January 7, 2020).

Enviro Control Inc. (1983). Industrial hygiene characterization of urea formaldehyde and polyurethane foam insulation. (DHHS (NIOSH) Publication Number 83-108). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/docs/83-108/

Fehrenbacher, MC; Hummel, AA. (1996). Evaluation of the Mass Balance Model Used by the EPA for Estimating Inhalation Exposure to New Chemical Substances. Am Ind Hyg Assoc J 57: 526-536.

Flaris, V; Singh, G; Rao, AR. (2009). Recycling electronic waste. Plast Eng 65: 10-15. http://dx.doi.org/10.1002/j.1941-9635.2009.tb00452.x

Fransman, W; Mclean, D; Douwes, J; Demers, PA; Leung, V; Pearce, N. (2003). Respiratory symptoms and occupational exposures in New Zealand plywood mill workers. Ann Occup Hyg 47: 287-295. http://dx.doi.org/10.1093/annhyg/meg046

FRM Risk. (2019). [Redacted] Industrial hygiene air contaminant assessment report.

FWIC. (2020). Comments of the Federal Wood Industries Coalition regarding the draft scope of the risk evaluation for formaldehyde (comment submitted by Jackson Morrill). Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0037

Garbassi, F; Po, R. (2001). Engineering thermoplastics. In Kirk-Othmer Encyclopedia of Chemical Technology. Hoboken, NJ: John Wiley & Sons, Inc. http://dx.doi.org/10.1002/0471238961.0514070903120107.a01.pub2

Geivanidis, S; Pistikopoulos, P; Samaras, Z. (2003). Effect on exhaust emissions by the use of methylcyclopentadienyl manganese tricarbonyl (MMT) fuel additive and other lead replacement gasolines. Sci Total Environ 305: 129-141. http://dx.doi.org/10.1016/S0048-9697(02)00476-X

Gerberich, HR; Seaman, GC. (2013). Formaldehyde. In JI Kroshwitz; M Howe-Grant (Eds.), Kirk-Othmer encyclopedia of chemical technology (4th ed., pp. 929-951). New York, NY: John Wiley & Sons.

Gockel, DL; Horstman, SW; Scott, CM. (1981). Formaldehyde emissions from carbonless copy paper forms. Am Ind Hyg Assoc J 42: 474-476. http://dx.doi.org/10.1080/15298668191420099

Goris, JA; Ang, S; Navarro, C. (1998). Laboratory safety: Minimizing the toxic effects of formaldehyde. Lab Med 29: 39-42. http://dx.doi.org/10.1093/labmed/29.1.39

Greeson, HK, Jr; Browning, KJ; Farrell, JD. (2012). Formaldehyde reduction for durable press cotton fabrics. AATCC Rev 13: 36-40.
Gunter, BJ. (1977). Health Hazard Evaluation Report No. 77-37-413, Gates Rubber Company, Denver, Colorado. (HHE 77-37-413). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/77-37-413.pdf
GWPC and IOGCC. (2022). FracFocus: Chemical disclosure registry [Database]. Retrieved from https://fracfocus.org/data-download
Hall, RM; Bernard, B; Harney, J; McCleery, R; Gillen, M; Hess, JE; Kiefer, M; Mattorano, D; Delaney, L; Mead, K. (2002). Health Hazard Evaluation Report 2002–0136, United Stated Senate and House of Representatives, Washington, D.C., July 2002. (HETA #2002–0136–2880). Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/2002-0136-2880.pdf
Harley, KG; Calderon, L; Nolan, JES; Maddalena, R; Russell, M; Roman, K; Mayo-Burgos, S; Cabrera, J; Morga, N; Bradman, A. (2021). Changes in Latina women's exposure to cleaning chemicals associated with switching from conventional to "green" household cleaning products: The LUCIR intervention study. Environ Health Perspect 129: 97001. http://dx.doi.org/10.1289/EHP8831
Heitbrink, W; Cooper, T; Edmonds, M; Bryant, C; Ruch, W. (1993). In-depth survey report: control technology for autobody repair and painting shops at Valley Paint and Body Shop, Amelia, Ohio. Heitbrink, W; Cooper, T; Edmonds, M; Bryant, C; Ruch, W. https://www.cdc.gov/niosh/surveyreports/pdfs/179-14a.pdf?id=10.26613/NIOSHEPHB17914a
Hernon, JT. (1981). Alum-formaldehyde tannage. III. Manufacture of New Zealand sheepskins all-white tanned grain or suede leather. J Am Leather Chem Assoc 76: 80-82.
Ho, S; Ip, H; Ho, K; Ng, L; Chan, C; Dai, W; Cao, J. (2013). Hazardous airborne carbonyls emissions in industrial workplaces in China. J Air Waste Manag Assoc 63: 864-877. http://dx.doi.org/10.1080/10962247.2013.797519
Ho, SSH; Ip, HSS; Ho, KF; Ng, LPT; Dai, WT; Cao, J; Chan, CS; Ho, LB. (2014). Evaluation of hazardous airborne carbonyls on a university campus in southern China. J Air Waste Manag Assoc 64: 903-916. http://dx.doi.org/10.1080/10962247.2014.903214
Hosgood, HD, III; Zhang, L; Tang, X; Vermeulen, R; Hao, Z; Shen, M, in; Qiu, C; Ge, Y; Hua, M; Ji, Z; Li, S; Xiong, J, un; Reiss, B; Liu, S; Xin, KX; Azuma, M; Xie, Y; Freeman, LB; Ruan, X; Guo, W; Galvan, N, oe; Blair, A; Li, L; Huang, H; Smith, MT; Rothman, N; Lan, Q. (2013). Occupational exposure to formaldehyde and alterations in lymphocyte subsets. Am J Ind Med 56: 252-257. http://dx.doi.org/10.1002/ajim.22088
Hovding, G. (1959). Free formaldehyde in textiles. A cause of contact eczema. Acta Derm Venereol 39: 357-368.
Hovding, G. (1961). Contact eczema due to formaldehyde in resin finished textiles. Acta Derm Venereol 41: 194-200.
IARC. (1982). IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans: Some industrial chemicals and dyestuffs (pp. 1-398). Lyon, France: International Agency for Research on Cancer :: IARC. http://monographs.iarc.fr/ENG/Monographs/vol29/volume29.pdf
ICFI. (1984). Formaldehyde emissions from building products: cost-effectiveness of reduction strategies. Chapter II: formaldehyde-emitting wood products and alternatives for controlling emissions [TSCA Submission]. (OTS0524645. 40-84021993. 44004 B1C-1. TSCATS/409186). EPA.
Ioras, F; Mcnulty, T; Natthondan, V; Ratnasingam, J. (2010). Dust, noise and chemical solvents exposure of workers in the wooden furniture industry in South East Asia. Journal of Applied Sciences 10: 1413-1420. http://dx.doi.org/10.3923/jas.2010.1413.1420

IPC International. (2019). IPC presentation to EPA on formaldehyde in the electroless copper plating process. Presentation presented at Meeting with IPC and EPA to discuss conditions of use for formaldehyde, Washington, DC.

IPC International. (2020). Comment submitted by Kelly Scanlon, Director of Environment, Health and Safety Policy and Research, IPC regarding the draft scope of the risk evaluation for formaldehyde. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0050

Jahromi, WHBMDS. (2005). Melamine resins. In Kirk-Othmer Encyclopedia of Chemical Technology. New York, NY: John Wiley & Sons. https://onlinelibrary.wiley.com/doi/abs/10.1002/0471238961.melabind.a01

Kilburn, KH; Seidman, BC; Warshaw, R. (1985). Neurobehavioral and respiratory symptoms of formaldehyde and xylene exposure in histology technicians. Arch Environ Occup Health 40: 229-233. http://dx.doi.org/10.1080/00039896.1985.10545924

Kim, S. (2010). Control of formaldehyde and TVOC emission from wood-based flooring composites at various manufacturing processes by surface finishing. J Hazard Mater 176: 14-19. http://dx.doi.org/10.1016/j.jhazmat.2009.03.113

Kinnes, GM. (1990). Health hazard evaluation report: HETA-88-279-2026, Kardon Industries, St. Paris, Ohio. (HETA 88-279-2026). Cinncinati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/1988-0279-2026.pdf

Kinnes, GM; Mortimer, VD. (1999). Health hazard evaluation report, HETA 97-0106-2770: Sommer-Allibert Industries, USA, Inc., Kansas City, Missouri, December 1999. (HETA #97-0106-2770). Cincinnati, OH: National Institute for Occupational Safety and Health.

Kitwattanavong, M; Prueksasit, T; Morknoy, D; Tunsaringkarn, T; Siriwong, W. (2013). Health risk assessment of petrol station workers in the inner city of Bangkok, Thailand, to the exposure to BTEX and carbonyl compounds by inhalation. Hum Ecol Risk Assess 19: 1424-1439. http://dx.doi.org/10.1080/10807039.2012.685814

Klincewicz, SL; Reh, CM. (1989). Health hazard evaluation report: HETA-87-411-1972, Naval Weapons Support Center, Crane, Indiana. (HETA 87-411-1972). Cinncinati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/1987-0411-1972.pdf

Koch Turf. (2016). Nitroform Slow-Release Urea-Formaldehyde (UF) fertilizer. Wichita, KS.

Kominsky, JR; Stroman, RE. (1977). Health Hazard Evaluation Determination, Report No. HHE-77-15-421, Leed and Northrup Corporation, Expendable Devices Division Ellwood City, Pennsylvania (pp. 77-15). (NIOSH/00074930). Kominsky, JR; Stroman, RE. https://www.cdc.gov/niosh/hhe/reports/pdfs/77-15-421.pdf

Kralj, AAK. (2015). The re-usages of wastewater within industry: the positive impact of contaminants. J Clean Prod 95: 124-130. http://dx.doi.org/10.1016/j.jclepro.2015.02.054

Kullman, GJ. (1989). Health Hazard Evaluation Report HETA 88-269-1993, Meyersdale Manufacturing Co., Meyersdale, Pennsylvania, October 1989. (HETA 88-269-1993). Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/1988-0269-1993.pdf

LaDou, J. (2006). Printed circuit board industry [Review]. Int J Hyg Environ Health 209: 211-219. http://dx.doi.org/10.1016/j.ijheh.2006.02.001

Lavoue, J; Beaudry, C; Goyer, N; Perrault, G; Gerin, M. (2005). Investigation of determinants of past and current exposures to formaldehyde in the reconstituted wood panel industry in Quebec. Ann Occup Hyg 49: 587-602. http://dx.doi.org/10.1093/annhyg/mei014

Łebkowska, M; Narożniak-Rutkowska, A; Pajor, E. (2013). Effect of a static magnetic field of 7 mT on formaldehyde biodegradation in industrial wastewater from urea-formaldehyde resin production by activated sludge. Bioresour Technol 132: 78-83. http://dx.doi.org/10.1016/j.biortech.2013.01.020

Lee, N; Lee, BK; Jeong, S; Yi, GY; Shin, J. (2012). Work environments and exposure to hazardous substances in Korean tire manufacturing. Saf Health Work 3: 130-139. http://dx.doi.org/10.5491/SHAW.2012.3.2.130

Lee, SA. (1988). Health Hazard Evaluation Report HETA 87-309-1906, Louisiana-Pacific Corporation, Missoula, Montana, June 1988. (HETA #87-309-1906). Cincinnati, OH: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/1987-0309-1906.pdf

Li, JF. (2017). Health Hazard Evaluation Report: HHE-2016-0145-3292, October 2017. Evaluation of employee exposures at a plastic bag sealing plant. (2016-0145-3292). Cincinnati, OH: NIOSH.

Lin, D; Guo, Y; Yi, J; Kuang, D, an; Li, X; Deng, H; Huang, K, un; Guan, L, ei; He, Y; Zhang, X; Hu, D, ie; Zhang, Z; Zheng, H; Zhang, X; Mchale, CM; Zhang, L; Wu, T. (2013). Occupational exposure to formaldehyde and genetic damage in the peripheral blood lymphocytes of plywood workers. J Occup Health 55: 284-291. http://dx.doi.org/10.1539/joh.12-0288-OA

Löfstedt, H; Westberg, H; Seldén, AI; Bryngelsson, IL; Svartengren, M. (2011a). Respiratory symptoms and lung function in foundry workers using the hot box method: A 4-year follow-up. J Occup Environ Med 53: 1425-1429. http://dx.doi.org/10.1097/JOM.0b013e3182363c17

Löfstedt, H; Westberg, H; Seldén, AI; Lundholm, C; Svartengren, M. (2009). Respiratory symptoms and lung function in foundry workers exposed to low molecular weight isocyanates. Am J Ind Med 52: 455-463. http://dx.doi.org/10.1002/ajim.20693

Löfstedt, H; Westberg, H; Seldén, AI; Rudblad, S; Bryngelsson, IL; Ngo, Y; Svartengren, M. (2011b). Nasal and ocular effects in foundry workers using the hot box method. J Occup Environ Med 53: 43-48. http://dx.doi.org/10.1097/JOM.0b013e318181ff05cc

Lyapina, M; Zhelezova, G; Petrova, E; Boev, M. (2004). Flow cytometric determination of neutrophil respiratory burst activity in workers exposed to formaldehyde. Int Arch Occup Environ Health 77: 335-340. http://dx.doi.org/10.1007/s00420-004-0516-3

Majumdar (neé som), D; Dutta, C; Mukherjee, AK; Sen, S. (2008). Source apportionment of VOCs at the petrol pumps in Kolkata, India; exposure of workers and assessment of associated health risk. Transport Res Transport Environ 13: 524-530. http://dx.doi.org/10.1016/j.trd.2008.09.011

Mäkinen, M; Kalliokoski, P; Kangas, J. (1999). Assessment of total exposure to phenol-formaldehyde resin glue in plywood manufacturing. Int Arch Occup Environ Health 72: 309-314. http://dx.doi.org/10.1007/s004200050380

Manuel Rodriguez, M; Aristeguieta, C. (2009). Evaluation of employees' chemical exposures while blending and repackaging glass beads for road markings. (HETA 2008-0017-3095). Manuel Rodriguez, M; Aristeguieta, C.

Marlow, DA. (1995). Health hazard evaluation report HETA 94-0309-2514, Homecrest Industries Incorporated, Wadena, Minnesota. (HETA 94-0309-2514). Cincinnati, OH: National Institute for Occupational Safety and Health.

Marquart, H; Franken, R; Goede, H; Fransman, W; Schinkel, J. (2017). Validation of the dermal exposure model in ECETOC TRA. Ann Work Expo Health 61: 854-871. http://dx.doi.org/10.1093/annweh/wxx059

Material Research. (2019). Formaldehyde: Technical report on the conditions of use. Washington, DC: Earthjustice. https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0018

Mauer, MP; Cook, CK. (1999). Health hazard evaluation report HETA 97-0242-2725, Delphi Chassis Systems, Dayton, Ohio, February 1999. (HETA #97-0242-2725). Cincinnati, OH: National Institute for Occupational Safety and Health.

McCammon, C. (1998). Health hazard evaluation report 97-0138-2677 Shindoni, Inc. Tesuque, New Mexico February 1998. (HETA #97-0138-2677). Cincinnati, OH: National Institute for Occupational Safety and Health.

Methner, MM; Tapp, L; Ramsey, J. (2014). Health Hazard Evaluation Report: HETA-2012-0025-3207, May 2014. Evaluation of Metals, Solvents, Formaldehyde, Ventilation, and Ergonomic Risks During the Manufacture of Electrical Cable Accessories. (NTIS/11820040_a). Methner, MM; Tapp, L; Ramsey, J.

Minitab. (2022). A comparison of the Pearson and Spearman correlation methods. Available online at https://support.minitab.com/en-us/minitab/21/help-and-how-to/statistics/basic-statistics/supporting-topics/correlation-and-covariance/a-comparison-of-the-pearson-and-spearman-correlation-methods/ (accessed November 9, 2022).

Mirabelli, MC; Holt, SM; Cope, JM. (2011). Anatomy laboratory instruction and occupational exposure to formaldehyde. Occup Environ Med 68: 375-378. http://dx.doi.org/10.1136/oem.2010.059352

Moezzipour, B; Abdolkhani, A, li; Doost-Hoseini, K; Ramazani, SAA; Tarmian, A. (2018). Practical properties and formaldehyde emission of medium density fiberboards (MDFs) recycled by electrical method. Holz als Roh- und Werkstoff 76: 1287-1294. http://dx.doi.org/10.1007/s00107-018-1291-2

Monsanto Research Corp. (1981). Preliminary plant visit industrial hygiene report: Formaldehyde production facility, Monsanto Plastics and Resins Company, Eugene, Oregon. (114-22a). Cincinnati, OH: U.S. Environmental Protection Agency. https://www.cdc.gov/niosh/surveyreports/pdfs/114-22a.pdf

Monsanto Research Corp. (1983). Detailed industrial hygiene survey: formaldehyde production, Georgia-Pacific Corporation, Albany, Oregon. (114-15b). Cincinnati, OH: U.S. Environmental Protection Agency. https://www.cdc.gov/niosh/surveyreports/pdfs/114-15b.pdf

NAIMA. (2019). Comment submitted by Angus E. Crane, Executive Vice President, General Counsel, North American Insulation Manufacturers Association (NAIMA) regarding initiation of prioritization under the Toxic Substances Control Act. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0008

NASA. (2020). Comment submitted by Denise Thaller, Director, Environmental Management Division, National Aeronautics and Space Administration (NASA) regarding draft scopes of the risk evaluations to be conducted for seven chemical substances under the Toxic Substance Control Act (TSCA). (EPA-HQ-OPPT-2018-0438-0057). Washington, DC. https://www.regulations.gov/document/EPA-HQ-OPPT-2018-0438-0057

NICNAS. (2006). Priority existing chemical assessment report no. 28: Formaldehyde (pp. 121-143). Sydney, Australia: Australian Government Department of Health, National Industrial Chemicals Notification and Assessment Scheme. https://www.industrialchemicals.gov.au/sites/default/files/PEC28-Formaldehyde.pdf

NIOSH. (1973). Health hazard evaluation: Gates Rubber Company. (Report No. 72-86).

NIOSH. (1974a). Health hazard evaluation determination: Osborne Photographic Laboratories, Inc. (Report no. 73-191-149).

NIOSH. (1974b). Survey of Burlington Industries, Inc., Burlington House Finishing Plant, Form Fabrics Plant, Durham Domestics Plant, Brookneal Finishing Plant. (IWS-33.18). Cincinnati, OH. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB82151077.xhtml

NIOSH. (1980). Health hazard evaluation determination report: HHE-79-72-680, Energyloc, Inc., Portland, Oregon (pp. 79-72). (NIOSH/00099394). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/79-72-680.pdf

NIOSH. (1981a). Current intelligence bulletin 34: Formaldehyde: evidence of carcinogenicity. Washington, DC.

NIOSH. (1981b). Health hazard evaluation report: HHE 80-103-827. Joel & Aronoff, Ridgefield, NJ. (HHE 80-103-827). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/80-103-827.pdf

NIOSH. (1981c). Health hazard evaluation report: HHE 80-192-828. Rock Hill Printing and Finishing Company, Rock Hill, NC. (HHE 80-192-828). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/80-192-828.pdf

NIOSH. (1981d). Walk-Through Survey Report: Monsanto Plastics and Resins Company, Phenolormaldehyde Resin Facility, Port Plastics Plant, River Road, Addyston, Ohio, Report No. CT-108-11a (pp. 108-111). (NIOSH/00183681). Mortimer VD Jr.

NIOSH. (1982a). Health hazard evaluation report: HETA-80-144-1109. Film Processing Industry, Hollywood, California (pp. 1-34). (NIOSH/00127502). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/80-144-1109.pdf

NIOSH. (1982b). Health hazard evaluation report: HETA-82-264-1232. Olympic Medal Laboratories, Bremerton, Washington (pp. 1-10). (NIOSH/00127577). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/82-264-1232.pdf

NIOSH. (1982c). Health hazard evaluation report: HETA 82-342-1223. William Blount High School, Maryville, TN. (HETA 82-342-1223). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/82-342-1223.pdf

NIOSH. (1983a). Health evaluation and technical assistance report: HETA-81-422-1387. California Society For Histotechnology, Los Angeles, California (pp. 1-49). (NIOSH/00137474). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/1981-0422-1387.pdf

NIOSH. (1983b). Health hazard evaluation report: HETA-82-349-1332. Woolrich Woolen Mills, Inc., Woolrich, Pennsylvania (pp. 82-349). (NIOSH/00133466). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/82-349-1332.pdf

NIOSH. (1984a). Health hazard evaluation report: HETA-83-301-1478. Lion Uniform Company, Beattyville, Kentucky (pp. 1-26). (HETA 83-301-1478). Cincinnati, Ohio: U.S. Department of Health and Human Services. https://www.cdc.gov/niosh/hhe/reports/pdfs/83-301-1478.pdf

NIOSH. (1984b). Health hazard evaluation report: HETA·84-065-1519. Southern Oregon State College, Ashland, OR. (HETA 84-065-1519). Washington, DC: Center for Disease Control. https://www.cdc.gov/niosh/hhe/reports/pdfs/84-65-1519.pdf

NIOSH. (1986). Current intelligence bulletin: Reprints - Bulletins 31 thru 47. (DHHS (NIOSH) Publication Number 86-122). Cincinnati, OH: Center for Disease Control and Prevention. https://www.cdc.gov/niosh/docs/86-122/

NIOSH. (1993). Health hazard evaluation report no. HETA-92-092-2333, General Castings Power Street facility, Cincinnati, Ohio. (HETA-92-092-2333).

NIOSH. (1998). Health Hazard Evaluation Report HETA 97-0154-2693, Siemens Energy and Automation, Inc., Distribution Products Division, Urbana, Ohio. (HETA-97-0154-2693; HETA9701542693). Cincinnati, OH. Div. of Surveillance, Hazard Evaluations and Field Studies.
: National Institute for Occupational Safety and Health.

NIOSH. (2000). NIOSH Hazard Review: Carbonless copy paper. (DHHS (NIOSH) Publication No. 2001–107). Atlanta, GA: Center for Disease Control and Prevention.

NIOSH. (2003a). Niosh health hazard evaluation report- Bemis. (HETA 2003-0102-2921).

NIOSH. (2003b). Respirator Usage in Private Sector Firms. Washington D.C.: United States Department of Labor, Bureau of Labor Statistics and National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/docs/respsurv/

NIOSH. (2013). Evaluation of potential employee exposures during crime and death investigations at a county coroner's office. (Report No. 2011-0146-3170). Washington, DC: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. http://www.cdc.gov/niosh/hhe/reports/pdfs/2011-0146-3170.pdf

Norback, D; Wieslander, G; Edling, C. (1995). Occupational exposure to volatile organic compounds (VOCs), and other air pollutants from the indoor application of water-based paints. Ann Occup Hyg 39: 783-794. http://dx.doi.org/10.1016/0003-4878(95)00034-8

NTP. (2010). Final report on carcinogens. Background document for formaldehyde [NTP] (pp. i-512).

NZ DOH. (1981). Review of occupational health problems associated with formaldehyde exposure (26) [TSCA Submission]. (OTS0507047. 44004 B2-9. TSCATS/034013).

Oberle, W. (2015). Monte Carlo simulations: Number of iterations and accuracy. (ARL-TN-0684). Aberdeen Proving Ground, MD: US Army Research Laboratory. https://apps.dtic.mil/sti/pdfs/ADA621501.pdf

OECD. (2002). SIDS Initial Assessment Report: Formaldehyde (CAS no: 50-00-0) [OECD SIDS]. Paris, France: UNEP Publications. https://hpvchemicals.oecd.org/ui/handler.axd?id=5525377e-1442-43d0-8c76-f8cacfadf8bb

OECD. (2004a). Emission scenario document on leather processing. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)13&doclanguage=en

OECD. (2004b). Emission scenario document on lubricants and lubricant additives. In OECD Series On Emission Scenario Documents. (JT00174617). Paris, France. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)21&doclanguage=en

OECD. (2009a). Emission scenario document on adhesive formulation. (ENV/JM/MONO(2009)3; JT03263583). Paris, France. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2009)3&doclanguage=en

OECD. (2009b). Emission scenario documents on coating industry (paints, lacquers and varnishes). (JT03267833). Paris, France. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env%20/jm/mono(2009)24&doclanguage=en

OECD. (2010). Emission Scenario Document on Photoresist Use in Semiconductor Manufacturing. In Series on Emission Scenario Documents No 9. Paris: OECD Environmental Health and Safety Publications. http://dx.doi.org/10.1787/9789264221161-en

OECD. (2011a). Emission scenario document on coating application via spray-painting in the automotive refinishing industry. (ENV/JM/MONO(2004)22/REV1). Paris, France: Organization for Economic Co-operation and Development. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)22/rev1&doclanguage=en

OECD. (2011b). Emission Scenario Document on the application of radiation curable coatings, inks, and adhesives via spray, vacuum, roll, and curtain coating.

OECD. (2011c). Emission scenario document on the chemicals used in water-based washing operations at industrial and institutional laundries. (JT03304937). Paris, France. https://www.oecd-ilibrary.org/docserver/9789264220973-en.pdf?expires=1587647360&id=id&accname=guest&checksum=B8C714E510603EB565B89A8AE6A24C14

OECD. (2012). Emission scenario document on chemicals used in oil well production. (JT03318094). Paris, France. https://www.oecd-ilibrary.org/docserver/9789264220966-

en.pdf?expires=1587647294&id=id&accname=guest&checksum=B15B4CD8B176EC15C6A050541C9B1F6A

OECD. (2015a). Emission scenario document (ESD) on chemical vapour deposition in the semiconductor industry. Paris, France: Organisation for Economic Co-operation and Development, OECD Environment Directorate, Environment, Health and Safety Division. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2015)5&doclanguage=en

OECD. (2015b). Emission scenario document on use of adhesives. (Number 34). Paris, France. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2015)4&doclanguage=en

OECD. (2017). Emission scenario document (ESD) on the use of textile dyes. (ENV/JM/MONO(2015)50). Paris, France: OECD, Inter-Organization Programme for the Sound Management of Chemicals (IOMC). http://www.oecd.org/chemicalsafety/risk-assessment/emissionscenariodocuments.htm

OECD. (2020). Emission scenario document on chemical additives used in automotive lubricants. Paris, France.

Offermann, FJ. (2017). Formaldehyde emissions from laminate flooring [Editorial]. ASHRAE J 59: 102-105.

Oh, YS; Kim, JM. (2015). Properties of oriented strandboard bonded with phenol-urea-formaldehyde resin. J Trop Forest Sci 27: 222-226.

Oliva-Teles, MT; Paiga, P; Delerue-Matos, CM; Alvim-Ferraz, MCM. (2009). Evaluation of Formaldehyde in Foundry Waste Sands Using Liquid Chromatography. Anal Lett 42: 492-504. http://dx.doi.org/10.1080/00032710802363453

OPW Engineered Systems. (2014). Loading Systems Catalog. OPW Engineered Systems: A Dover Company. ES-LS-6/15-2M; Uploaded November 18, 2014. OPW Engineered Systems. http://www.opwglobal.com/docs/libraries/sales-literature/chemical-industrial/engineered-systems/brochures/opw-es-loading_systems_cat.pdf?sfvrsn=6

Oracle. (2017). Selecting probability distributions. In Oracle® Crystal Ball User's Guide; 2017 (Release 11124). Austin, TX. https://docs.oracle.com/cd/E57185_01/CYBUG/apas03.html

OSHA. (2023). OSHA technical manual: Section II: Chapter 1: Personal sampling for air contaminants. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, Office of Training and Education. https://www.osha.gov/otm/section-2-health-hazards/chapter-1

Pala, M; Ugolini, D; Ceppi, M; Rizzo, F; Maiorana, L; Bolognesi, C; Schilirò, T; Gilli, G; Bigatti, P; Bono, R; Vecchio, D. (2008). Occupational exposure to formaldehyde and biological monitoring of Research Institute workers. Cancer Detect Prev 32: 2008. http://dx.doi.org/10.1016/j.cdp.2008.05.003

Palisade. (2015a). Palisade Knowledge Base: 2.6. How many iterations do I need? Available online at https://kb.palisade.com/index.php?pg=kb.page&id=125 (accessed November 9, 2022).

Palisade. (2015b). Palisade Knowledge Base: 2.19. Random number generators. Available online at https://kb.palisade.com/index.php?pg=kb.page&id=25 (accessed November 9, 2022).

Palisade. (2018). Palisade Knowledge Base: 2.18. Latin Hypercube versus Monte Carlo sampling. Available online at https://kb.palisade.com/index.php?pg=kb.page&id=28 (accessed November 9, 2022).

Palisade. (2022). Define correlation matrix. Available online at https://help.palisade.com/v8/en/@RISK/1-Define/5-Correlation/Define-Correlation-Matrix.htm (accessed November 9, 2022).

Parsons Engineering Science. (1997). Allied Signal Aerospace Greenwood, South Carolina indoor air sampling and air quality investigation [TSCA Submission]. In Letter from Allied Signal Inc to USEPA re indoor air sampling and air quality investigations at Illinois and S Carolina facilities,

with attachments and dated 12/15/1997. (OTS0559390. 96-980000052. TSCATS/445531b). Allied Signal Incorporated.
Patankar, SC; Dodiya, SK; Yadav, GD. (2015). Cascade engineered synthesis of ethyl benzyl acetoacetate and methyl isobutyl ketone (MIBK) on novel multifunctional catalyst. J Mol Catal Chem 409: 171-182. http://dx.doi.org/10.1016/j.molcata.2015.08.018
Peteffi, GP; Basso da Silva, L; Antunes, MV; Wilhelm, C; Valandro, ET; Glaeser, J; Kaefer, D; Linden, R. (2015). Evaluation of genotoxicity in workers exposed to low levels of formaldehyde in a furniture manufacturing facility. Toxicol Ind Health 32: 1763-1773. http://dx.doi.org/10.1177/0748233715584250
Phoenix Brands. (2007). Fab/Dynamo/ABC/Ajax 2x heavy duty liquid detergent. Available online at https://www.whatsinproducts.com//brands/show_msds/1/9592 (accessed January 7, 2020).
Price, JH. (1978). Health Hazard Evaluation Determination, Report No. HE 77-41-505, General American Transportation Corporation, Masury, Ohio, July 1978. (HE 77-41-505). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/77-41-505.pdf
Price, JH. (1979). Health Hazard Evaluation Determination, report HE 78-13-577, Equitable Bag Company, Inc, Florence, Kentucky. (HE 78-13-577). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/78-13-577.pdf
Quémerais, B. (2013). Occupational exposure to atmospheric emissions produced during live gun firing. Environment and Pollution 2: 57-69. http://dx.doi.org/10.5539/ep.v2n4p57
Rivera, R. (1976). Health Hazard Evaluation Report No. 75-143-333, Unitog Company, Warrensburg, Missouri. (HHE-75-143-333). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/75-143-333.pdf
Robinson, CF; Waxweiler, RJ; Fowler, DP. (1986). Mortality among production workers in pulp and paper mills. Scand J Work Environ Health 12: 552-560. http://dx.doi.org/10.5271/sjweh.2101
Rodriguez, M; West, C; Brueck, SE. (2012). Air contaminant, noise, and dermal hazards during aluminum beverage can manufacturing – Texas. (HETA 2008-0099-3152). Rodriguez, M; West, C; Brueck, SE.
Romanazzi, V; Pirro, V; Bellisario, V; Mengozzi, G; Peluso, M; Pazzi, M; Bugiani, M; Verlato, G; Bono, R. (2013). 15-F2t isoprostane as biomarker of oxidative stress induced by tobacco smoke and occupational exposure to formaldehyde in workers of plastic laminates. Sci Total Environ 442: 20-25. http://dx.doi.org/10.1016/j.scitotenv.2012.10.057
Roper, P. (1976). Health Hazard Evaluation Determination Report No. 74-86-269, Owens-Corning Fiberglass Corporation, Newark, Ohio. (HHE-77-31-432). Cincinnati, OH: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/74-86-269.pdf
Rossiter, WJ, Jr; Mathey, RG. (1985). Urea-formaldehyde foam insulations: a review of their properties and performance. (NBS Technical Note 1210). Washington, DC: U.S. Department of Commerce. https://search.proquest.com/docview/14195737?accountid=171501
Rothman, N; Lan, Q; Smith, MT; Vermeulen, R; Zhang, L. (2017). Response to letter to the editor of Carcinogenesis by Pira et al., 2017 [Letter]. Carcinogenesis 38: 1253-1255. http://dx.doi.org/10.1093/carcin/bgx111
Rovira, J; Domingo, JL. (2019). Human health risks due to exposure to inorganic and organic chemicals from textiles: A review [Review]. Environ Res 168: 62-69. http://dx.doi.org/10.1016/j.envres.2018.09.027
Roy, DR. (1999). Histology and pathology laboratories. Chemical hazard prevention and medical/health surveillance [Review]. AAOHN J 47: 199-205. http://dx.doi.org/10.1177/216507999904700502
RTI. (1980). Environmental assessment of iron casting. (PB80187545). https://search.proquest.com/docview/14151399?accountid=171501

Saary, MJ; House, RA; Holness, DL. (2001). Dermatitis in a particleboard manufacturing facility. Contact Derm 44: 325-330. http://dx.doi.org/10.1034/j.1600-0536.2001.044006325.x

Salisbury, S. (1996). Health Hazard Evaluation Report 96-0091-2597 Photoart (Stannard Associates, Inc.) Fredricksburg, Virginia September 1996. (HETA #96-0091-2597). Cincinnati, OH: National Institute for Occupational Safety and Health.

Sancini, A; Rosati, MV; De Sio, S; Casale, T; Caciari, T; Samperi, I; Sacco, C; Fortunato, BR; Pimpinella, B; Andreozzi, G; Tomei, G; Tomei, F. (2014). Exposure to formaldehyde in health care: an evaluation of the white blood count differential. G Ital Med Lav Ergon 36: 153-159.

Scarselli, A; Corfiati, M; Di Marzio, D; Iavicoli, S. (2017). National Estimates of Exposure to Formaldehyde in Italian Workplaces. Ann Work Expo Health 61: 33-43. http://dx.doi.org/10.1093/annweh/wxw004

Scheyer, LE; Kachman, SD; Polsani, M. (2001). Use of soy protein hydrolyzate to reduce formaldehyde emissions from pigment print pastes. AATCC Rev 1: 45-48.

Schripp, T; Wensing, M. (2009). Emission of VOCs and SVOCs from electronic devices and office equipment. In E Uhde; T Salthammer (Eds.), Organic indoor air pollutants (2nd ed., pp. 405-430). Weinheim, Germany: Wiley. http://dx.doi.org/10.1002/9783527628889.ch17

Schwensen, JF; Friis, UF; Menné, T; Flyvholm, MA; Johansen, JD. (2017). Contact allergy to preservatives in patients with occupational contact dermatitis and exposure analysis of preservatives in registered chemical products for occupational use. Int Arch Occup Environ Health 90: 319-333. http://dx.doi.org/10.1007/s00420-017-1203-5

Seow, WJ; Zhang, L; Vermeulen, R; Tang, X; Hu, W; Bassig, BA; Ji, Z; Shiels, MS; Kemp, TJ; Shen, M; Qiu, C; Reiss, B; Beane Freeman, LE; Blair, A; Kim, C; Guo, W; Wen, C; Li, L; Pinto, LA; Huang, H; Smith, MT; Hildesheim, A; Rothman, N; Lan, Q. (2015). Circulating immune/inflammation markers in Chinese workers occupationally exposed to formaldehyde. Carcinogenesis 36: 852-857. http://dx.doi.org/10.1093/carcin/bgv055

Shinohara, N; Okazaki, Y; Mizukoshi, A; Wakamatsu, S. (2019). Exposure to benzene, toluene, ethylbenzene, xylene, formaldehyde, and acetaldehyde in and around gas stations in Japan. Chemosphere 222: 923-931. http://dx.doi.org/10.1016/j.chemosphere.2019.01.166

SIA. (2020). SIA comments on the draft scope of the risk evaluation for formaldehyde. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0053

Solenis. (2020). Comment submitted by Dwight Chapman, Strategic Marketing Manager, Solenis LLC regarding the draft scope of the risk evaluation for formaldehyde. Available online at https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0038

Sousa, FW; Cavalcante, RM; Rocha, CA; Nascimento, RF; Ferreira, AG. (2015). Carbonyl compounds from urban activities and their associated cancer risks: The influence of seasonality on air quality (Fortaleza-Ce, Brazil). Urban Climate 13: 110-121. http://dx.doi.org/10.1016/j.uclim.2015.03.004

Stantec ChemRisk. (2023). Submission by ACC Formaldehyde TSCA Risk Evaluation Consortium regarding analysis of industrial hygiene monitoring data for formaldehyde manufacturing and processing. Washington, DC: American Chemistry Council. https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0118

Steinsvag, K; Bratveit, M; Moen, BE. (2007). Exposure to carcinogens for defined job categories in Norway's offshore petroleum industry, 1970 to 2005. Occup Environ Med 64: 250-258. http://dx.doi.org/10.1136/oem.2006.028225

Stern, FB; Beaumont, JJ; Halperin, WE; Murthy, LI; Hills, BW; Fajen, JM. (1987). Mortality of chrome leather tannery workers and chemical exposures in tanneries. Scand J Work Environ Health 13: 108-117. http://dx.doi.org/10.5271/sjweh.2073

Sussell, A. (1995). Health hazard evaluation report No. HETA-91-0239-2509, Medite Of New Mexico, Las Vegas, New Mexico (pp. 91-0239). (HETA 91-0239-2509). Cincinnati, OH: National Institute of Occupation Safety and Health.

Taylor, AW. (2004). Fertilizers. Hoboken, NJ: John Wiley & Sons. http://dx.doi.org/10.1002/0471238961.0605182008150606.a01.pub2

Teixeira, JV; Miranda, S; Monteiro, RA; Lopes, FV; Madureira, J; Silva, GV; Pestana, N; Pinto, E; Vilar, VJ; Boaventura, RA. (2013). Assessment of indoor airborne contamination in a wastewater treatment plant. Environ Monit Assess 185: 59-72. http://dx.doi.org/10.1007/s10661-012-2533-0

Thetkathuek, A; Yingratanasuk, T; Ekburanawat, W. (2016). Respiratory Symptoms due to Occupational Exposure to Formaldehyde and MDF Dust in a MDF Furniture Factory in Eastern Thailand. 2016: 3705824. http://dx.doi.org/10.1155/2016/3705824

Thorud, S; Gjolstad, M; Ellingsen, DG; Molander, P. (2005). Air formaldehyde and solvent concentrations during surface coating with acid-curing lacquers and paints in the woodworking and furniture industry. J Environ Monit 7: 586-591. http://dx.doi.org/10.1039/b418887j

Tikuisis, T; Phibbs, MR; Sonnenberg, KL. (1995). Quantitation of employee exposure to emission products generated by commercial-scale processing of polyethylene. Am Ind Hyg Assoc J 56: 809-814. http://dx.doi.org/10.1080/15428119591016647

Tikuisis, T; Taylor, G; Sonnenberg, K; Cavanagh, J. (2010). Quantification of Emission Compounds Generated During Commercial-Scale Processing of Advanced Sclairtech TM Polyethylene. Journal of Plastic Film and Sheeting 26: 167-191. http://dx.doi.org/10.1177/8756087910380310

Tomer, A; Kane, J. (2015). The great port mismatch. U.S. goods trade and international transportation. The Global Cities Initiative. A joint project of Brookings and JPMorgan Chase. https://www.brookings.edu/wp-content/uploads/2015/06/brgkssrvygcifreightnetworks.pdf

Tuomi, T; Engstrom, B; Niemela, R; Svinhufvud, J; Reijula, K. (2000). Emission of ozone and organic volatiles from a selection of laser printers and photocopiers. Appl Occup Environ Hyg 15: 629-634. http://dx.doi.org/10.1080/10473220050075635

TVA. (1991). Formaldehyde in urea product and urea production -- Status report with cover letter dated 02/01/91 and attachments [TSCA Submission]. (OTS0000803; FYI-OTS-0391-0803; TSCATS/416031). Unocal Corp.

U.S. BLS. (2014). Employee Tenure News Release. Available online at http://www.bls.gov/news.release/archives/tenure_09182014.htm

U.S. BLS. (2016). May 2016 Occupational Employment and Wage Estimates: National Industry-Specific Estimates. Available online at http://www.bls.gov/oes/tables.htm

U.S. BLS. (2023). U.S. Census Bureau of Labor Statistics Data from 2021. Washington, DC: United States Department of Labor. Retrieved from https://www.bls.gov/oes/tables.htm

U.S. Census Bureau. (2015). Statistics of U.S. Businesses (SUSB). https://www.census.gov/data/tables/2015/econ/susb/2015-susb-annual.html

U.S. Census Bureau. (2019a). Survey of Income and Program Participation data. Available online at https://www.census.gov/programs-surveys/sipp/data/datasets/2008-panel/wave-1.html (accessed May 16, 2019).

U.S. Census Bureau. (2019b). Survey of Income and Program Participation: SIPP introduction and history. Washington, DC. https://www.census.gov/programs-surveys/sipp/about/sipp-introduction-history.html

U.S. EPA. (1991a). Chemical engineering branch manual for the preparation of engineering assessments. Volume I. Ceb Engineering Manual. Washington, DC: Office of Pollution Prevention and Toxics, US Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P10000VS.txt

U.S. EPA. (1991b). Locating and estimating air emissions from sources of formaldehyde (revised). (450491012). U.S. EPA. https://www3.epa.gov/ttn/chief/le/formal.pdf

U.S. EPA. (1992a). Guidelines for exposure assessment. Federal Register 57(104):22888-22938 [EPA Report]. In Risk Assessment Forum. (EPA/600/Z-92/001). Washington, DC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=15263

U.S. EPA. (1992b). A laboratory method to determine the retention of liquids on the surface of hands [EPA Report]. (EPA/747/R-92/003). Washington, DC.

U.S. EPA. (1993). Generic Scenario: Application of Agricultural Pesticides.

U.S. EPA. (1994a). Guidelines for Statistical Analysis of Occupational Exposure Data: Final. United States Environmental Protection Agency :: U.S. EPA.

U.S. EPA. (1994b). National Emission Standards for Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry for Process Vents, Storage Vessels, Transfer Operations, and Wastewater. (40 C.F.R. §§ 63.110 and 63.126-130). Washington, DC.

U.S. EPA. (1994c). Water treatment disinfectants application - generic scenario for estimating occupational exposures and environmental releases. Washington, DC. https://www.epa.gov/tsca-screening-tools/using-predictive-methods-assess-exposure-and-fate-under-tsca

U.S. EPA. (1995a). Ap-42: Chapter 4.12 - Manufacture of rubber products [EPA Report]. Washington, DC. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-fifth-edition-volume-i-chapter-4-evaporation-loss-0

U.S. EPA. (1995b). AP-42: Chapter 8 - Inorganic chemical industry [EPA Report]. Washington, DC. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-fifth-edition-volume-i-chapter-8-inorganic-chemical-0

U.S. EPA. (1995c). Protocol for Equipment Leak Emission Estimates. (EPA-453/R-95-017). Research Triangle Park, NC: Office of Air and Radiation, Office of Air Quality and Planning Standards. https://www3.epa.gov/ttn/chief/efdocs/equiplks.pdf

U.S. EPA. (1999). Flexographic printing - generic scenario for estimating occupational exposures and environmental releases: Draft. Washington, DC. https://www.epa.gov/tsca-screening-tools/using-predictive-methods-assess-exposure-and-fate-under-tsca

https://www.epa.gov/tsca-screening-tools/using-predictive-methods-assess-exposure-and-fate-under-tsca

U.S. EPA. (2002). Flexographic ink options: A cleaner technologies substitutes assessment. Volume 1 [EPA Report]. (EPA 744-R-02-001A). Cincinnati, OH: U.S. Environmental Protection Agency, National Service Center for environmental Publications. https://www.epa.gov/sites/default/files/2014-01/documents/flexographic_ctsa_vol1.pdf

U.S. EPA. (2003). Estimating 2003 building-related construction and demolition materials amounts. https://www.epa.gov/smm/estimating-2003-building-related-construction-and-demolition-materials-amounts

U.S. EPA. (2004a). Additives in plastics processing (converting into finished products) -generic scenario for estimating occupational exposures and environmental releases. Draft. Washington, DC.

U.S. EPA. (2004b). Spray coatings in the furniture industry - generic scenario for estimating occupational exposures and environmental releases.

U.S. EPA. (2010). Manufacture and use of printing inks - generic scenario for estimating occupational exposures and environmental releases: Draft. Washington, DC.

U.S. EPA. (2013). Updating CEB's method for screening-level estimates of dermal exposure. Chemical Engineering Branch.

U.S. EPA. (2015a). Chapter 5: Petroleum industry. Compilation of air pollutant emission factors. Volume I: Stationary point and area sources, fifth edition, AP-42. Research Triangle Park, NC: Office of Air and Radiation, Office of Air Quality and Planning Standards. https://www3.epa.gov/ttn/chief/ap42/ch05/index.html

U.S. EPA. (2015b). ChemSTEER user guide - Chemical screening tool for exposures and environmental releases. Washington, D.C. https://www.epa.gov/sites/production/files/2015-05/documents/user_guide.pdf

U.S. EPA. (2016). Chemical Data Reporting (CDR): Complete 2016 submissions. Washington, DC.

U.S. EPA. (2017a). Learn the Basics of Hazardous Waste. Available online at https://www.epa.gov/hw/learn-basics-hazardous-waste

U.S. EPA. (2017b). Toxics release inventory [Database]. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics. Retrieved from https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools

U.S. EPA. (2020a). 2020 CDR: Commercial and consumer use. Washington, DC.

U.S. EPA. (2020b). Draft Scope of the Risk Evaluation for Formaldehyde CASRN 50-00-0 April 2020. (EPA-740-D-20-014). https://www.epa.gov/sites/production/files/2020-04/documents/casrn-50-00-0_formaldehyde_draft_scope_4_15_2020_1.pdf

U.S. EPA. (2020c). Final scope of the risk evaluation for formaldehyde; CASRN 50-00-0. (EPA 740-R-20-014). Washington, DC: Office of Chemical Safety and Pollution Prevention. https://www.epa.gov/sites/default/files/2020-09/documents/casrn_50-00-0-formaldehyde_finalscope_cor.pdf

U.S. EPA. (2021a). Application of spray polyurethane foam insulation - Generic scenario for estimating occupational exposures and environmental releases - Final. Washington, DC. https://www.epa.gov/tsca-screening-tools/using-predictive-methods-assess-exposure-and-fate-under-tsca

U.S. EPA. (2021b). Draft systematic review protocol supporting TSCA risk evaluations for chemical substances, Version 1.0: A generic TSCA systematic review protocol with chemical-specific methodologies. (EPA Document #EPA-D-20-031). Washington, DC: Office of Chemical Safety and Pollution Prevention. https://www.regulations.gov/document/EPA-HQ-OPPT-2021-0414-0005

U.S. EPA. (2021c). Use of chemicals in fuels and related products - Generic scenario for estimating occupational exposures and environmental releases (Methodology review draft). Washington, DC: Office of Pollution Prevention and Toxics, Risk Assessment Division.

U.S. EPA. (2022a). Chemical repackaging - Generic scenario for estimating occupational exposures and environmental releases (revised draft) [EPA Report]. Washington, DC.

U.S. EPA. (2022b). Commercial use of automotive detailing products - Generic scenario for estimating occupational exposures and environmental releases (Methodology review draft) [EPA Report]. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Risk Assessment Division.

U.S. EPA. (2022c). Discharge Monitoring Report (DMR) data for 1,4-dioxane, 2013-2019. Washington, DC. Retrieved from https://echo.epa.gov/trends/loading-tool/water-pollution-search

U.S. EPA. (2022d). Emission scenario document on chemicals used in hydraulic fracturing (draft). Paris, France: Organization for Economic Co-operation and Development.

U.S. EPA. (2022e). National emissions inventory (NEI). Available online at https://www.epa.gov/air-emissions-inventories/national-emissions-inventory (accessed August 31, 2022).

U.S. EPA. (2022f). Toxics Release Inventory (TRI) data for 1,4-dioxane, 2013-2019. Washington, DC. Retrieved from https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools

U.S. EPA. (2023a). AP-42: Chapter 4 - Evaporation loss sources. Washington, DC.

U.S. EPA. (2023b). AP-42: Chapter 5 - Petroleum industry. Washington, DC.

U.S. EPA. (2023c). Draft Risk Evaluation for Formaldehyde – Systematic Review Supplemental File: Data Quality Evaluation and Data Extraction Information for Environmental Release and Occupational Exposure. Washington, DC: Office of Pollution Prevention and Toxics, Office of Chemical Safety and Pollution Prevention.

U.S. EPA. (2023d). Use of laboratory chemicals - Generic scenario for estimating occupational exposures and environmental releases (Revised draft generic scenario) [EPA Report]. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Existing Chemicals Risk Assessment Division.

U.S. EPA. (2024). Draft Human Health Risk Assessment Characterization of Formaldehyde. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics.

USTMA. (2019). U.S. Tire Manufacturers Association: Tire manufacturing and tire materials overview slides. Presentation presented at Meeting with US Tire Manufacturers Association and EPA to discuss conditions of use for formaldehyde, Washington, DC.

USTMA. (2020). Comment submitted by U.S. Tire Manufacturers Association (USTMA), dated 06/08/2020. (EPA-HQ-OPPT-2018-0438-0054). Washington, DC. https://www.regulations.gov/comment/EPA-HQ-OPPT-2018-0438-0054

Vaajasaari, K; Kulovaara, M; Joutti, A; Schultz, E; Soljamo, K. (2004). Hazardous properties of paint residues from the furniture industry. J Hazard Mater 106: 71-79. http://dx.doi.org/10.1016/j.jhazmat.2003.11.004

Van der Wal, JF. (1982). Formaldehyde measurements in Dutch houses, schools and offices in the years 1977-1980. Atmos Environ 16: 2471-2478. http://dx.doi.org/10.1016/0004-6981(82)90137-8

van der Willigen, AH; Stolz, E; van Joost, T. (1987). Sensitization to phenol formaldehyde resin in rubber glue. Contact Derm 16: 291-292. http://dx.doi.org/10.1111/j.1600-0536.1987.tb01467.x

Vangronsveld, E; Berckmans, S; Verbinnen, K; Van Leeuw, C; Bormans, C. (2010). Isocyanate and total inhalable particulate air measurements in the European wood panel industry. Int J Hyg Environ Health 213: 475-488. http://dx.doi.org/10.1016/j.ijheh.2010.08.011

Vicente, ED; Ribeiro, JP; Custódio, D; Alves, CA. (2017). Assessment of the indoor air quality in copy centres at Aveiro, Portugal. Air Qual Atmos Health 10: 117-127. http://dx.doi.org/10.1007/s11869-016-0401-8

Viegas, S; Ladeira, C; Gomes, M; Nunes, C; Brito, M; Prista, J. (2013). Exposure and genotoxicity assessment methodologies - the case of formaldehyde occupational exposure. Current Analytical Chemistry 9: 476-484. http://dx.doi.org/10.2174/1573411011309030017

Viegas, S; Prista, J. (2010). Aspects to consider for selection of chemical risk assessment methodology: The case of formaldehyde occupational exposure. WIT Trans Ecol Environ 132: 23-32. http://dx.doi.org/10.2495/ETOX100031

Vinzents, P; Laursen, B. (1993). A national cross-sectional study of the working environment in the Danish wood and furniture industry: Air pollution and noise. Ann Occup Hyg 37: 25-34. http://dx.doi.org/10.1093/annhyg/37.1.25

Wan, H; Wang, XM; Barry, A; Shen, J. (2014). Recycling wood composite panels: Characterizing recycled materials. BioResources 9: 7554-7565.

Westberg, H; Löfstedt, H; Seldén, A; Lilja, BG; Nayström, P. (2005). Exposure to low molecular weight isocyanates and formaldehyde in foundries using Hot Box core binders. Ann Occup Hyg 49: 719-725. http://dx.doi.org/10.1093/annhyg/mei040

Wicks, ZW, Jr; Jones, FN. (2013). Coatings. In Kirk-Othmer encyclopedia of chemical technology. Hoboken, NJ: John Wiley & Sons. http://dx.doi.org/10.1002/0471238961.0315012023090311.a01.pub3

Williams, LL. (2002). Amino resins and plastics. In Kirk-Othmer encyclopedia of chemical technology. New York, NY: John Wiley & Sons. http://dx.doi.org/10.1002/0471238961.0113091423091212.a01.pub2

Xu, W; Stewart, EJ. (2016). A comparison of engineering controls for formaldehyde exposure during grossing activities in health care anatomic pathology laboratories. J Occup Environ Hyg 13: 529-537. http://dx.doi.org/10.1080/15459624.2016.1149182

Zendehdel, R; Abdolmaleki, P; Jouni, FJ; Mazinani, M. (2017). Genetic variation and risk of DNA damage in peripheral blood lymphocytes of Iranian formaldehyde-exposed workers. Hum Exp Toxicol 37: 960327117728385. http://dx.doi.org/10.1177/0960327117728385

Zhang, L; Tang, X; Rothman, N; Vermeulen, R; Ji, Z; Shen, M; Qiu, C; Guo, W; Liu, S; Reiss, B; Freeman, LB; Ge, Y; Hubbard, AE; Hua, M; Blair, A; Galvan, N; Ruan, X; Alter, BP; Xin, KX; Li, S; Moore, LE; Kim, S; Xie, Y; Hayes, RB; Azuma, M; Hauptmann, M; Xiong, J; Stewart, P; Li, L; Rappaport, SM; Huang, H; Fraumeni, JF, Jr; Smith, MT; Lan, Q. (2010). Occupational exposure to formaldehyde, hematotoxicity, and leukemia-specific chromosome changes in cultured myeloid progenitor cells. Cancer Epidemiol Biomarkers Prev 19: 80-88. http://dx.doi.org/10.1158/1055-9965.EPI-09-0762

Zimmer, AT; Hadwen, G. (1993). HETA 92-287-2294 March 1993 Federal Records Center, Dayton, Ohio. (HETA 92-287-2294). National Institute for Occupational Safety and Health.

APPENDICES

Appendix A ABBREVIATIONS AND ACRONYMS

AC	Acute concentrations
ACA	American Coatings Association
ACC	American Chemistry Council
ACGIH	American Conference of Governmental Industrial Hygienists
ADC	Average daily concentration
ADD	Average daily dose
ADR	Acute Dose Rate
APDR	Acute potential dermal dose rates
APF	Assigned protection factor
BLS	Bureau of Labor Statistics
CASRN	Chemical Abstracts Service Registry Number
CDR	Chemical Data Reporting
CEB	Chemical Engineering Branch
CEHD	Chemical Exposure Health Data
CFR	Code of Federal Regulations
COU	Condition of use
CT	Central tendency
CWA	Clean Water Act
DIY	Do-it-yourself
DMR	Discharge monitoring report
EPA	Environmental Protection Agency
ESD	Emission Scenario Document
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FT	Full-text (screening)
GS	Generic Scenario
HAP	Hazardous air pollutant
HE	High-end
HERO	Health and Environmental Research Online (EPA Database)
HHE	Health hazard evaluation (NIOSH)
IBC	Intermediate bulk container
IFC	Industrial Function Category
IIOAC	Integrated Indoor/Outdoor Air Calculator (EPA)
K_{OC}	Soil organic carbon: water partitioning coefficient
K_{OW}	Octanol: water partition coefficient
LADC	Lifetime Average Daily Concentration
LOD	Limit of detection
Log K_{OC}	Logarithmic organic carbon: water partition coefficient
Log K_{OW}	Logarithmic octanol: water partition coefficient
LOQ	Limit of quantitation
MDF	Medium-density fiberboard
MRD	Methodology Review Draft (EPA)
MW	Molecular weight
NAICS	North American Industry Classification System
ND	Non-detect
NEI	National Emissions Inventory

NIOSH	National Institute for Occupational Safety and Health
NPDES	National Pollutant Discharge Elimination System
OARS	Occupational Alliance for Risk Science
OAQPS	Office of Air Quality Planning and Standards
OCF	One-component foam
OCSPP	Office of Chemical Safety and Pollution Prevention
OD	Operating days
OECD	Organisation for Economic Co-operation and Development
OES	Occupational exposure scenario
ONU	Occupational non-user
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
PBZ	Personal breathing zone
PECO	Population, exposure, comparator, and outcome
PEL	Permissible exposure limit (OSHA)
PESS	Potentially exposed or susceptible subpopulations
PF	Protection factor
PNOR	Particulates not otherwise regulated
POD	Point of departure
POTW	Publicly owned treatment works (wastewater)
PPE	Personal protective equipmen
ppm	Parts per million
PV	Production volume
QA/QC	Quality assurance/quality control
REL	Recommended exposure limit (NIOSH)
RCRA	Resource Conservation and Recovery Act
SACC	Science Advisory Committee on Chemicals (EPA)
SAR	Supplied-air respirator
SCBA	Self-contained breathing apparatus
SDS	Safety data sheet
SDWA	Safe Drinking Water Act
SHEDS-HT	Stochastic Human Exposure and Dose Simulation-High Throughput
SIC	Standard Industrial Classification
SOC	Standard Occupational Classification
SPF	Spray polyurethane foam
STEL	Short-term exposure limit (OSHA)
SUSB	Statistics of United States Businesses
TIAB	Title/abstract (screening)
TLV	Threshold limit value (ACGIH)
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TWA	Time-weighted average
U.S.	United States
VOC	Volatile organic compound
VP	Vapor pressure
wt%	Weight percent

Appendix B LIST OF SUPPLEMENTAL FILES

Risk Evaluation for Formaldehyde CASRN: 50-00-0, Supplemental Information on Occupational Exposure Modeling Results – Provides a summary of the calculated exposure results for the modeled OESs. The summary table includes the high-end and central tendency exposure results presented in units of both ppm and mg/m^3. Additionally, the file summarizes the model input parameters and equations used to calculate the exposures by exposure point for each scenario.

Risk Evaluation for Formaldehyde CASRN: 50-00-0, Supplemental Information on Occupational Exposure Monitoring Data – Provides a compilation of monitoring data from systematic review and OSHA CEHD data used in the occupational exposure assessment. The monitoring data is sorted into tabs for each of the OESs and includes information such as the HERO ID of the source, the data quality rating of the source, details of the monitoring data results, and worker/ONU distinctions. This file is not comprehensive of all available formaldehyde monitoring data, which is provided in (U.S. EPA, 2023c). Selected sources were pulled from (U.S. EPA, 2023c) during evidence integration based on evidence integration considerations (temporal representativeness, attributable to the exposure scenario, etc.).

> *Draft Risk Evaluation for Formaldehyde (HCHO) – Systematic Review Supplemental File: Data Quality Evaluation and Data Extraction Information for Environmental Release and Occupational Exposure* (U.S. EPA, 2023c) – Provides a compilation of tables for the data extraction and data quality evaluation information for Formaldehyde (HCHO). Each table shows the data point, set, or information element that was extracted and evaluated from a data source that has information relevant for the evaluation of environmental release and occupational exposure. This supplemental file may also be referred to as the "HCHO Data Quality Evaluation and Data Extraction Information for Environmental Release and Occupational Exposure."

Appendix C MODEL APPROACHES AND PARAMETER SELECTION

This appendix presents the modeling approach and model equations used in estimating occupational exposures for each of the applicable OESs. The models were developed through review of the literature and consideration of existing EPA/OPPT models, ESDs, and/or 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 was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 8.0.0. The Latin hypercube sampling method generates a sample of possible values from a multi-dimensional distribution and is considered a stratified method, meaning 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 the 95th and 50th percentile Monte Carlo simulation model result values for assessment. The 95th percentile value represents the high-end exposure level, whereas the 50th percentile value represents the typical exposure level. The following subsections detail the model design equations and parameters for each of the OESs.

C.1 EPA/OPPT Standard Models

This appendix section discusses the standard models used by EPA to estimate environmental releases of chemicals and occupational inhalation exposures. All the models presented in this section are models that were previously developed by EPA and are not the result of any new model development work for this risk evaluation. Therefore, this appendix does not provide the details of the derivation of the model equations which have been provided in other documents such as the *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b), *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments, Volume 1* (U.S. EPA, 1991a). *Evaporation of pure liquids from open surfaces* (Arnold and Engel, 2001), and *Evaluation of the Mass Balance Model Used by the References Environmental Protection Agency for Estimating Inhalation Exposure to New Chemical Substances* (Fehrenbacher and Hummel, 1996). The models include loss fraction models as well as models for estimating chemical vapor generation rates used in subsequent model equations to estimate the volatile releases to air and occupational inhalation exposure concentrations.

The *EPA/OPPT Penetration Model* estimates releases to air from evaporation of a chemical from an open, exposed liquid surface. 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 Equation_Apx C-1:

Equation_Apx C-1.

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

Where:

$G_{activity}$	=	Vapor generation rate for activity [g/s]
MW	=	Formaldehyde molecular weight [g/mol]

VP	=	Formalin 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. 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. The EPA/OPPT Mass Transfer Coefficient Model calculates the average vapor generation rate of the chemical from the exposed liquid surface using Equation_Apx C-2:

Equation_Apx C-2.

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

Where:

$G_{activity}$	=	Vapor generation rate for activity [g/s]
MW	=	Formaldehyde molecular weight [g/mol]
VP	=	Formalin 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. 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. This model is used for unloading activities because it is assumed while one vessel is being unloaded another is assumed to be loaded. The EPA/OAQPS AP-42 Loading Model calculates the average vapor generation rate from loading or unloading using Equation_Apx C-3:

Equation_Apx C-3.

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

Where:

$G_{activity}$	=	Vapor generation rate for activity [g/s]
$F_{saturation\_factor}$	=	Saturation factor [unitless]
MW	=	Formaldehyde molecular weight [g/mol]
$V_{container}$	=	Volume of container [gal/container]
VP	=	Formalin vapor pressure [torr]
$RATE_{fill}$	=	Fill rate of container [containers/hr]
R	=	Universal gas constant [L*torr/mol-K]
T	=	Temperature [K]

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 formaldehyde in the liquid of interest. However, EPA did not utilize a vapor pressure correction factor (*i.e.,* set it as 1) when modeling vapor generation rates for formaldehyde. This was because the vapor pressure of formalin was used instead of neat formaldehyde, as neat formaldehyde's vapor pressure exceeds the threshold (35 torr) for the above models. To account for lower vapor generation rates modeled using formalin's vapor pressure as compared to neat formaldehyde, EPA did not apply a vapor correction factor.

If calculating an environmental release, the vapor generation rate calculated from one of the above models (Equation_Apx C-1. , Equation_Apx C-2, and Equation_Apx C-3) is then used along with an operating time to calculate the release amount:

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 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 (Equation_Apx C-1, Equation_Apx C-2, and Equation_Apx C-3) is used to calculate the vapor generation rate for the given activity. With this vapor generation rate, the *EPA/OPPT Mass Balance Inhalation Model* calculates the volumetric concentration of formaldehyde using Equation_Apx C-4:

Equation_Apx C-4.

$$Cv_{activity} = Minimum: \begin{cases} \left[\dfrac{170{,}000 * T * G_{activity}}{MW \quad * Q * k}\right] \\ \left[\dfrac{1{,}000{,}000ppm * VP}{P}\right] \end{cases}$$

Where:

$Cv_{activity}$	=	Exposure activity volumetric concentration [ppm]
$G_{activity}$	=	Exposure activity vapor generation rate [g/s]
MW	=	Formaldehyde molecular weight [g/mol]
Q	=	Ventilation rate [ft^3/min]
k	=	Mixing factor [unitless]
T	=	Temperature [K]
VP	=	Formalin vapor pressure [torr]
P	=	Pressure [torr]

Mass concentration can be estimated by multiplying the volumetric concentration by the molecular weight of formaldehyde and dividing by molar volume at standard temperature and pressure.

EPA uses the above equations in the formaldehyde occupational exposure models, and EPA references the model equations by model name and/or equation number within Appendix B.

C.2 Developing Models that Use Monte Carlo Methods

This appendix provides background information on Monte Carlo methods, including an overview of deterministic and stochastic processes, an overview of the implementation of Monte Carlo methods, and a discussion of EPA's approach for building models that utilized Monte Carlo methods.

This appendix is only intended to provide general background information; information related to the specific models for which EPA implemented Monte Carlo methods is included in Appendices C.3 through C.8.

C.2.1 Background on Monte Carlo Methods

A *deterministic* process has a single output (or set of outputs) for a given input (or set of inputs). The process does not involve randomness and the direction of the process is known.

In contrast, *stochastic* processes are non-deterministic. The output is based on random trials and can proceed via multiple, or even infinite, directions.

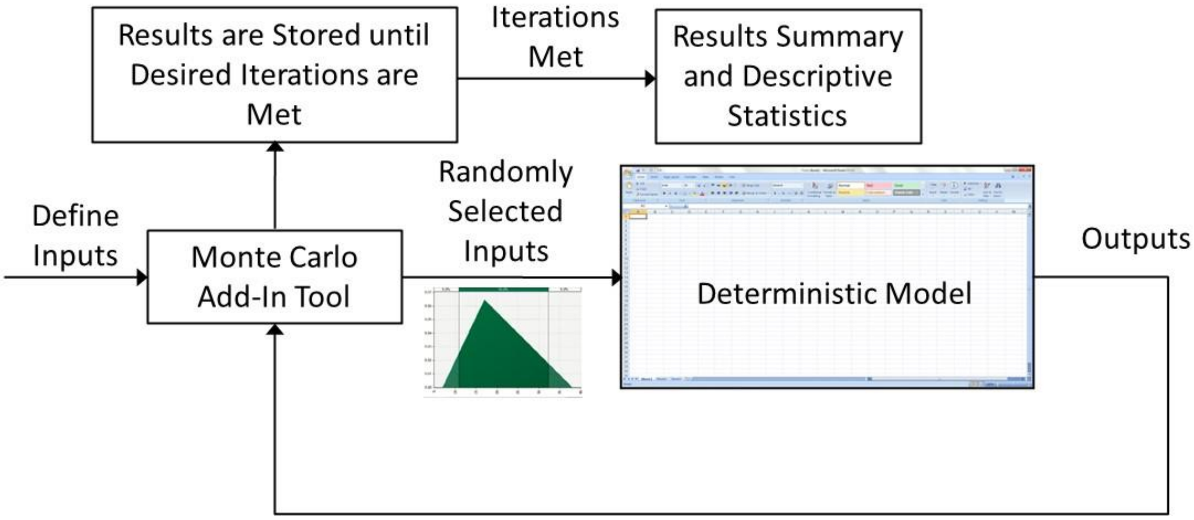
Monte Carlo methods fall under the umbrella of stochastic modeling. Monte Carlo methods are a replication technique for propagating uncertainty through a model. The model is run multiple times, and each run uses different input values and generates different output values: each run is independent of each other. The sample of output values is used to estimate the properties of the actual probability distribution of the outputs.

C.2.2 Implementation of Monte Carlo Methods

The implementation of Monte Carlo methods generally follows the following steps:

1. Define probability distributions for input parameters.
2. Generate a set of input values by randomly drawing a sample from each probability distribution.
3. Execute the deterministic model calculations.
4. Save the output results.
5. Repeat steps 2 through 4 through the desired number of iterations.
6. Aggregate the saved output results and calculate statistics.

Figure_Apx C-1 illustrates a flowchart of a Monte Carlo method implemented in a Microsoft Excel-based model using a Monte Carlo add-in tool, such as the Palisade @Risk software.



Figure_Apx C-1. Flowchart of a Monte Carlo Method Implemented in a Microsoft Excel-Based Model Using a Monte Carlo Add-In Tool

C.2.3 Building the Model

The steps for building a release or exposure model that incorporates Monte Carlo methods are as follows:

1. Build the deterministic model.
2. Define probability distributions for input parameters.
3. Select model outputs for aggregation of simulation results.
4. Select simulation settings and run model.
5. Aggregate the simulation results and calculate output statistics.

Each of these steps is discussed in the subsections below.

C.2.3.1 Build the Deterministic Model

First, the model is built as a deterministic model. EPA uses Microsoft Excel in order to use Palisade's @Risk software that is used for probabilistic analyses in Excel. The model parameters and equations are programmed into the spreadsheet. Model parameters are programmed in a summary table format for transparency and to aid in the assignment of probability distributions. Such summary tables are included in the model-specific write-ups in Appendices C.3 through C.8.

C.2.3.2 Define Probability Distributions for Input Parameters

Defining a probability distribution for an input parameter generally involves three steps:

1. Select the model input parameters for which probability distributions will be developed.
2. Determine a probability distribution from the available data.
3. Investigate if any parameters are statistically correlated. Define a statistical correlation among parameters if a correlation is desired.

Step 1: Select Input Parameters for Probability Distribution Development

When selecting parameters for which probability distributions will be developed, the following factors are considered:

- The availability of data to inform a distribution.
- The dependency of the input parameters on one another.
- The sensitivity of the model results to each input parameter.

Availability of Data to Inform a Distribution: Data sources to investigate for available data to inform probability distributions of model inputs include but are not limited to the following:

- EPA Generic Scenarios,
- OECD Emission Scenario Documents,
- Peer reviewed literature,
- Published chemical assessments, and
- Other gray literature.[1]

Model parameters may vary greatly in their available data. There may be a single study that provides detailed measurements or observation data. There may be multiple studies that provide limited measurements or observations. There may be only overall statistics available for a parameter. For a given model development, the available data goes through a systematic review process to evaluate the data quality, integrate the data, and decide how to use the data.

Dependency of Input Parameters on One Another: The model parameters are evaluated for any dependency on each other. When each varied parameter is sampled according to its defined probability distribution, they are sampled independently of each other. Therefore, the value of a sampled parameter should be independent of the other sampled parameters. An exception is if a statistical correlation is desired among two or more parameters. Correlating sampled parameters is discussed below in Step 3.

An example of dependency is the relationship between a facility's number of operating days, annual production volume (PV), and daily PV. These three parameters are not all independent of each other. The annual PV may be calculated from the daily PV and the operating days. Alternatively, the daily PV may be calculated from the annual PV and the operating days. Additionally, operating days may be calculated from the annual PV and daily PV. It is necessary to first understand the mathematical relationship among these parameters before selecting parameters for which probability distributions will be developed.

Sensitivity of the Model Results to Each Input Parameter: One consideration in selecting model parameters for probability distribution development is the sensitivity of the model outputs to each parameter. A sensitivity analysis can inform how sensitive each model output is to each model input parameter. EPA may choose to prioritize probability distribution development for parameters to which model outputs are more sensitive. Since the model outputs are more sensitive to these parameters, it would be more important to capture variability and/or uncertainty for these parameters compared to parameters to which model outputs are less sensitive.

A sensitivity analysis is conducted by varying each desired parameter and performing a Monte Carlo simulation. The varied range for each parameter should be consistent with the expected range in values for the parameter. The @Risk software can perform sensitivity analyses. The statistic of the outputs for which sensitivity is measured, such as mean, mode, or a percentile, can be selected. As the simulation is run, the software tracks how each output changes with respect to each varied input.

[1] Gray literature is defined as the broad category of data/information sources not found in standard, peer-reviewed literature databases. Gray literature includes data/information sources such as white papers, conference proceedings, technical reports, reference books, dissertations, information on various stakeholder websites, and various databases.

Step 2: Determine a Probability Distribution

To determine a probability distribution, first, all the information known about the parameter is evaluated (Oracle, 2017). The following considerations can help guide summarizing important information about the parameter (Analytica, 2015):

- Discrete or continuous
    - Consider whether the parameter is discrete or continuous. Does the parameter have a finite or countable number of possible values? Is the parameter logical or Boolean such as having possible values of "yes or no" or "true or false"? Can the parameter be represented by all real numbers within a domain?
- Bounds
    - Consider whether the parameter has bounds. A parameter may have a lower bound and/or an upper bound. Alternatively, a parameter may be unbounded and can range to negative and/or positive infinity.
- Modes
    - Consider whether the parameter has one or more modes. Does the parameter have no mode (such as represented by a uniform distribution)? If it has a mode, is it unimodal or multimodal? If multimodal, is the parameter a combination of two or more populations? In which case, the parameter may be best separated into its separate components and then develop probability distributions for the individual components.
- Symmetric or skewed
    - Consider whether the parameter is symmetric or skewed. If skewed, consider whether the parameter is positively skewed (thicker upper tail) or negatively skewed (thicker lower tail).

Second, review standard probability distributions and identify possible candidates that meet the considerations identified in the first step (Oracle, 2017). The following are common probability distributions:

- Uniform distribution
    - A uniform distribution has finite upper and lower bounds and all values between the bounds have equal probability.
- Triangular distribution
    - A triangular distribution has finite upper and lower bounds and a modal value. The modal value is the value that occurs most frequently. If the most frequent value is not known another statistic, such as the mean or a percentile, could be used to define the triangular distribution.
- Normal distribution
    - The parameters of a normal distribution are its mean and standard deviation. A normal distribution is unbounded, and values range from negative to positive infinity. If desired, the range of values of a normal distribution may be truncated to finite bounds to prevent unrealistic values from being sampled.
- Lognormal distribution
    - If a variable is lognormally distributed, it means that the logarithm of that variable is normally distributed. The parameters of a lognormal distribution are its mean and standard deviation. A lognormal distribution is bounded from zero to positive infinity. A lognormal distribution may be shifted and its upper bound truncated to fit the observed data and prevent unrealistic values from being sampled.

Lastly, select the best suited probability distribution (Oracle, 2017). Review the available data for the parameter to determine how to define the distribution's parameters. For example, if the only available data are an overall range (with a minimum and a maximum), then a uniform distribution is the appropriate distribution to use. If the only available data are an overall range and a mode, then a triangular distribution is the appropriate distribution to use. If historical data for the parameter are available, consider data fitting to determine the appropriate distribution and regress the distribution parameter values.

Step 3: Check for and Define Statistical Correlations

When developing a Monte Carlo model and setting statistical distributions for parameters, EPA evaluates possible correlations among parameters. When distributions are defined for the parameters, each parameter is independently sampled on each iteration of the model. This may result in combinations of parameter values that are not logical for the scenario. In the example of a model that uses annual PV, daily PV, and operating days as parameters, there are set distributions for annual PV and operating days, with the daily production volume calculated from the other two parameters. But annual PV and operating days may be correlated. For example, if a site has a fixed manufacturing capacity (as determined by the equipment size and production lines), then annual PV is a function of the number of operating days. A facility is more likely to scale-up or scale-down their annual PV by varying the operating days rather than varying their daily PV. Varying annual PV and operating days independently in the model may arrive at value combinations that are not logical. For example, one iteration may sample a high annual PV value with a low number of operating days that may result in a high daily production rate that is not logical. In this example, a different probability distribution strategy may be appropriate, such as defining probability distributions for daily PV and operating days since those two parameters are likely more independent of each other than annual PV and operating days.

When developing distributions from observed data, there are statistical tests that can be performed to indicate a statistical correlation. Two common ones are: 1) the Pearson product-moment correlation coefficient, which measures the linear correlation between two data sets; and 2) Spearman's rank correlation coefficient, which is a measure of rank correlation and how well a relationship between two data sets can be described using a monotonic function. A monotonic relationship is one where the two variables change together but not necessarily at a constant rate (Minitab, 2022). A linear correlation is necessarily monotonic. But a monotonic correlation is not necessarily linear.

Both the Pearson and Spearman coefficients range from −1 to +1. A value close to ±1 indicates a strong correlation (either positive or negative). A positive correlation means as one variable increases, the other also increases. A negative correlation means as one variable increases, the other decreases. A value close to 0 means a weak or no correlation exists between the variables. The Pearson correlation only measures linear relationships, and the Spearman correlation only measures monotonic relationships. If two variables are correlated by a relationship that is neither linear nor monotonic, then the Pearson and Spearman coefficients would not be informative of the nature of the correlation (Minitab, 2022).

After testing for statistical correlations, statistical correlations can be defined for input parameters using @Risk. @Risk only uses Spearman coefficients to define statistical correlations among input parameters. Spearman coefficients to correlate two or more input parameters are defined through a correlation matrix. The correlation matrix allows the Spearman coefficient to be defined for each pair of correlated input parameters (Palisade, 2022).

C.2.3.3 Select Model Outputs for Aggregation of Simulation Results

The last step before running the model is to select the model outputs for which statistical results are desired. Defining these outputs in @Risk will allow the software to save the output results from each iteration and aggregate the simulation results over all iterations together.

C.2.3.4 Select Simulation Settings and Run Model

Simulation settings must be defined before running the model. Important simulation settings include the number of iterations, the sampling method, and the random number generator.

- **Number of iterations:** Generally speaking, a larger number of iterations is desired to ensure adequate sampling and representation of lower probability events. The number of iterations to achieve a desired margin of error for a given confidence interval for an output can be calculated using the Central Limit Theorem (Oberle, 2015; Palisade, 2015a). The equation shows that the margin of error is inversely proportional to the square root of the number of iterations. Therefore, the greater the number of iterations, the smaller the margin of error. Calculating the number of iterations can be difficult as the sample standard deviation is not known beforehand. EPA typically uses 100,000 iterations to ensure convergence and have minimal cost to the simulation time.
- **Sampling method:** The sampling method is the method used to draw random samples from the input parameter probability distributions. @Risk uses two methods: Latin Hypercube (the default) and Monte Carlo. Monte Carlo sampling is a purely random sampling method. This can lead to clustering and under-representing low probability events. Latin Hypercube sampling is a stratified sampling method. This ensures the sampled input parameter distribution matches the assigned probability distribution closely. EPA typically uses Latin Hypercube sampling because it is efficient and can achieve convergence with fewer iterations than Monte Carlo sampling (Palisade, 2018).
- **Random number generato**r**:** The random number generator is used to generate pseudorandom numbers that are used in an algorithm to draw random samples from the probability distributions. The @Risk default is Mersenne Twister, which is a robust and efficient random number generator (Palisade, 2015b).

C.2.3.5 Aggregate the Simulation Results and Produce Output Statistics

During the simulation, @Risk will save the defined model outputs for aggregation on each iteration. After the simulation is completed, EPA can generate desired statistical results and distributions of the defined outputs. EPA typically uses the 50th percentile and 95th percentile of the output as the central tendency and high-end estimates, respectively.

C.3 Use of Formulations containing Formaldehyde in Automotive Care Products Model Approach and Parameters

This appendix presents the modeling approach and equations used to estimate occupational exposures for formaldehyde during the use of automotive care products OES. This approach utilizes the *Draft GS on Commercial Use of Automotive Detailing Products* combined with Monte Carlo simulation (a type of stochastic simulation).

Based on the GS, EPA identified the following inhalation exposure points:

- Exposure point A: Transfer operation exposures from unloading transport containers; and
- Exposure point B: Application and use of automotive detailing products.

Occupational exposures for formaldehyde during the use of automotive care products are a function of formaldehyde's physical properties, container size, mass fractions, and other model parameters. While 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: ventilation rate, mixing factor, saturation factor, loss factor, container sizes, working years, operating and exposure days, formaldehyde concentration in the auto detailing product, annual number of cars detailed per site, use rate of automotive detailing product per car, and mass concentration of formaldehyde in air for exposure point B. EPA used the outputs from a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to calculate release amounts and exposure concentrations for this OES.

C.3.1 Model Equations

Table_Apx C-1 provides the models and associated variables used to calculate occupational exposures for each exposure point within each iteration of the Monte Carlo simulation. EPA used these occupational exposures to develop a distribution of exposure outputs for the Automotive care OES. EPA assumed that the same worker performed each exposure activity resulting in a total exposure duration of up to 8 hours per day. The variables used to calculate each of the following exposure concentrations and durations include deterministic or variable input parameters, known constants, physical properties, conversion factors, and other parameters. The values for these variables are provided in the following sections. The Monte Carlo simulation calculated an 8-hour TWA exposure concentration for each iteration using the exposure concentration and duration associated with each activity and assuming exposures outside the exposure activities were zero. EPA then selected 50th percentile and 95th percentile values to estimate the central tendency and high-end exposure concentrations, respectively.

Table_Apx C-1. Models and Variables Applied for Exposure Points in the Automotive Care OES

Exposure Point	Model(s) Applied	Variables Used
Exposure point A: Inhalation exposure during container Unloading or transferring	EPA/OPPT Mass Balance Inhalation Model with vapor generation rate from EPA/OAQPS AP-42 Loading Model	Vapor Generation Rate: F_{FA}; VP; $F_{saturation\_unloading}$; MW; V_{small_cont}; R; T; $RATE_{fill\_smallcont}$; Q; k; Vm Exposure Duration: $RATE_{fill\_smallcont}$
Exposure point B: Container cleaning exposure	Vapor generation rate assessed both with the assumption that all formaldehyde evaporates and with industry data from the Draft GS	Not applicable

Note that the number of exposure days is set equal to the number of operating days per year multiplied by a fractional value from the draft GS. The draft GS sets a single value at 0.962, which is the EPA standard 250 working days per year divided by a maximum 260 operating days for automotive detailing shops using data cited in the draft GS. This value was modified slightly to a uniform distribution from 0.962 to 1 since automotive detailing shops tend to be smaller businesses where workers may be less likely to take time off.

C.3.2 Model Input Parameters

Table_Apx C-2 summarizes the model parameters and their values for the Automotive care products OES Monte Carlo simulation. Additional explanations of EPA's selection of the distributions for each parameter are provided following the table.

6230 **Table_Apx C-2. Summary of Parameter Values and Distributions Used in the Automotive Care Products Models**

Input Parameter	Symbol	Unit	Deterministic Values	Uncertainty Analysis Distribution Parameters				Rationale/Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Working Years	*WY*	years	36	10.4	44	36	Triangular	See Section C.3.10
Indoor or Outdoor	D_{In_Out}	–	1	0	1	1	Discrete	Binary distribution for the ventilation rate in the indoor and outdoor scenarios
Ventilation Rate	*Q*	ft3/min	3,000	500	10,000	3,000	Triangular	See Section C.3.13
			237,600	132,000	237,600	–	Uniform	See Section C.3.13
Mixing Factor	*k*	dimensionles s	0.5	0.1	1	0.5	Triangular	See Section C.3.14
Saturation Factor Unloading	$F_{saturation\_unloading}$	kg/kg	0.5	0.5	1.45	0.5	Triangular	C.3.8See Section C.3.8
Container Volume	$V_{smallcont}$	gal/container	0.125	0.03125	15	0.125	Triangular	See Section C.3.11
Operating Days	*OD*	days/yr	260	174	260	260	Discrete	See Section C.3.7
Exposure Days Fraction	Ef_{frac}	days/days	0.962	0.962	1	–	Uniform	See Section C.3.5
Formaldehyde Concentration in the Auto Detailing Product	F_{FA}	kg/kg	0.1	0.01	0.3	0.1	Triangular	See Section C.3.4
Annual Number of Cars Detailed per Site	N_{cars}	cars/yr	2,191	1609	3213	2191	Triangular	See Section C.3.3
Use Rate of Auto Detailing Products per Car	V_{car}	gal/car	0.015625	0.0078125	0.125	0.015625	Discrete	See Section C.3.3
Activity B Mass Concentration of Chemical in Air (Application and Use of Automotive Detailing Products)	Cm_B	mg/m^3	0.89	0.005	3.7	0.89	Discrete	Discrete distribution from draft GS
Formaldehyde Molar Volume	*Vm*	L/mol	24.45	–	–	–	–	Physical property

Input Parameter	Symbol	Unit	Deterministic Values	Uncertainty Analysis Distribution Parameters				Rationale/Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Formaldehyde Molecular Weight	MW	g/mol	30.026	–	–	–	–	Physical property
Fill Rate of Small Container	$RATE_{fill\_smallcont}$	containers/ hr	60	–	–	–	–	See Section C.3.12
Lifetime years	LT	years	78	–	–	–	–	See Section C.3.6
Averaging time over a lifetime (chronic)	ATc	hours	683,280	–	–	–	–	Calculated
Hours exposed per day for activity B	h_B	hours	5	–	–	–	–	From draft GS
Assessed Vapor Pressure	VP	Torr	1.3	–	–	–	–	Physical property
Formaldehyde Weight Fraction in formalin	$F_{formalin}$	kg/kg	0.37	–	–	–	–	Concentration of formaldehyde in formalin
Auto Detailing Product Density	rho_{prod}	kg/L	1	–	–	–	–	Value provided by draft GS
Gas Constant	R	L*torr/mol-K	62.36367	–	–	–	–	Physical constant
Temperature	T	K	298	–	–	–	–	Process parameter
Pressure	P	torr	760	–	–	–	–	Process parameter

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C.3.3 Throughput Parameters

The *Draft GS on the Commercial Use of Automotive Detailing Products* estimates the annual number of cars detailed per site using information from freestanding shops, carwash combination sites, and cars for mobile detailing sites. The EPA modeled the distribution for annual number of cars detailed per site using the recommended range of 1,609 to 3,213 cars with an underlying triangular distribution and a mode of 2,191 cars. The values sampled from this distribution are multiplied by the values sampled from the discrete, equal probability distribution for the use rate of automotive detailing products per car to calculate a value for annual use rate of automotive detailing products per site.

C.3.4 Concentration of Formaldehyde

Reporters for the Use of Automotive Care Products OES in the 2016 CDR data indicated formaldehyde concentrations of both less than 1 percent and 1 to 30 percent. Additionally, the draft GS on the Commercial Use of Automotive Detailing Products specified a default additive concentration of 10 percent. Thus, the EPA assessed the concentration of formaldehyde in a range from 1 to 30 percent in a triangular distribution, with a mode of 10 percent.

C.3.5 Exposure Duration

EPA generally uses an exposure duration of eight hours per day for averaging full-shift exposures.

C.3.6 Lifetime Years

EPA assumes a lifetime of 78 years for all worker demographics.

C.3.7 Operating Days

The Draft GS on Commercial Use of Automotive Detailing Products estimates the number of operating days from employment data obtained through the BLS's Occupational Employment Statistics. The draft GS presents a range of operating days from 174 to 260 days/year; this is based on the assumption of 12- or 8-hour shifts respectively. Assuming either 8-, 10-, or 12-hour shifts results in a discrete distribution of 260, 208, and 174 operating days, respectively, with equal probability for each in the Automotive Care Products Model.

C.3.8 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 (U.S. EPA, 1991a). The CEB Manual indicates that saturation concentration for bottom filling was expected to be about 0.5 (U.S. EPA, 1991a). 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, EPA assigned a mode value of 0.5 for bottom filling as bottom filling minimizes volatilization (U.S. EPA, 1991a). 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).

C.3.9 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). In the simulation developed for the Industrial use of lubricants OES based on the *ESD on Chemical Additives Used in Automotive Lubricants*, EPA used the default diameters of vessels from the ChemSTEER User Guide for container cleaning.

For container cleaning activities, the ChemSTEER User Guide indicates a single default value of 5.08 cm (U.S. EPA, 2015b). Therefore, EPA could not develop a distribution of values for this parameter and used the single value 5.08 cm.

C.3.10 Worker Years

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

- Minimum value: BLS Current Population Survey (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 ADC and LADC calculations, respectively.

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

The U.S. Census' (U.S. Census Bureau, 2019a) 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, 2019b). 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, 2019a, b). For this 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.[2] 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 (Census Bureau, 2012b). EPA calculated the average tenure for the following age groups: (1) workers aged 50 and older; (2) workers aged 60 and older; and (3) workers of all ages employed at time of survey. EPA 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, EPA excluded data where the sample size is less than five from our analysis.

Table_Apx C-3 summarizes the average tenure for workers aged 50 and older from SIPP data. Although

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

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.

Table_Apx C-3. Overview of Average Worker Tenure from U.S. Census SIPP (Age Group 50+)

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
Manufacturing sectors (NAICS 31–33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42–81)	36.1	36	39	44

Source: (U.S. Census Bureau, 2019a).
Note: Industries where sample size is less than five are excluded from this analysis.

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx C-4 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 C-4. Median Years of Tenure with Current Employer by Age Group

Age	January 2008	January 2010	January 2012	January 2014
16 years and over	4.1	4.4	4.6	4.6
16 to 17 years	0.7	0.7	0.7	0.7
18 to 19 years	0.8	1.0	0.8	0.8
20 to 24 years	1.3	1.5	1.3	1.3
25 years and over	5.1	5.2	5.4	5.5
25 to 34 years	2.7	3.1	3.2	3.0
35 to 44 years	4.9	5.1	5.3	5.2
45 to 54 years	7.6	7.8	7.8	7.9
55 to 64 years	9.9	10.0	10.3	10.4
65 years and over	10.2	9.9	10.3	10.3

C.3.11 Container Size

The *Draft GS on Commercial Use of Automotive Detailing Products* specifies a range of 4 ounces to 15 gallons, with 16-ounce containers being the most common based on reviewed retailer websites. EPA developed a triangular distribution using this range and mode.

C.3.12 Container Fill Rates

The *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b) provides a typical fill rate of 20 containers per hour for containers with 20 to 100 gallons of liquid and a typical fill rate of 60 containers per hour for containers with less than 20 gallons of liquid. EPA estimates unload rates for containers as equivalent to the fill rates. Therefore, EPA could not develop a distribution of values for these parameters and used the single value 60 containers/hr.

C.3.13 Ventilation Rate

The CEB Manual (U.S. EPA, 1991a) 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. EPA 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 (U.S. EPA, 1991a). Additionally, the CEB Manual indicates a general ventilation rate range from 132,000 to 237,600 ft^3/min with a uniform distribution for worker activities taking place in outdoor settings. Because EPA was not able to identify industry specific data on how often automotive care products are used indoors or outdoors, the distributions were both used in the assessment with equal probability.

C.3.14 Mixing Factor

The CEB Manual (U.S. EPA, 1991a) 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 (U.S. EPA, 1991a). 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, EPA 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).

C.3.15 Exposure Days Fraction

The *Draft GS on the Commercial Use of Automotive Detailing Products* specifies the value of 0.962 for the exposure days fraction (*i.e.*, the fraction of total operating days that the typical worker is working/exposed). EPA assessed the exposure days fraction on a uniform distribution from 0.962 to 1 since automotive detailing shops tend to be smaller businesses where workers may be less likely to take time off.

C.4 Industrial Use of Lubricants

This appendix presents the modeling approach and equations used to estimate occupational exposures for formaldehyde during the industrial use of lubricants OES. This approach utilizes the *ESD on Chemical Additives Used in Automotive Lubricants* combined with Monte Carlo simulation (a type of stochastic simulation).

Based on the ESD, EPA identified the following inhalation exposure points:

- Exposure point A: Container unloading or transferring; and
- Exposure point B: Container cleaning.

Occupational exposures for formaldehyde during industrial use of lubricants are a function of formaldehyde's physical properties, container size, mass fractions, and other model parameters. While 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: ventilation rate, mixing factor, air speed, working years, operating days, and unloading saturation factor. The Agency used the outputs from a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to calculate release amounts and exposure concentrations for this OES.

C.4.1 Model Equations

Table_Apx C-5 provides the models and associated variables used to calculate occupational exposures for each exposure point within each iteration of the Monte Carlo simulation. EPA used these occupational exposures to develop a distribution of exposure outputs for the industrial use of lubricants OES. EPA assumed that the same worker performed each exposure activity resulting in a total exposure duration of up to 8 hours per day. The variables used to calculate each of the following exposure concentrations and durations include deterministic or variable input parameters, known constants, physical properties, conversion factors, and other parameters. The values for these variables are provided in the next section. The Monte Carlo simulation calculated an 8-hour TWA exposure concentration for each iteration using the exposure concentration and duration associated with each activity and assuming exposures outside the exposure activities were zero. EPA then selected 50th percentile and 95th percentile values to estimate the central tendency and high-end exposure concentrations, respectively.

Table_Apx C-5. Models and Variables Applied for Exposure Points in the Industrial Use of Lubricants OES

Exposure Point	Model(s) Applied	Variables Used
Exposure Point A: Inhalation Exposure during Container Unloading or Transferring	EPA/OPPT Mass Balance Inhalation Model with vapor generation rate from EPA/OAQPS AP-42 Loading Model	Vapor generation rate: F_{FA}; VP; $F_{saturation\_unloading}$; MW; V_{import_cont}; R; T; $RATE_{fill\_smallcont}$; Q; k; VmFA Exposure Duration: $RATE_{fill\_smallcont}$
Exposure Point B: Container Cleaning Exposure	EPA/OPPT Penetration Model or EPA/OPPT Mass Transfer Coefficient Model, based on air speed (Appendix C.1)	Vapor Generation Rate: F_{FA}; VP; $F_{saturation\_loading}$; MW_{TCEP}; V_{small_cont}; R; T; $RATE_{cont\_clean}$; Q; k; $VmFA$ Exposure duration: V_{small_cont}; $RATE_{cont\_clean}$

Note that the number of exposure days is set equal to the number of operating days per year up to a maximum of 250 days per year. If the number of operating days is greater than 250 days per year, EPA assumed that a single worker would not work more than 250 days per year such that the maximum exposure days per year was still 250.

C.4.2 Model Input Parameters

Table_Apx C-6 summarizes the model parameters and their values for the Use of Lubricants Containing Formaldehyde Monte Carlo simulation. Additional explanations of EPA's selection of the distributions for each parameter are provided after this table.

6408 **Table_Apx C-6. Summary of Parameter Values and Distributions Used in the Industrial Use of Lubricants Models**

Input Parameter	Symbol	Unit	Deterministic Values	Uncertainty Analysis Distribution Parameters				Rationale/Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Working Years	*WY*	years	36	10.4	44	36	Triangular	BLS/CPS and SIPP
Ventilation Rate	*Q*	ft3/min	3,000	500	10,000	3,000	Triangular	ChemSTEER User Guide/CEB Manual provided values
Mixing Factor	*k*	dimensionless	0.5	0.1	1	0.5	Triangular	ChemSTEER User Guide/CEB Manual provided values
Saturation Factor Unloading	$F_{saturation\_unloading}$	kg/kg	0.5	0.5	1.45	0.5	Triangular	ChemSTEER User Guide/CEB Manual provided values
Operating Days	*OD*	Days/year	253	249	254	253	Triangular/Discrete	Use of Automotive Lubricants ESD indicates an expected operating days range of 250–253 days/yr, with 253 days/yr being the default value; added one to lower bound and subtracted one from lower bound to create discrete triangular distribution
Air Speed	$RATE_{air\_speed}$	cm/s	10	1.3	202.2	–	Lognormal	Distribution using EPA's air speed model for industrial uses; converted to ft/min for model use
		ft/min	19.7	2.56	398	–	Lognormal	
Annual Facility Throughput (kg/yr)	$Q_{lubricant}$	kg/yr	40,000	–	–	–	–	Automotive Lubricants ESD
Formaldehyde Molar Volume	*VmFA*	L/mol	24.45	–	–	–	–	Molar volume at STP
Formaldehyde Molecular Weight	*MW*	g/mol	30.026	–	–	–	–	From the 2020 *Final Scope of the Risk Evaluation for Formaldehyde; CASRN 50-00-0* (U.S. EPA, 2020c)
Fill Rate of Small Container	$RATE_{fill\_smallcont}$	containers/ hr	60	–	–	–	–	Automotive Lubricants ESD
Container Cleaning Rate	$RATE_{cont\_clean}$	containers/hr	20	–	–	–	–	Automotive Lubricants ESD
Unloading Container Volume	$V_{smallcont}$	gal/container	5	–	–	–	—	Automotive Lubricants ESD
Hours exposed per day	*ED*	hrs/day	8	—	—	—	—	Assuming a full 8-hour shift
Lifetime years	*LT*	years	78	—	—	—	—	Average lifetime years

Input Parameter	Symbol	Unit	Deterministic Values	Uncertainty Analysis Distribution Parameters				Rationale/Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Averaging time over a lifetime (chronic)	AT_c	hours	683,280	—	—	—	—	Converted lifetime years to hours
Formaldehyde Use of Lubricants Mass Fraction	F_{FA}	kg/kg	0.002	–	–	–	–	(NICNAS, 2006)
Diameter of Opening for Container Cleaning	$D_{opening}$	cm	5.08	–	–	–	–	From 1991 CEB Manual
Assessed Vapor Pressure	VP	Torr	1.3	–	–	–	–	Vapor pressure of formalin at 20 °C
Gas Constant	R	L*torr/mol-K	62.36367	–	–	–	–	Universal gas constant
Temperature	T	K	298	–	–	–	–	Standard temperature
Pressure	P	torr	760	–	–	–	–	Standard pressure

C.4.3 Annual Facility Throughput

The *ESD on Chemical Additives Used in Automotive Lubricants* estimates the annual facility throughput from facility data obtained through the U.S. Census Bureau, as well as production data from automotive servicing shops. The EPA was not able to find OES-specific data on throughput for the Industrial use of lubricants, so the estimate of 40,000 kg/site-year from Automotive lubricants ESD was used as surrogate data for this model.

C.4.4 Concentration of Formaldehyde

The inhalation exposures for the Industrial Use of Lubricants Model were assessed at a concentration of 0.2 percent based on data from the 2006 formaldehyde report from the NICNAS (NICNAS, 2006).

C.4.5 Exposure Duration

EPA generally uses an exposure duration of eight hours per day for averaging full-shift exposures.

C.4.6 Lifetime Years

EPA assumes a lifetime of 78 years for all worker demographics.

C.4.7 Operating Days

The *ESD on Chemical Additives Used in Automotive Lubricants* estimates the number of operating days from employment data obtained through the U.S. Bureau of Labor Statistics (BLS) Occupational Employment Statistics. The ESD presents a range of operating days from 250 to 253 days/year. The Industrial Use of Lubricants model expanded this range to 249-254 days/year in order to account for the bounds in the discrete triangular distribution having a probability value of zero.

C.4.8 Air Speed

Baldwin and Maynard measured indoor air speeds across a variety of occupational settings in the United Kingdom (Baldwin and Maynard, 1998), specifically, 55 work areas were surveyed. 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. EPA 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). Since 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.

C.4.9 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 (U.S. EPA, 1991a). The CEB Manual indicates that saturation concentration for bottom filling was expected to be about 0.5 (U.S. EPA, 1991a). 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, EPA assigned a mode value of 0.5 for bottom filling as bottom filling minimizes volatilization (U.S. EPA, 1991a). 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).

C.4.10 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). In the simulation developed for the Industrial Use of Lubricants OES based on the *ESD on Chemical Additives Used in Automotive Lubricants*, EPA used the default diameters of vessels from the ChemSTEER User Guide for container cleaning.

For container cleaning activities, the ChemSTEER User Guide indicates a single default value of 5.08 cm (U.S. EPA, 2015b). Therefore, EPA could not develop a distribution of values for this parameter and used the single value 5.08 cm from the *ChemSTEER User Guide.*

C.4.11 Worker Years

EPA has developed a triangular distribution for working years. EPA has defined the parameters of the triangular 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 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 ADC and LADC calculations, respectively.

The BLS (U.S. BLS, 2014) provides information on employee tenure with *current employer* obtained from the CPS, which 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 and over. CPS data are released every 2 years. The data are available by demographics and by generic industry sectors but are not available by NAICS codes.

The U.S. Census’ (U.S. Census Bureau, 2019a) 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, 2019b).

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, 2019a, b). For this 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.[3] 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 (Census Bureau, 2012b). EPA calculated the average tenure for the following age groups: (1) workers aged 50 and older, (2) workers aged 60 and older, and (3) workers of all ages employed at time of survey. EPA 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, EPA excluded data where the sample size is less than five from our analysis.

Table_Apx C-7 summarizes the average tenure for workers aged 50 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.

Table_Apx C-7. Overview of Average Worker Tenure from U.S. Census SIPP (Age Group 50+)

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
Manufacturing sectors (NAICS 31–33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42–81)	36.1	36	39	44

Source: (U.S. Census Bureau, 2019a).
Note: Industries where sample size is less than five are excluded from this analysis.

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx C-8 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.

[3] 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). EPA then subtracted any intervening months when not working (ETIMEOFF).

Table_Apx C-8. Median Years of Tenure with Current Employer by Age Group

Age	January 2008	January 2010	January 2012	January 2014
16 years and over	4.1	4.4	4.6	4.6
16 to 17 years	0.7	0.7	0.7	0.7
18 to 19 years	0.8	1.0	0.8	0.8
20 to 24 years	1.3	1.5	1.3	1.3
25 years and over	5.1	5.2	5.4	5.5
25 to 34 years	2.7	3.1	3.2	3.0
35 to 44 years	4.9	5.1	5.3	5.2
45 to 54 years	7.6	7.8	7.8	7.9
55 to 64 years	9.9	10.0	10.3	10.4
65 years and over	10.2	9.9	10.3	10.3

C.4.12 Container Size

The *ESD on Chemical Additives Used in Automotive Lubricants* assumed a container volume of 5 gallons per container for each of the assessed worker activities. The 5-gallon container assumption comes from the *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b) provided values for small containers, which are assumed to be the type of containers used in unloading of lubricants and container cleaning activities.

C.4.13 Container Fill Rates

The *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b) provides a typical fill rate of 20 containers per hour for containers with 20 to 100 gallons of liquid and a typical fill rate of 60 containers per hour for containers with less than 20 gallons of liquid. EPA estimates unload rates for containers as equivalent to the fill rates. Therefore, EPA could not develop a distribution of values for these parameters and used the single value 20 containers/hr or 60 containers/hr from the ChemSTEER User Guide depending upon the exposure activity.

C.4.14 Ventilation Rate

The CEB Manual (U.S. EPA, 1991a) 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. EPA 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 (U.S. EPA, 1991a).

C.4.15 Mixing Factor

The CEB Manual (U.S. EPA, 1991a) 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 (U.S. EPA, 1991a). 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, EPA 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).

C.5 Use of Formulations Containing Formaldehyde for Water Treatment Model Approach and Parameters

For Use of Formulations containing Formaldehyde for Water treatment OES, the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model is used to estimate the airborne concentration associated with generic chemical loading scenarios at industrial facilities. This model is discussed in Appendix C.7.

C.6 Use of Fertilizers Containing Formaldehyde in Outdoors including Lawns

C.6.1 Model Equations

This appendix presents the modeling approach and equations used to estimate occupational exposures for formaldehyde during the Use of Fertilizer containing Formaldehyde in Outdoors Including Lawns OES. This approach utilizes the *GS on Application of Agricultural Pesticide* combined with Monte Carlo simulation (a type of stochastic simulation).

Based on the GS, EPA identified the following inhalation exposure points:

- Exposure point A: Container unloading or transferring; and
- Exposure point B: Equipment cleaning.

Occupational exposures for formaldehyde during use of fertilizer containing formaldehyde for in outdoors including lawns are a function of formaldehyde's physical properties, container size, mass fractions, and other model parameters. While 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: ventilation rate, mixing factor, saturation factor, working years, formaldehyde mass fraction in the urea-formaldehyde product, hours exposed for exposure point B, and production volume. EPA used the outputs from a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to calculate release amounts and exposure concentrations for this OES.

C.6.2 Model Input Parameters

Table_Apx C-9 provides the models and associated variables used to calculate occupational exposures for each exposure point within each iteration of the Monte Carlo simulation. EPA used these occupational exposures to develop a distribution of exposure outputs for the use of fertilizer OES. EPA assumed that the same worker performed each exposure activity resulting in a total exposure duration of up to 8 hours per day. The variables used to calculate each of the following exposure concentrations and durations include deterministic or variable input parameters, known constants, physical properties, conversion factors, and other parameters. The values for these variables are provided in the next section. The Monte Carlo simulation calculated an 8-hour TWA exposure concentration for each iteration using the exposure concentration and duration associated with each activity and assuming exposures outside the exposure activities were zero. EPA then selected 50th percentile and 95th percentile values to estimate the central tendency and high-end exposure concentrations, respectively.

6594 **Table_Apx C-9. Models and Variables Applied for Exposure Points in the Use of Fertilizer OES**

Exposure Point	Model(s) Applied	Variables Used
Exposure point A: Inhalation exposure during container unloading	EPA/OPPT Penetration Model or EPA/OPPT Mass Transfer Coefficient Model, based on air speed (Appendix A.1)	Vapor Generation Rate: F_{FA}; VP; $F_{saturation\_unloading}$; MW; V_{import_cont}; R; T; $RATE_{fill\_smallcont}$; Q; k; Vm_{FA} Exposure Duration: $RATE_{fill\_smallcont}$
Exposure point B: Equipment cleaning exposure	EPA/OPPT Penetration Model or EPA/OPPT Mass Transfer Coefficient Model, based on air speed (Appendix A.1)	Vapor Generation Rate: F_{FA}; VP; $F_{saturation\_loading}$; MW ; V_{small_cont}; R; T; $RATE_{cont\_clean}$; Q; k; Vm_{FA} Exposure Duration: V_{small_cont}; $RATE_{cont\_clean}$

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6596 Table_Apx C-10 summarizes the model parameters and their values for the Use of Fertilizers containing
6597 Formaldehyde Monte Carlo simulation. Additional explanations of EPA's selection of the distributions
6598 for each parameter are provided after this table.

6599 **Table_Apx C-10. Summary of Parameter Values and Distributions Used in the Use of Fertilizer Models**

Input Parameter	Symbol	Unit	Deterministic Values	Uncertainty Analysis Distribution Parameters				Rationale/Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Working Years	WY	years	36	10.4	44	36	Triangular	See Section C.6.10
Ventilation Rate	Q	ft3/min	237,000	237,000	3,300,000	237,000	Triangular	See Section C.6.13
Mixing Factor	k	dimensionless	0.5	0.1	1	0.5	Triangular	See Section C.6.14
Saturation Factor Unloading	$F_{saturation\_unloading}$	kg/kg	0.5	0.5	1.45	0.5	Triangular	See Section C.6.8
Formaldehyde Mass Fraction in Urea-Formaldehyde Product	F_{FA_fert}	kg/kg	0.001	0.001	0.01	0.001	Triangular	See Section C.6.4
Hours Exposed per Day for Activity B (Equipment Cleaning)	h_B	hours/site-day	4	0.5	4	4	Triangular	See Section C.6.15
Production Volume	PV	kg/yr	N/A	1403070	1575196	N/A	Uniform	See Section C.6.3
Number of Sites	N_s	sites	2,212	–	–	–	–	See Section G.28
Operating Days	OD	days/site-yr	250	–	–	–	–	Generic OES Estimate
Formaldehyde Molar Volume	$VmFA$	L/mol	24.45	–	–	–	–	Physical property
Formaldehyde Molecular Weight	MW	g/mol	30.026	–	–	–	–	Physical property
Fill Rate of Small Container	$RATE_{fill\_smallcont}$	containers/ hr	60	–	–	–	–	See Section C.6.12
Container Size	V_{cont}	gal/ container	5	–	–	–	–	See Section C.6.11
Diameter Opening for Container Unloading	$D_{container}$	cm	5.08	–	–	–	–	See Section C.6.9
Hours exposed per day	ED	hrs/day	8	–	–	–	–	Standard value
Lifetime years	LT	years	78	–	–	–	–	See Section C.6.6
Averaging time over a lifetime (chronic)	ATc	hours	683280	–	–	–	–	Calculated

Input Parameter	Symbol	Unit	Deterministic Values	Uncertainty Analysis Distribution Parameters				Rationale/Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Diameter of Opening for Equipment Cleaning	$D_{equipment}$	cm	92	–	–	–	–	See Section C.6.9
RATEair_speed	$RATE_{air\_speed}$	ft/min	440	–	–	–	–	See Section C.6.7
Assessed Vapor Pressure	VP	Torr	1.3	–	–	–	–	Physical property of formalin
Fertilizer Density	$rho_{fertilizer}$	kg/L	1	–	–	–	–	See Section C.6.16
Gas Constant	R	L*torr/mol-K	62.36367	–	–	–	–	Physical Constant
Temperature	T	K	298	–	–	–	–	Assumed Process Parameter
Pressure	P	torr	760	–	–	–	–	Assumed Process Parameter

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C.6.3 Annual Facility Throughput

According to the 2020 CDR reporting for the Use of Formulations containing formaldehyde in outdoor use, the production volume (PV) of fertilizer containing formaldehyde is expected to fall in the range of 1,403,070-1,575,196 kg/yr. Without a basis for an underlying distribution, the EPA modeled the production volume for this OES using a uniform distribution with these values as the lower and upper bounds.

C.6.4 Concentration of Formaldehyde

The inhalation exposures for the Use of Fertilizers model were assessed at a maximum concentration of 1 percent based on reporting data for the Lawn Care OES in the 2020 CDR (U.S. EPA, 2020a). The minimum concentration assessed was 0.01 percent based on formaldehyde report data from the Tennessee Valley Authority (TVA) (TVA, 1991).

C.6.5 Exposure Duration

EPA generally uses an exposure duration of eight hours per day for averaging full-shift exposures.

C.6.6 Lifetime Years

EPA assumes a lifetime of 78 years for all worker demographics.

C.6.7 Air Speed

Baldwin and Maynard measured indoor air speeds across a variety of occupational settings in the United Kingdom (Baldwin and Maynard, 1998), specifically, 55 work areas were surveyed. 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. EPA 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). Since 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.

C.6.8 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 (U.S. EPA, 1991a). The CEB Manual indicates that saturation concentration for bottom filling was expected to be about 0.5 (U.S. EPA, 1991a). 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, EPA assigned a mode value of 0.5 for bottom filling as bottom filling minimizes volatilization (U.S. EPA, 1991a). 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).

C.6.9 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). In the simulation developed for the Use of Fertilizer OES, EPA used the default diameters of vessels from the ChemSTEER User Guide for container cleaning.

For container unloading activities, the ChemSTEER User Guide indicates a single default value of 5.08 cm (U.S. EPA, 2015b). Therefore, EPA could not develop a distribution of values for this parameter and used the single value 5.08 cm from the ChemSTEER User Guide.

For equipment cleaning activities, the ChemSTEER User Guide indicates a single default value of 92 cm (U.S. EPA, 2015b). Therefore, EPA could not develop a distribution of values for this parameter and used the single value 5.08 cm from the ChemSTEER User Guide.

C.6.10 Worker Years

EPA has developed a triangular distribution for working years. EPA has defined the parameters of the triangular 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 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 ADC and LADC calculations, respectively.

The BLS (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 and over; CPS data are released every two years. The data are available by demographics and by generic industry sectors but are not available by NAICS codes.

The U.S. Census' (U.S. Census Bureau, 2019a) 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, 2019b). 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, 2019a, b). For this panel, lifetime tenure data are available by Census Industry Codes, which can be cross-walked 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.[4] 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 (Census Bureau, 2012b). EPA calculated the average tenure for the following age groups: (1) workers age 50 and older, (2) workers age 60 and older, and (3) workers of all ages employed at time of survey. EPA 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, EPA excluded data where the sample size is less than five from our analysis.

Table_Apx C-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.

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

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
Manufacturing sectors (NAICS 31–33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42–81)	36.1	36	39	44

Source: (U.S. Census Bureau, 2019a).
Note: Industries where sample size is less than five are excluded from this analysis.

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx C-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 C-12. Median Years of Tenure with Current Employer by Age Group

Age	January 2008	January 2010	January 2012	January 2014
16 years and over	4.1	4.4	4.6	4.6
16 to 17 years	0.7	0.7	0.7	0.7
18 to 19 years	0.8	1.0	0.8	0.8
20 to 24 years	1.3	1.5	1.3	1.3

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

Age	January 2008	January 2010	January 2012	January 2014
25 years and over	5.1	5.2	5.4	5.5
25 to 34 years	2.7	3.1	3.2	3.0
35 to 44 years	4.9	5.1	5.3	5.2
45 to 54 years	7.6	7.8	7.8	7.9
55 to 64 years	9.9	10.0	10.3	10.4
65 years and over	10.2	9.9	10.3	10.3

C.6.11 Container Size

The *GS on Application of Agricultural Pesticide* assumed a container volume of 5 gallons per container for each of the assessed worker activities. The 5-gallon container assumption comes from the *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b) provided values for small containers, which are assumed to be the type of containers used in unloading of fertilizers and container cleaning activities.

C.6.12 Container Fill Rates

The ChemSTEER User Guide provides a typical fill rate of 20 containers per hour for containers with 20 to 100 gallons of liquid and a typical fill rate of 60 containers per hour for containers with less than 20 gallons of liquid. EPA estimates unload rates for containers as equivalent to the fill rates. Therefore, EPA could not develop a distribution of values for these parameters and used the single value 20 containers/hr or 60 containers/hr from the *ChemSTEER User Guide for the EPA/OPPT Mass Balance Inhalation Model* (U.S. EPA, 2015b) depending upon the exposure activity.

C.6.13 Ventilation Rate

The CEB Manual (U.S. EPA, 1991a) 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. EPA 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 (U.S. EPA, 1991a).

C.6.14 Mixing Factor

The CEB Manual (U.S. EPA, 1991a) 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 (U.S. EPA, 1991a). 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, EPA 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).

C.6.15 Hours of Exposure for Equipment Cleaning

The ChemSTEER User Guide provides default values for equipment cleaning activities based on equipment vessel size. The EPA did not identify industry-specific data on the size and nature of the equipment to be cleaned. The maximum and minimum for this distribution were based on the upper and lower bounds of possible vessel sizes and quantities for this worker activity.

C.6.16 Fertilizer Density

The EPA did not identify any industry-specific data on the density of fertilizers containing formaldehyde. The density of fertilizer was assessed at 1 kg/L based on the low expected concentrations of additives in the *GS on Application of Agricultural Pesticides.*

C.7 Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model Methodology

This appendix presents the modeling approach and model equations used in the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA exposure models. The model approach is a generic inhalation exposure assessment at industrial facilities that is applicable for any volatile chemical with the following COUs:

- Manufacture (loading of chemicals into containers);
- Processing as a reactant/intermediate (unloading of chemicals);
- Processing into formulation, mixture, or reaction products;
- Import (repackaging); and
- Other similar COUs at industrial facilities (*e.g.*, industrial processing aid).

As an example, formaldehyde at a manufacturing facility is expected to be packaged and loaded into a container before distributing to another industrial processing or use site (*e.g.*, formulation sites, sites using Formaldehyde as an intermediate, and sites using formaldehyde as a processing aid). At the industrial processing or use site, formaldehyde is then unloaded from the container into a process vessel before being incorporated into a mixture, used as a chemical intermediate, or otherwise processed/used. For the model, EPA assumes formaldehyde is unloaded into tank trucks and railcars and transported and distributed in bulk. EPA also assumes the chemical is handled as a pure substance (100 percent concentration).

Because formaldehyde is volatile (vapor pressure above 0.01 torr at room temperature), fugitive emissions may occur when formaldehyde is loaded into or unloaded from a tank truck or railcar. Sources of these emissions include

- Displacement of saturated air containing Formaldehyde as the container/truck is filled with liquid;
- Emissions of saturated air containing Formaldehyde that remains in the loading arm, transfer hose, and related equipment; and
- Emissions from equipment leaks from processing units such as pumps, seals, and valves.

These emissions result in subsequent exposure to workers involved in the transfer activity. The following subsections address these emission sources.

C.7.1 Displacement of Saturated Air Inside Tank Truck and Railcars

For screening-level assessments, EPA typically uses the EPA/OAQPS AP-42 Loading Model to conservatively assess exposure during container unloading activities (U.S. EPA, 2015b). The model estimates release to air from the displacement of air containing chemical vapor as a container/vessel is filled with liquid (U.S. EPA, 2015b). The model assumes the unloading activity displaces an air volume equal to the size of the container, and that displaced air is either 50 percent or 100 percent saturated with chemical vapor (U.S. EPA, 2015b).

Process units at facilities that manufacture Formaldehyde as a primary product; use Formaldehyde as a reactant or manufacture Formaldehyde as a product or co-product; or are located at a plant that is a major source of hazardous air pollutants (HAPs) as defined in section 112(a) of the Clean Air Act are required to install and operate a vapor capture system and control device (or vapor balancing system) for loading/unloading operations (U.S. EPA, 1994b). Therefore, 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 is 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. This emission source is addressed in the next subsection.

C.7.2 Emissions of Saturated Air inside Tank Truck and Railcars

After loading is complete, transfer hoses and/or loading arms are disconnected from tank trucks and railcars. Saturated air containing the chemical of interest that remains in transfer equipment may be released to air, presenting a source of fugitive emissions. The quantity of Formaldehyde released will depend on concentration in the vapor and the volume of vapor in the loading arm/hose/piping.

Table_Apx C-13 presents the dimensions for several types of loading systems according to an OPW Engineered Systems catalog (OPW Engineered Systems, 2014). OPW Engineered Systems specializes in the engineering, designing, and manufacturing of systems for loading and unloading a wide range of materials including petroleum products, liquefied gases, asphalt, solvents, and hazardous and corrosive chemicals. These systems include loading systems, swivel joints, instrumentation, quick and dry-disconnect systems, and safety breakaways. Based on the design dimensions, the table presents the calculated total volume of loading arm/system and assumes the volume of vapor containing Formaldehyde equals the volume of the loading arm/system.

EPA expects formaldehyde is expected to be delivered in either tank trailers or tank cars. Therefore, EPA modeled the central tendency scenario as tank truck loading/unloading. EPA modeled the high-end scenario as railcar loading/unloading since railcars are larger and more likely to use longer transfer arms (and thus represent a higher exposure potential than tank trucks). To estimate the high-end transfer arm volume, EPA calculated the 95th percentile of the OPW Engineered Systems loading arms volumetric data resulting in a high-end value of 17.7 gallons. For the central tendency tank truck scenario, EPA assumed a 2-inch diameter, 12-ft long transfer hose. This hose has a volume of 2.0 gallons.

Once the volume is known, the emission rate, E_T (g/s), can be calculated as follows:

Equation_Apx C-5.

$$E_T = \frac{f \times MW \times 3{,}786.4 \times V_h \times X \times VP}{t_{disconnect} \times T \times R \times 3{,}600 \times 760}$$

Default values for Equation_Apx C-5 can be found in Table_Apx C-14.

6835 **Table_Apx C-13. Example Dimension and Volume of Loading Arm/Transfer System**

OPW Engineered Systems Transfer Arm	Length of Loading Arm/Connection (in) [a]				Volume, V_h (gal) [b]			
	2-Inch	3-Inch	4-Inch	6-Inch	2-Inch	3-Inch	4-Inch	6-Inch
Unsupported Boom-Type Bottom Loader	149.875	158.5	165.25	191.75	2.0	4.9	9.0	23.5
"A" Frame Loader M-32-F	153.75	159.75	164.5	N/A	2.1	4.9	8.9	N/A
"A" Frame Hose Loader AFH-32-F	180.75	192.75	197.5	N/A	2.5	5.9	10.7	N/A
CWH Series Counterweighted Hose Loader	N/A	N/A	309	N/A	N/A	N/A	16.8	N/A
Spring Balanced Hose Loader SRH-32-F	204.75	216.75	221.5	N/A	2.8	6.6	12.0	N/A
Spring Balanced Hose Loader LRH-32-F	N/A	270	277.625	N/A	N/A	8.3	15.1	N/A
Top Loading Single Arm Fixed Reach	201.75	207.75	212.5	N/A	2.7	6.4	11.6	N/A
Top Loading Scissor Type Arm	197.875	206.5	213.25	N/A	2.7	6.3	11.6	N/A
Supported Boom Arm B-32-F	327.375	335	341.5	N/A	4.5	10.3	18.6	N/A
Unsupported Boom Arm GT-32-F	215.875	224.5	231.25	N/A	2.9	6.9	12.6	N/A
Slide Sleeve Arm A-32F	279	292.5	305.125	N/A	3.8	9.0	16.6	N/A
Hose without transfer arm								
Hose (EPA judgment)	120	–	–	–	1.6	–	–	–

Source: (OPW Engineered Systems, 2014).
[a] Total length includes length of piping, connections, and fittings.
[b] Calculated based on dimension of the transfer hose/connection, $V_h = \pi r^2 L$ (converted from cubic inch to gallons).

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6837 **Table_Apx C-14. Default Values for Calculating Emission Rate of Formaldehyde from**
6838 **Transfer/Loading Arm**

Parameter	Parameter Description	Default Value	Unit
E_T	Emission rate of chemical from transfer/loading system	Calculated from model equation	g/s
f	Saturation factor [a]	1	dimensionless
MW	Molecular weight of the chemical	30.026	g/mol
V_h	Volume of transfer hose	See Table_Apx C-13	gallons
r	Fill rate [a]	2 (tank truck) 1 (railcar)	containers/hr
$t_{disconnect}$	Time to disconnect hose/couplers (escape of saturated vapor from disconnected hose or transfer arm into air)	0.25	hr
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of formalin	1.3	torr
T	Temperature	298	K
R	Universal gas constant	82.05	atm-cm^3/gmol-K

[a] Saturation factor and fill rate values are based on established EPA/OPPT release and inhalation exposure assessment methodologies (U.S. EPA, 2013, 3809033).

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C.7.3 Emissions from Leaks

During loading/unloading activities, emissions may also occur from equipment leaks from valves, pumps, and seals. Per 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, 1995c), the following equation can be used to estimate emission rate E_L, calculated as the sum of average emissions from each process unit:

Equation_Apx C-6.

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

Parameters for calculating equipment leaks using Equation_Apx C-6 can be found in Table_Apx C-15.

Table_Apx C-15. Parameters for Calculating Emission Rate of Formaldehyde from Equipment Leaks

Parameter	Parameter Description	Default Value	Unit
E_L	Emission rate of chemical from equipment leaks	Calculated from model equation	g/s
F_A	Applicable average emission factor for the equipment type	See Section C.7.4	kg/hr-source
WF_{TOC}	Average weight fraction of chemical in the stream	1	Dimensionless
N	Number of pieces of equipment of the applicable equipment type in the stream	See Section C.7.4	Source

To estimate emission leaks using this modeling approach, EPA modeled a central tendency loading rack scenario using tank truck loading/unloading and a high-end loading rack scenario using railcar loading/unloading. EPA used engineering judgment to estimate the type and number of equipment associated with the loading rack in the immediate vicinity of the loading operation. EPA assumes at least one worker will be near the loading rack during the entire duration of the loading operation.

Table_Apx C-15 presents the average emission factor for each equipment type, based on the synthetic organic chemical manufacturing industry (SOCMI) emission factors as provided by EPA's 1995 Protocol (U.S. EPA, 1995c) and the likely number of pieces of each equipment used for each chemical loading/unloading activity, based on EPA's judgment. Note these emission factors are for emission rates of total organic compound emission and are assumed to be applicable to formaldehyde. In addition, these factors are most valid for estimating emissions from a population of equipment and are not intended to be used to estimate emissions for an individual piece of equipment over a short period of time.

C.7.4 Exposure Estimates

The vapor generation rate, *G*, or the total emission rate over time, can be calculated by aggregating emissions from all sources:

- During the transfer period, emissions are only due to leaks, with emission rate $G = E_L$.
- After transfer, during the disconnection of the hose(s), emissions are due to both leaks and escape of saturated vapor from the hose/transfer arm with emission rate $G = E_T + E_L$.

The vapor generation rate can then be used with the EPA Mass Balance Inhalation Model to estimate worker exposure during loading/unloading activities (U.S. EPA, 2015b). That model estimates the exposure concentration using Equation_Apx C-7 and the default parameters found in Table_Apx C-16

(U.S. EPA, 2015b). Table_Apx C-16 presents exposure estimates for Formaldehyde using this approach. These estimates assume one unloading/loading event per day and Formaldehyde is loaded/unloaded at 100 percent concentration. The loading operation occurs in an outdoor area with minimal structure, with wind speeds of 9 mph (central tendency) or 5 mph (high-end).

Equation_Apx C-7.

$$C_m = \frac{C_v}{V_m}$$

Table_Apx C-16. Parameters for Calculating Exposure Concentration Using the EPA/OPPT Mass Balance Model

Parameter	Parameter Description	Default Value	Unit
C_m	Mass concentration of chemical in air	Calculated from model equation	mg/m^3
C_v	Volumetric concentration of chemical in air	Calculated as the lesser of: $\frac{170{,}000 \times T \times G}{MW \times Q \times k}$ or $\frac{1{,}000{,}000 \times X \times VP}{760}$	ppm
T	Temperature of air	298	K
G	Vapor generation rate	E_L during transfer period E_T+E_L after transfer/during disconnection of hose/transfer arm	g/s
MW	Molecular weight of the chemical	30.026	g/mol
Q	Outdoor ventilation rate	237,600 (central tendency) $26{,}400 \times \left(60 \times \frac{vz}{5280}\right)$ (high-end)	ft^3/min
vz	Air speed	440	ft/min
k	Mixing factor	0.5	dimensionless
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	1.3	torr
V_m	Molar volume	24.45 @ 25ºC, 1 atm	L/mol

EPA calculated 8-hour TWA exposures as shown in Equation_Apx C-8. The 8-hour TWA exposure is the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. EPA assumed one container is loaded/unloaded per shift: one tank truck per shift for the central tendency scenario and one railcar per shift for the high-end scenario.

Equation_Apx C-8.

$$8 - hr\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{8}$$

Where:

$C_{m(leak\ only)}$ = Airborne concentration (mass-based) due to leaks during unloading while hose connected (mg/m^3)

$C_{m(leak\ and\ hose)}$ = Airborne concentration (mass-based) due to leaks and displaced air during hose disconnection (mg/m^3)

h_{event} = Exposure duration of each loading/unloading event (hr/event); calculated as the inverse of the fill rate, *r*: 0.5 hr/event for tank trucks and 1 hr/event for railcars

h_{shift} = Exposure duration during the shift (hr/shift); calculated as $h_{event} \times N_{cont}$: 0.5 hr/shift for tank trucks and 1 hr/shift for railcars

$t_{disconnect}$ = Time duration to disconnect hoses/couplers (during which saturated vapor escapes from hose into air) (hr/event)

N_{cont} = Number of containers loaded/unloaded per shift (event/shift); assumed one tank truck per shift for central tendency scenario and one railcar per shift for high-end scenario

Table_Apx C-17. Calculated Emission Rates and Resulting Exposures from the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model for Formaldehyde

Scenario	E_L (g/s)	E_T (g/s)	$E_L + E_T$ (g/s)	C_m (Leaks Only) (mg/m³)	C_m (Leaks and Hose Vapor) (mg/m³)	8-Hour TWA (mg/m³)
Central Tendency	0.044	1.73E−05	0.044	0.76	0.76	0.047
High-End	0.049	1.56E−04	0.049	1.52	1.53	0.19

C.8 Dermal Exposure Model Methodology

This appendix presents the modeling parameters used to estimate occupational dermal exposures. This method was developed through review of relevant literature and consideration of existing exposure models, such as EPA/OPPT models and the ECETOC TRA.

C.8.1 Model Input Parameters

The modelling equation approach for occupational dermal exposures is outlined in Section 2.6. The dermal load (Q_u) is the quantity of chemical on the skin after the dermal contact event. This value represents the quantity remaining after the bulk chemical formulation has fallen from the hand that cannot be removed by wiping the skin (*e.g.*, the film that remains on the skin). To estimate the dermal load from each activity, EPA used data from references cited by EPA's September 2013 engineering policy memorandum: *Updating CEB's Method for Screening-Level Assessments of Dermal Exposure* (U.S. EPA, 2013). The contact event modeled for the formaldehyde OESs was routine and incidental contact with liquids (*e.g.*, maintenance activities, manual cleaning of equipment, filling drums, connecting transfer lines, sampling, and bench-scale liquid transfers). For this event, the memorandum uses values of 0.7 to 2.1 mg/cm^2-event for routine liquid contact. EPA uses the maximum value of the range from the memorandum to estimate high-end dermal loads. The memorandum did not provide recommended values for a central tendency dermal loading estimate. Therefore, EPA analyzed data from EPA's technical report *A Laboratory Method to Determine the Retention of Liquids on the Surface of the Hands* (U.S. EPA, 1992b) that served as the basis for the liquid dermal loading values provided in the 2013 memorandum. To estimate central tendency liquid dermal loading values, EPA used the 50th percentile of the dermal loading results for the routine liquid contact activity. The 50th percentile value was 1.4 mg/cm^2-event for routine/incidental contact with liquids.

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Appendix D CROSSWALK OF NAICS CODES TO OES FOR OSHA CEHD DATA ANALYSIS

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6938 **Table_Apx D-1. Mapping of NAICS Codes to OES**

NAICS	NAICS Description	Mapped OES	Basis
111998	All Other Miscellaneous Crop Farming	Unknown	This industry primarily includes operations that include growing different crops not included in other agricultural NAICS codes. The Agricultural use OES fits best for this industry as formaldehyde is likely used in fertilizer applied to crop fields.
112120	Dairy Cattle and Milk Production	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde within the scope of this risk evaluation in dairy cattle and milk production has not been identified.
112130	Dual-Purpose Cattle Ranching and Farming	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde within the scope of this risk evaluation in dual-purpose cattle ranching and farming has not been identified.
112310	Chicken Egg Production	Unknown	Sector 11, which this NAICS code falls under is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde within the scope of this risk evaluation in chicken egg production has not been identified.
112340	Poultry Hatcheries	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde within the scope of this risk evaluation in poultry hatcheries has not been identified.
112511	Finfish Farming and Fish Hatcheries	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde within the scope of this risk evaluation in finfish farming and fish hatcheries has not been identified.
115111	Cotton Ginning	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde within the scope of this risk evaluation in cotton ginning has not been identified.
115116	Farm Management Services	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde in farm management services within the scope of this risk evaluation has not been identified.

NAICS	NAICS Description	Mapped OES	Basis
115210	Support Activities for Animal Production	Unknown	Sector 11, which this NAICS code falls under, is defined as "Agriculture, Forestry, Fishing and Hunting." A specific use of formaldehyde in support activities for animal production within the scope of this risk evaluation has not been identified.
211130	Natural Gas Extraction	Use of formaldehyde for oilfield well production	This industry includes the extraction and production of natural gas from wells, and the recovery of liquid hydrocarbons from oil and gas field gases. The Use of formaldehyde for oilfield well production OES best matches these processes.
212324	Kaolin and Ball Clay Mining	Unknown- Combustion sources	EPA is not aware of an intentional use of formaldehyde for Kaolin and Ball Clay Mining and the industry of mining was not identified through CDR. (NICNAS, 2006) indicated emissions from mining due to combustion sources such as vehicle exhaust, boilers, blating, and power generation. Therefore, EPA expects these exposures are likely the sole result of combustion sources.
213112	Support Activities for Oil and Gas Operations	Use of formaldehyde for oilfield well production	Industry is similar in function to the "Natural Gas Extraction" NAICS code. The Use of formaldehyde for oilfield well production OES best matches these processes.
221111	Hydroelectric Power Generation	Unknown	A specific use of formaldehyde within the scope of this risk evaluation in hydroelectric power generation has not been identified.
236220	Commercial and Institutional Building Construction	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
237310	Highway, Street, and Bridge Construction	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
238130	Framing Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Framing contractors engage in wood and steel construction activities. Building and construction materials OES is closest match with this NAICS code.
238140	Masonry Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
238210	Electrical Contractors and Other Wiring Installation Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
238310	Drywall and Insulation Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
238330	Flooring Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
238350	Finish Carpentry Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
238910	Site Preparation Contractors	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
311119	Other Animal Food Manufacturing	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
311612	Meat Processed from Carcasses	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
311710	Seafood Product Preparation and Packaging	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
311811	Retail Bakeries	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
311812	Commercial Bakeries	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
311824	Dry Pasta, Dough, and Flour Mixes Manufacturing from Purchased Flour	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
311830	Tortilla Manufacturing	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.

NAICS	NAICS Description	Mapped OES	Basis
311942	Spice and Extract Manufacturing	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
312111	Soft Drink Manufacturing	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
312112	Bottled Water Manufacturing	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
312120	Breweries	Unknown	NAICS code indicates food manufacturing, which may fall under non-TSCA uses. A specific use in food manufacturing for a TSCA COU within the scope of this risk evaluation is not known.
313110	Fiber, Yarn, and Thread Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313210	Broadwoven Fabric Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313220	Narrow Fabric Mills and Schiffli Machine Embroidery	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313230	Nonwoven Fabric Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313240	Knit Fabric Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313310	Textile and Fabric Finishing Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313312	Textile and Fabric Finishing Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
313320	Fabric Coating Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
314110	Carpet and Rug Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
314120	Curtain and Linen Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
314910	Textile Bag and Canvas Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
314994	Rope, Cordage, Twine, Tire Cord, and Tire Fabric Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.
314999	All Other Miscellaneous Textile Product Mills	Textile finishing	Textile finishing OES is closest match with this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
315210	Cut and Sew Apparel Contractors	Textile finishing	Textile finishing OES is closest match with this NAICS code.
315220	Men's and Boys' Cut and Sew Apparel Manufacturing	Textile finishing	Textile finishing OES is closest match with this NAICS code.
315990	Apparel Accessories and Other Apparel Manufacturing	Textile finishing	Textile finishing OES is closest match with this NAICS code.
316110	Leather and Hide Tanning and Finishing	Leather tanning	Leather tanning OES is a 1-to-1 match with this NAICS code.
321113	Sawmills	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321211	Hardwood Veneer and Plywood Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321212	Softwood Veneer and Plywood Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321213	Engineered Wood Member (except Truss) Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321219	Reconstituted Wood Product Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321911	Wood Window and Door Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match with NAICS code.
321912	Cut Stock, Resawing Lumber, and Planing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321918	Other Millwork (including Flooring)	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321920	Wood Container and Pallet Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321991	Manufactured Home (Mobile Home) Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
321992	Prefabricated Wood Building Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
321999	All Other Miscellaneous Wood Product Manufacturing	Composite wood product manufacturing	Composite wood product manufacturing closest match NAICS code.
322121	Paper (except Newsprint) Mills	Paper manufacturing	Paper manufacturing is closest match with this NAICS code.
322211	Corrugated and Solid Fiber Box Manufacturing	Paper manufacturing	Paper manufacturing is closest match with this NAICS code.
322219	Other Paperboard Container Manufacturing	Paper manufacturing	Paper manufacturing is closest match with this NAICS code.
322220	Paper Bag and Coated and Treated Paper Manufacturing	Paper manufacturing	Paper manufacturing is closest match with this NAICS code.
322291	Sanitary Paper Product Manufacturing	Paper manufacturing	Paper manufacturing is closest match with this NAICS code.
322299	All Other Converted Paper Product Manufacturing	Paper manufacturing	Paper manufacturing is closest match with this NAICS code.
323111	Commercial Printing (except Screen and Books)	Use of printing ink, toner and colorant products containing formaldehyde	Printing OES closest match with this NAICS code.
323113	Commercial Screen Printing	Use of printing ink, toner and colorant products containing formaldehyde	Printing OES closest match with this NAICS code.
324122	Asphalt Shingle and Coating Materials Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Subcategory for this COU lists "Asphalt, paving, roofing, and coating materials manufacturing," which matches best with this NAICS code.
324199	All Other Petroleum and Coal Products Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Could be either this OES, or processing as a reactant, as both list petrochemical manufacturing, a similar industry, under the subcategory for the corresponding COU. Processing aid is also a potential OES for this industry based on the COU but PROC – Formulations was chosen as the most likely OES.

NAICS	NAICS Description	Mapped OES	Basis
325110	Petrochemical Manufacturing	Processing as a reactant	Could be either this OES, or processing into formulations, as both list petrochemical manufacturing, under the subcategory for the corresponding COU. Processing aid is also a potential OES for this industry based on the COU but PROC – Reactant was chosen as the most likely OES.
325130	Synthetic Dye and Pigment Manufacturing	Processing as a reactant	Most commonly reported use codes under TRI for this NAICS description, it is expected that formaldehyde is used as a reactant in the dye/pigment manufacturing process.
325180	Other Basic Inorganic Chemical Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Subcategory for this COU lists "all other basic inorganic chemical manufacturing"
325193	Ethyl Alcohol Manufacturing	Unknown- Combustion sources	Emissions of formaldehyde in the ethanol production process during fermentation and drying processes would best fit under combustion sources.
325199	All Other Basic Organic Chemical Manufacturing	Processing as a reactant	Chemical manufacturing matches best with the processing as a reactant NAICS code.
325211	Plastics Material and Resin Manufacturing	Processing as a reactant	Formaldehyde is reacted to form FA-based resin materials
325311	Nitrogenous Fertilizer Manufacturing	Processing as a reactant	Formalin and urea-formaldehyde are used in the manufacture of solid urea and ureaform, which are used as slow-release nitrogen fertilizer. Therefore, EPA expects the most likely OES is Processing as a reactant.
325314	Fertilizer (Mixing Only) Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	NAICS description specifies "mixing only," thus Processing into formulations is most applicable OES.
325320	Pesticide and Other Agricultural Chemical Manufacturing	Other – pesticide manufacturing	Could be processing as a reactant or into a formulation per COU table; It is assigned to formulation COU but seperated as these processes may be non-TSCA (FIFRA) if formaldehyde is used for making or incorporated into a pesticide product. Required additional research into the company.
325412	Pharmaceutical Preparation Manufacturing	Other- pharmaceutical manufacturing	Processes may be non-TSCA (FDA). Required additional research into the company.

NAICS	NAICS Description	Mapped OES	Basis
325510	Paint and Coating Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	NAICS description matches with full COU description for this OES.
325520	Adhesive Manufacturing	Processing as a reactant	Process could be reactant or into formulation per COU table; Based on NAICS description, matched to this OES.
325611	Soap and Other Detergent Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Could be either Processing as a reactant or Processing into formulations OES based on TRI reporting for this NAICS code and based on the NAICS description. COU table includes soap under PROC – formulation.
325612	Polish and Other Sanitation Good Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	TRI for this NAICS code all indicate formulations OES, consistent with mapping of similar industry 325611 – Soap and Other Detergent Manufacturing. Formaldehyde is expected to be a component in manufacturing of polish and sanitation good manufacturing.
325613	Surface Active Agent Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	TRI reports this NAICS code as both processing as a reactant and PROC – formulation. COU table indicates surface active agents under PROC – formulation only.
325620	Toilet Preparation Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Consistent with mapping of similar industry 325611 - Soap and Other Detergent Manufacturing.
325910	Printing Ink Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Formaldehyde is known to be present in the finished product of printing ink, makes PROC – formulation the most likely match for this NAICS code. Printing OES would be too downstream for this NAICS code.
325991	Custom Compounding of Purchased Resins	Processing of formaldehyde into formulations, mixtures, or reaction products	OES is closest match for this NAICS description, consistent with TRI reporting for this code. Formaldehyde is known to be present in finished resins products.
325992	Photographic Film, Paper, Plate, and Chemical Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	Formaldehyde is used in photographic film processing, OES matches the chemical manufacturing portion of the NAICS description. EPA expects photo film processing OES is too downstream for a manufacturing industry.
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	Processing as a reactant	Broad NAICS description, could also be PROC-formulation OES or a repackaging OES. Processing as a Reactant was chosen as the best fitting OES over the alternatives.
326111	Plastics Bag and Pouch Manufacturing	Plastic product manufacturing	OES matches NAICS description.

NAICS	NAICS Description	Mapped OES	Basis
326112	Plastics Packaging Film and Sheet (including Laminated) Manufacturing	Plastic product manufacturing	OES matches NAICS description.
326113	Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing	Plastic product manufacturing	OES matches NAICS description.
326121	Unlaminated Plastics Profile Shape Manufacturing	Plastic Product Manufacturing	OES matches NAICS description.
326122	Plastics Pipe and Pipe Fitting Manufacturing	Plastic product manufacturing	Plastic product manufacturing closest OES.
326130	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing	Plastic product manufacturing	OES matches NAICS description.
326191	Plastics Plumbing Fixture Manufacturing	Plastic product manufacturing	Plastic Product manufacturing closest OES.
326199	All Other Plastics Product Manufacturing	Plastic product manufacturing	Plastic Product manufacturing closest OES.
326211	Tire Manufacturing (except Retreading)	Rubber product manufacturing	Rubber product manufacturing closest match with tire manufacturing.
326220	Rubber and Plastics Hoses and Belting Manufacturing	Rubber product manufacturing	Rubber product manufacturing closest match with tire manufacturing.
326291	Rubber Product Manufacturing for Mechanical Use	Rubber product manufacturing	Rubber product manufacturing closest match with tire manufacturing.
326299	All Other Rubber Product Manufacturing	Rubber product manufacturing	Rubber product manufacturing closest match with tire manufacturing.
327120	Clay Building Material and Refractories Manufacturing	Other Composite Material Manufacturing (*e.g.*, roofing, etc.)	OES matches NAICS description.

NAICS	NAICS Description	Mapped OES	Basis
327212	Other Pressed and Blown Glass and Glassware Manufacturing	Other Composite Material Manufacturing (*e.g.*, roofing, etc.)	OES matches NAICS description.
327331	Concrete Block and Brick Manufacturing	Other Composite Material Manufacturing (*e.g.*, roofing, etc.)	OES matches NAICS description.
327390	Other Concrete Product Manufacturing	Other Composite Material Manufacturing (*e.g.*, roofing, etc.)	OES matches NAICS description.
327910	Abrasive Product Manufacturing	Processing of formaldehyde into formulations, mixtures, or reaction products	While it could also be composite material manufacturing OES or PROC – Reactant OES, Other composite material manufacturing was chosen as best fit.
327991	Cut Stone and Stone Product Manufacturing	Other composite material manufacturing (*e.g.*, roofing, etc.)	OES matches NAICS description.
327993	Mineral Wool Manufacturing	Other composite material manufacturing (*e.g.*, roofing, etc.)	This industry is primarily engaged with mineral wool and mineral wool (*i.e.*, fiberglass) insulation products. Therefore, EPA expects the most likely OES is Other composite material manufacturing.
327999	All Other Miscellaneous Nonmetallic Mineral Product Manufacturing	Other composite material manufacturing (*e.g.*, roofing, etc.)	OES matches NAICS description and matches mapping for similar NAICS codes.
331110	Iron and Steel Mills and Ferroalloy Manufacturing	Foundries	Industry consists of processing iron ore, manufacturing iron, manufacturing steel, and making iron and steel products. Foundries OES is closest match with this NAICS code.
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	Foundries	Industry consists of manufacturing iron and steel pipes and tubes. Foundries OES is closest match with this NAICS code.
331221	Rolled Steel Shape Manufacturing	Foundries	Industry consists of rolling or drawing shapes from purchased steel. Foundries is the closest match with this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
331313	Alumina Refining and Primary Aluminum Production	Foundries	Industry includes making aluminum from alumina and casting aluminum into primary forms. Foundries OES is the closest match with this NAICS code.
331318	Other Aluminum Rolling, Drawing, and Extruding	Foundries	Similar industry to 331313, foundries OES is the closest match.
331410	Nonferrous Metal (except Aluminum) Smelting and Refining	Foundries	Industry smelts ores into nonferrous metals and refines nonferrous metals. Foundries OES is the closest match for this NAICS code.
331511	Iron Foundries	Foundries	Foundries OES is a match with this NAICS code.
331513	Steel Foundries (except Investment)	Foundries	Foundries OES is a match with this NAICS code.
331521	Nonferrous Metal Die-Casting Foundries	Foundries	Foundries OES is a match with this NAICS code.
331522	Nonferrous Metal Die-Casting Foundries	Foundries	Foundries OES is a match with this NAICS code.
331523	Nonferrous Metal Die-Casting Foundries	Foundries	Foundries OES is a match with this NAICS code.
331524	Aluminum Foundries (except Die-Casting)	Foundries	Foundries OES is a match with this NAICS code.
331529	Other Nonferrous Metal Foundries (except Die-Casting)	Foundries	Foundries OES is a match with this NAICS code.
332111	Iron and Steel Forging	Foundries	Forging typically involves the shaping of metal into desired shapes. Formaldehyde should serve the same function in this industry as in foundries.
332112	Nonferrous Forging	Foundries	Forging typically involves the shaping of metal into desired shapes. Formaldehyde should serve the same function in this industry as in foundries.
332114	Custom Roll Forming	Foundries	Industry includes shaping metal products, Foundries OES is closest match with this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
332117	Powder Metallurgy Part Manufacturing	Foundries	Industry includes molding and pressing metal, Foundries OES is closest match with this NAICS code.
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)	Foundries	Industry includes shaping metal products, Foundries OES is closest match with this NAICS code.
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Industry is comprised of manufacturing metal cookware and utensils. It is expected that formaldehyde is used in metal coating, therefore the Spray OES is the best match for this NAICS code.
332216	Saw Blade and Handtool Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Industry is comprised of manufacturing metal tools. It is expected that formaldehyde is used in metal coating for this process, therefore the spray OES is the best match for this NAICS code. The Non-spray coating OES could also be a potential alternative for this NAICS code.
332312	Fabricated Structural Metal Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Industry is comprised of fabricating structural metal products. Formaldehyde could be used in an adhesive or coating capacity, both of which fall under this OES.
332313	Plate Work Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Closest OES match for this NAICS code, formaldehyde likely used as adhesive or coating.
332321	Metal Window and Door Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Closest OES match for this NAICS code, formaldehyde likely used as adhesive or coating.
332322	Sheet Metal Work Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Closest OES match for this NAICS code, formaldehyde likely used as adhesive or coating.
332323	Ornamental and Architectural Metal Work Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Closest OES match for this NAICS code, formaldehyde likely used as adhesive or coating.

NAICS	NAICS Description	Mapped OES	Basis
332410	Power Boiler and Heat Exchanger Manufacturing	Use of automotive lubricants	This NAICS code is unexpected based on TRI/NEI and the COU table. The establishment for this NAICS code is "Hunter Engineering" located in Durant, MS which is an automotive servicing company based on online search of the company. Based on this information, the automotive lubricants OES was chosen.
332431	Metal Can Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be used in the base coat and varnishes of aluminum can products. OES matches the NAICS code.
332439	Other Metal Container Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is closest match for NAICS code, similar industry to metal can manufacturing.
332618	Other Fabricated Wire Product Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is closest match for NAICS code.
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is closest match for NAICS code.
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is closest match for NAICS code, most frequently mapped OES for this NAICS code in TRI.
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	Processing aid	COU mentions plating as an example which matches the NAICS description.
332911	Industrial Valve Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is most likely for this NAICS code, matches TRI mapping for facility with this NAICS code.
332912	Fluid Power Valve and Hose Fitting Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES most likely for this NAICS code, expected to be similar industry to 332911 (Industrial Valve Manufacturing).

NAICS	NAICS Description	Mapped OES	Basis
332913	Plumbing Fixture Fitting and Trim Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES most likely for this NAICS code, expected to be similar industry to 332911 (Industrial Valve Manufacturing).
332919	Other Metal Valve and Pipe Fitting Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES most likely for this NAICS code, expected to be similar industry to 332911 (Industrial Valve Manufacturing).
332992	Small Arms Ammunition Manufacturing	Use of explosive materials	Formaldehyde is expected to be used as a component in explosive materials for this OES. Explosive materials is the best OES fit for this NAICS code. It is also possible that another more upstream OES such as use of coating could also be an option for this OES.
332993	Ammunition (except Small Arms) Manufacturing	Use of explosive materials	Formaldehyde is expected to be used as a component in explosive materials for this OES. Explosive materials is the best OES fit for this NAICS code. It is also possible that another more upstream OES such as use of coating could also be an option for this OES.
332994	Small Arms, Ordnance, and Ordnance Accessories Manufacturing	Use of explosive materials	Formaldehyde is expected to be used as a component in explosive materials for this OES. Explosive materials is the best OES fit for this NAICS code. It is also possible that another more upstream OES such as use of coating could also be an option for this OES.
332995	Small Arms, Ordnance, and Ordnance Accessories Manufacturing	Use of explosive materials	Formaldehyde is expected to be used as a component in explosive materials for this OES. Explosive materials is the best OES fit for this NAICS code. It is also possible that another more upstream OES such as use of coating could also be an option for this OES.
332996	Fabricated Pipe and Pipe Fitting Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is most likely for this NAICS code.
332997	All Other Miscellaneous Fabricated Metal Product Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is most likely for this NAICS code.
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray OES is most likely for this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
333132	Oil and Gas Field Machinery and Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333244	Printing Machinery and Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333249	Other Industrial Machinery Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333314	Optical Instrument and Lens Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES.
333316	Photographic and Photocopying Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. The photo processing OES would likely be too downstream for this NAICS code. Could also be a processing aid OES, but spray OES selected as the most likely fit.
333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333511	Industrial Mold Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333517	Machine Tool Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.

NAICS	NAICS Description	Mapped OES	Basis
333613	Mechanical Power Transmission Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333618	Other Engine Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333914	Measuring, Dispensing, and Other Pumping Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333992	Welding and Soldering Equipment Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
333993	Packaging Machinery Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES. Other use OESs which could be alternatives would be too downstream for this manufacturing industry. Spray OES is the most likely match.
333994	Industrial Process Furnace and Oven Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES. Other use OESs which could be alternatives would be too downstream for this manufacturing industry. Spray OES is the most likely match.
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES, but the spray applications OES was the best fit.
334220	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).

NAICS	NAICS Description	Mapped OES	Basis
334290	Other Communications Equipment Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334310	Audio and Video Equipment Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334412	Bare Printed Circuit Board Manufacturing	Processing aid	Processing aid OES closest match for circuit board manufacturing, also consistent with TRI reporting for this NAICS code.
334416	Capacitor, Resistor, Coil, Transformer, and Other Inductor Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334418	Printed Circuit Assembly (Electronic Assembly) Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334511	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334512	Automatic Environmental Control Manufacturing for Residential, Commercial, and Appliance Use	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334514	Totalizing Fluid Meter and Counting Device Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).

NAICS	NAICS Description	Mapped OES	Basis
334517	Irradiation Apparatus Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
334519	Other Measuring and Controlling Device Manufacturing	Processing aid	Formaldehyde is expected to be used as an oxidizing/reducing agent or processing aid in computer and electronic product manufacturing NAICS codes (334XXX).
335110	Electric Lamp Bulb and Part Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
335122	Commercial, Industrial, and Institutional Electric Lighting Fixture Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
335129	Other Lighting Equipment Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
335311	Power, Distribution, and Specialty Transformer Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
335312	Motor and Generator Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
335313	Switchgear and Switchboard Apparatus Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
335999	All Other Miscellaneous Electrical Equipment and Component Manufacturing	Use of electronic and metal products	Use of electronic products is the closest match for this OES.
336111	Automobile Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336112	Light Truck and Utility Vehicle Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336211	Motor Vehicle Body Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
336212	Truck Trailer Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336213	Motor Home Manufacturing	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
336214	Travel Trailer and Camper Manufacturing	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
336310	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing	Use of automotive lubricants	OES closest match for NAICS code.
336320	Motor Vehicle Electrical and Electronic Equipment Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336340	Motor Vehicle Brake System Manufacturing	Use of automotive lubricants	OES closest match for NAICS code.
336360	Motor Vehicle Seating and Interior Trim Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336370	Motor Vehicle Metal Stamping	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
336390	Other Motor Vehicle Parts Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336399	Other Motor Vehicle Parts Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	OES closest match for NAICS code.
336411	Aircraft Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	Spray OES closest match for NAICS code; however, lubricant is also a possible match;
336412	Aircraft Engine and Engine Parts Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	Spray OES closest match for NAICS code; however, lubricant is also a possible match.
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	Spray OES closest match for NAICS code; however, lubricant is also a possible match.
336510	Railroad Rolling Stock Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	Spray OES closest match for NAICS code; however, lubricant is also a possible match.
336611	Ship Building and Repairing	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.
336612	Boat Building	Installation and demolition of formaldehyde based furnishings and building/construction materials in residential, public, and commercial buildings, and other structures	Building and construction materials OES is closest match with this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
336991	Motorcycle, Bicycle, and Parts Manufacturing	Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	Spray/roll OES is closest match with this NAICS code.
337110	Wood Kitchen Cabinet and Countertop Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337121	Upholstered Household Furniture Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337122	Nonupholstered Wood Household Furniture Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337125	Household Furniture (except Wood and Metal) Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337127	Institutional Furniture Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337211	Wood Office Furniture Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337214	Office Furniture (except Wood) Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337215	Showcase, Partition, Shelving, and Locker Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337910	Mattress Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
337920	Blind and Shade Manufacturing	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
339112	Surgical and Medical Instrument Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES. Other use OESs that could be alternatives would be too downstream for this manufacturing industry. Spray OES is the most likely match.

NAICS	NAICS Description	Mapped OES	Basis
339113	Surgical Appliance and Supplies Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES. Other use OESs that could be alternatives would be too downstream for this manufacturing industry. Spray OES is the most likely match.
339114	Dental Equipment and Supplies Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be an adhesive or coating in machinery/equipment manufacturing NAICS codes. Could also be a processing aid OES. Other use OESs that could be alternatives would be too downstream for this manufacturing industry. Spray OES is the most likely match.
339910	Jewelry and Silverware Manufacturing	Processing Aid	Formaldehyde is used in electroless plating of copper and silver as a processing aid.
339920	Sporting and Athletic Goods Manufacturing	Plastic Product Manufacturing	Assumed plastic sporting/athletic products, industry does not include athletic apparel manufacturing.
339930	Doll, Toy, and Game Manufacturing	Plastic product manufacturing	Assumed plastic doll/toy/game products.
339940	Office Supplies (except Paper) Manufacturing	Plastic product manufacturing	Assumed to be used in plastic office supply products.
339991	Gasket, Packing, and Sealing Device Manufacturing	Plastic product manufacturing	Assumed plastic gasket/packing/sealing products.
339992	Musical Instrument Manufacturing	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Formaldehyde is expected to be used in coating or adhesive for musical instruments. Spray OES fits best for this NAICS code.
339993	Fastener, Button, Needle, and Pin Manufacturing	Plastic product manufacturing	Assumed plastic fastener, button, needle, and pin products.
339994	Broom, Brush, and Mop Manufacturing	Plastic product manufacturing	Assumed plastic broom, brush, and mop products.
339999	All Other Miscellaneous Manufacturing	Plastic product manufacturing	Consistent with mapping for other 33999X NAICS codes.
423210	Furniture Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.

NAICS	NAICS Description	Mapped OES	Basis
423220	Home Furnishing Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers aren not repackaging so Storage/retail OES is most applicable.
423310	Lumber, Plywood, Millwork, and Wood Panel Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
423690	Other Electronic Parts and Equipment Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
423730	Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
423850	Service Establishment Equipment and Supplies Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
423910	Sporting and Recreational Goods and Supplies Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
423930	Recyclable Material Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
423990	Other Miscellaneous Durable Goods Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424120	Stationery and Office Supplies Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424210	Drugs and Druggists' Sundries Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424310	Piece Goods, Notions, and Other Dry Goods Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.

NAICS	NAICS Description	Mapped OES	Basis
424320	Men's and Boys' Clothing and Furnishings Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424330	Women's, Children's, and Infants' Clothing and Accessories Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424410	General Line Grocery Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424470	Meat and Meat Product Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424690	Other Chemical and Allied Products Merchant Wholesalers	Repackaging	This industry is primarily engaged with merchant wholesale distribution of chemicals and allied products. Therefore, EPA expects the most likely OES is Repackaging.
424710	Petroleum Bulk Stations and Terminals	Use of formulations containing formaldehyde in fuels	NAICS code is closest match for the Fuels OES, industry is comprised of establishments with bulk liquid storage of petroleum products.
424920	Book, Periodical, and Newspaper Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are not repackaging so Storage/retail OES is most applicable.
424930	Flower, Nursery Stock, and Florists' Supplies Merchant Wholesalers	Storage and retail of articles	Assumed that wholesalers are nott repackaging so Storage/retail OES is most applicable.
425120	Wholesale Trade Agents and Brokers	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
441110	New Car Dealers	Use of formulations containing formaldehyde in automotive care products	Industry includes repair and maintenance services for Cars, OES is best fit for that function of the NAICS code. Automotive lubricants is a possible alternative OES at these sites as well.
442110	Furniture Stores	Storage and retail of articles	Exposure from this NAICS code expected to fall into Storage and retail of articles assessment category.
442299	All Other Home Furnishings Stores	Storage and retail of articles	Exposure from this NAICS code expected to fall into Storage and retail of articles assessment category.

NAICS	NAICS Description	Mapped OES	Basis
444110	Home Centers	Storage and retail of articles	Exposure from this NAICS code expected to fall into Storage and retail of articles assessment category.
444130	Hardware Stores	Storage and retail of articles	Exposure from this NAICS code expected to fall into Storage and retail of articles assessment category.
444190	Other Building Material Dealers	Storage and retail of articles	Exposure from this NAICS code expected to fall into Storage and retail of articles assessment category.
445210	Meat Markets	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
446120	Cosmetics, Beauty Supplies, and Perfume Stores	Unknown	Likely non-TSCA uses. No specific use for this NAICS code within the scope of this risk evaluation is known.
447110	Gasoline Stations with Convenience Stores	Use of formulations containing formaldehyde in fuels	OES is closest match, gas station employees could be exposed to formaldehyde in fuels.
448110	Men's Clothing Stores	Storage and retail of articles	This OES is upstream of the NAICS description; however it is the best fit.
448120	Women's Clothing Stores	Storage and retail of articles	This OES is upstream of the NAICS description; however it is the best fit.
448150	Clothing Accessories Stores	Storage and retail of articles	This OES is upstream of the NAICS description; however it is the best fit.
451110	Sporting Goods Stores	Storage and retail of articles	This OES is upstream of the NAICS description; however it is the best fit.
451130	Sewing, Needlework, and Piece Goods Stores	Storage and retail of articles	OES is closest match for this NAICS description.
451212	News Dealers and Newsstands	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
452210	Department Stores	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
453998	All Other Miscellaneous Store Retailers (except Tobacco Stores)	Use of packaging, paper, and hobby products	Examples listed for this industry includes art supply stores, which would match this OES. NAICS code is very general and could reasonably be multiple different OESs.
481111	Scheduled Passenger Air Transportation	Unknown- Combustion sources	Likely combustion sources for transportation of people.

NAICS	NAICS Description	Mapped OES	Basis
482111	Line-Haul Railroads	Unknown- Combustion sources	Assumed no repackaging, thus combustion sources is closest fit
484110	General Freight Trucking, Local	Unknown- Combustion sources	Assumed no repackaging, thus combustion sources is closest fit
485111	Mixed Mode Transit Systems	Unknown- Combustion sources	Likely combustion sources for transportation of people.
487110	Scenic and Sightseeing Transportation, Land	Unknown- Combustion sources	Likely combustion sources for transportation of people.
488210	Support Activities for Rail Transportation	Repackaging	Industry includes loading and unloading rail cars, Repackaging OES would be closest match for that activity.
488320	Marine Cargo Handling	Unknown- Combustion sources	Assumed no repackaging, thus combustion sources is closest fit
488490	Other Support Activities for Road Transportation	Unknown- Combustion sources	Industry includes establishments providing services to road network users. The combustion sources is the closest match for this NAICS code.
488991	Packing and Crating	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
491110	Postal Service	Use of packaging, paper, and hobby products	Closest OES would be Use of paper for this NAICS description.
492110	Couriers and Express Delivery Services	Use of packaging, paper, and hobby products	Closest OES would be Use of paper for this NAICS description.
493110	General Warehousing and Storage	Repackaging	Could be this or Distribution in commerce OES; assessing repackaging as conservative.
493190	Other Warehousing and Storage	Repackaging	Could be this or Distribution in commerce OES; assessing repackaging as conservative.
511110	Newspaper Publishers	Use of printing ink, toner and colorant products containing formaldehyde	OES matches NAICS description.

NAICS	NAICS Description	Mapped OES	Basis
511120	Periodical Publishers	Use of printing ink, toner and colorant products containing formaldehyde	OES matches NAICS description.
522110	Commercial Banking	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
524113	Direct Life Insurance Carriers	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
531110	Lessors of Residential Buildings and Dwellings	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
531390	Other Activities Related to Real Estate	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
532210	Consumer Electronics and Appliances Rental	Storage and retail of articles	OES matches NAICS description.
541330	Engineering Services	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
541380	Testing Laboratories	General laboratory use	OES matches NAICS description.
541690	Other Scientific and Technical Consulting Services	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
541713	Research and Development in Nanotechnology	Use of electronic and metal products	Closest OES match for this NAICS code, nanotechnology expected to be applied to electronic products which contain formaldehyde.
541921	Photography Studios, Portrait	Photo processing using formulations containing formaldehyde	Closest OES for this NAICS description.
541940	Veterinary Services	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a school setting. Lab use OES matches best to this NAICS code.
561210	Facilities Support Services	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.

NAICS	NAICS Description	Mapped OES	Basis
561311	Employment Placement Agencies	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
561320	Temporary Help Services	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
561422	Telemarketing Bureaus and Other Contact Centers	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
561720	Janitorial Services	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Closest fit is spray applications (spray applied cleaning products etc.).
561730	Landscaping Services	Use of fertilizer containing formaldehyde in outdoors including lawns	OES matches NAICS description.
562211	Hazardous Waste Treatment and Disposal	Worker handling of wastes	OES matches NAICS description.
562219	Other Nonhazardous Waste Treatment and Disposal	Worker handling of wastes	OES matches NAICS description.
562910	Remediation Services	Worker handling of wastes	Remediation processes are being assessed under the Worker handling of wastes OES for the occupational exposure assessment
562998	All Other Miscellaneous Waste Management Services	Worker handling of wastes	OES matches NAICS description.
611110	Elementary and Secondary Schools	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
611210	Junior Colleges	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a school setting. Lab use OES matches best to this NAICS code. It is possible that this NAICS code would fall under general population and not be within the scope of the risk evaluation.

NAICS	NAICS Description	Mapped OES	Basis
611310	Colleges, Universities, and Professional Schools	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a school setting. Lab use OES matches best to this NAICS code. It is possible that this NAICS code would fall under general population and not be within the scope of the risk evaluation.
611511	Cosmetology and Barber Schools	Unknown	Likely non-TSCA uses. No specific use for this NAICS code within the scope of this risk evaluation is known.
621111	Offices of Physicians (except Mental Health Specialists)	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
621112	Offices of Physicians, Mental Health Specialists	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
621210	Offices of Dentists	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
621320	Offices of Optometrists	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code
621399	Offices of All Other Miscellaneous Health Practitioners	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
621491	HMO Medical Centers	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
621492	Kidney Dialysis Centers	Unknown	Likely non-TSCA uses.
621511	Medical Laboratories	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
621910	Ambulance Services	Unknown	The use of formaldehyde in ambulances is unknown.
621999	All Other Miscellaneous Ambulatory Health Care Services	Unknown	The use of formaldehyde in ambulances is unknown.
622110	General Medical and Surgical Hospitals	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.
622310	Specialty (Except Psychiatric and Substance Abuse) Hospitals	General laboratory use	Formaldehyde is expected to be used as a lab chemical in a medical setting. Lab use OES matches best to this NAICS code.

NAICS	NAICS Description	Mapped OES	Basis
623110	Nursing Care Facilities (Skilled Nursing Facilities)	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
624310	Vocational Rehabilitation Services	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
711110	Theater Companies and Dinner Theaters	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
711310	Promoters of Performing Arts, Sports, and Similar Events with Facilities	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
713290	Other Gambling Industries	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
713990	All Other Amusement and Recreation Industries	Unknown	EPA is not aware of the use of formaldehyde for this NAICS code.
811111	General Automotive Repair	Use of automotive lubricants	Both COU and OES are applicable to this NAICS description.
811121	Automotive Body, Paint, and Interior Repair and Maintenance	Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	Spray application expected for automotive repainting.
811192	Car Washes	Use of formulations containing formaldehyde in automotive care products	Formadlehyde is expected to be used as a component in cleaning solutions in car washes. This would make the closest fit the Automotive care OES.
811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance	Industrial use of lubricants	Lubricants expected to be used for machinery repair and maintenance.
811420	Reupholstery and Furniture Repair	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
811490	Other Personal and Household Goods Repair and Maintenance	Furniture manufacturing	Furniture manufacturing closest match with NAICS code.
812111	Barber Shops	Unknown	Likely non-TSCA uses. No close match to OES.

NAICS	NAICS Description	Mapped OES	Basis
812112	Beauty Salons	Unknown	Likely non-TSCA uses. No close match to OES.
812113	Nail Salons	Unknown	Likely non-TSCA uses. No close match to OES
812210	Funeral Homes and Funeral Services	Unknown	Likely non-TSCA uses. No close match to OES
812220	Cemeteries and Crematories	Unknown	Likely non-TSCA uses. No close match to OES
812921	Photofinishing Laboratories (except One-Hour)	Photo processing using formulations containing formaldehyde	OES matches NAICS description.
921130	Public Finance Activities	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
921190	Other General Government Support	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
922130	Legal Counsel and Prosecution	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
922140	Correctional Institutions	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
922160	Fire Protection	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
922190	Other Justice, Public Order, and Safety Activities	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
923110	Administration of Education Programs	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.

NAICS	NAICS Description	Mapped OES	Basis
923130	Administration of Human Resource Programs (except Education, Public Health, and Veterans' Affairs Programs)	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
923140	Administration of Veterans' Affairs	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
924110	Administration of Air and Water Resource and Solid Waste Management Programs	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
924120	Administration of Conservation Programs	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
926120	Regulation and Administration of Transportation Programs	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
926150	Regulation, Licensing, and Inspection of Miscellaneous Commercial Sectors	Unknown	EPA expects emission from multiple types of products in an office setting, but some of the sites may not be offices. Not attributable to an OES.
928110	National Security	Use of explosive materials	This NAICS code encapsulates the entire armed forces. Assumed use of explosive materials as closest OES match.

Appendix E ANAYLSIS OF FULL-SHIFT CALCULATIONS OF OSHA CEHD DATA

EPA uses the OSHA chemical exposure health data (CEHD) (OSHA, 2019) which includes a variety of workplace monitoring data. The general approach to extracting and utilizing OSHA CEHD data is provided in Section 2.5.1. Of note, OSHA CEHD contains sampling data measured over different sampling durations. OSHA notes for the database that OSHA compliance officers do not always obtain an 8-hour or full-shift sample. Where the total sample time is less than eight hours, an assumption needs to be made about the exposure potential for the remainder of the shift. In cases where EPA has additional knowledge of the exposure activities or sources, the EPA may assume that the sampled time is intended to represent a full shift of exposure. In such cases, the sample concentration is assumed to be representative of the full 8-hour TWA without adjustment. For the formaldehyde risk evaluation, this assumption was made based on the available supporting information provided with the monitoring data.

The OSHA CEHD does not provide this additional supporting information such as worker activities or sampling plans. As formaldehyde has both an 8-hour PEL and a 15-minute STEL, EPA assumes that compliance officers could be sampling for the purposes of comparing specific activities with the OSHA STEL and not for OSHA PEL purposes. To reduce the level of uncertainties in the exposure estimates, EPA implemented a cut-off of 5.5 hours for extraction of samples for full-shift analysis and assumed that the unsampled time exposure was zero (*e.g.*, 8-hour TWA = [sample concentration A × sample time A + sample concentration B × sample time B + 0 × remaining sample time in 8-hour shift/8 hours], where samples A and B are for the same worker/sample ID). According to the OSHA technical manual, full-shift sampling is defined to at least cover the total time of a work shift minus an hour (OSHA, 2023). For the purposes of the formaldehyde risk assessment, EPA was interested in assessing 8-hour work shift exposures. Based on this OSHA definition, the threshold for a full-time 8-hour shift would be 7 hours; however, EPA also assumed that leniency would be given for activities where sampling would not occur (*e.g.*, the workers moving in and out of the regulated area, changing out of PPE, decontaminating, and taking lunch outside of the regulated area). EPA selected 1.5 hours as the representation of time spent on these activities leading to a threshold value of 5.5 hours for extraction of samples for a full-shift analysis. This assumption may potentially underestimate exposures if during the actual unsampled time, exposures are non-zero. EPA investigated the impact of this assumption on OSHA data that was mapped to an in-scope OESs.

Table_Apx E-1 shows the calculated sample concentrations from the OSHA data considering all samples with a combined sampling duration above zero. These concentrations only reflect OSHA data and are not fully representative of the estimate for the exposure scenarios as EPA integrates across multiple sources for the occupational exposure estimates used. The central tendency and high-end result are shown for the approach with no 8-hour adjustment, and the approach EPA utilized with an 8-hour adjustment.

6985 **Table_Apx E-1. Analysis of OSHA CEHD Formaldehyde Data from 1992 to 2020 (All Samples)**

Occupational Exposure Scenario (OES)	Number of Samples	Sample Concentrations (ppm)			
		Central Tendency (No Adjustment)	High End (No Adjustment)	Central Tendency (8-Hour Adjustment)	High End (8-Hour Adjustment)
Manufacturing of formaldehyde	20	0.125	1.832	0.025	0.308
Processing as a Reactant	120	0.189	1.973	0.033	0.823
Use of Coatings, Paints, Adhesives, or Sealants (*e.g.*, spray or unknown)	463	0.080	0.652	0.040	0.489
Rubber product manufacturing	62	0.017	0.287	0.008	0.071
Composite Wood Product Manufacturing	285	0.113	1.305	0.063	0.581
Other Composite Material Manufacturing (*e.g.*, roofing, etc.)	127	0.074	0.386	0.032	0.335
Plastic Product Manufacturing	334	0.089	0.471	0.024	0.274
Paper Manufacturing	130	0.064	0.446	0.015	0.352
Processing of formaldehyde into formulations, mixtures, or reaction products	157	0.098	2.095	0.018	0.593
Processing Aid	89	0.060	0.293	0.018	0.179
Use of formaldehyde for oilfield well production	8	0.027	0.324	0.005	0.158
Storage and Retail of Articles	118	0.109	0.921	0.034	0.469
Furniture Manufacturing	296	0.107	0.888	0.051	0.596
Repackaging	38	0.092	0.803	0.025	0.477
Foundries	652	0.094	0.614	0.062	0.413
Use of electronic and metal products	44	0.094	0.566	0.050	0.415
Textile finishing	270	0.067	0.576	0.024	0.314
Installation and demolition of formaldehyde-based furnishings and building/construction materials in Residential, public and commercial buildings, and other structures	73	0.065	0.382	0.013	0.264
Use of automotive lubricants	18	0.036	0.257	0.018	0.116
Industrial use of lubricants	2	0.152	0.195	0.005	0.006
Use of explosive materials	29	0.065	0.208	0.017	0.060

Occupational Exposure Scenario (OES)	Number of Samples	Sample Concentrations (ppm)			
		Central Tendency (No Adjustment)	High End (No Adjustment)	Central Tendency (8-Hour Adjustment)	High End (8-Hour Adjustment)
Use of formulations containing formaldehyde in automotive care products	3	0.044	0.278	0.012	0.023
Use of formulations containing formaldehyde in fuels	10	0.330	2.201	0.089	0.331
Leather tanning	5	0.230	2.191	0.122	0.194
Use of printing ink, toner, and colorant products containing formaldehyde	21	0.047	0.106	0.016	0.091
Photo processing using formulations containing formaldehyde	18	0.039	0.077	0.007	0.036
Worker handling of wastes	13	0.050	0.382	0.025	0.058
General laboratory use	452	0.156	1.489	0.031	0.476
Use of packaging, paper, and hobby products	12	0.026	0.200	0.005	0.015

In general, EPA found that when central tendency and high-end TWAs were calculated using all of the available sampling data, the average percentage difference across all OESs between the two different approaches for TWA calculation was a 67 percent decrease in the central tendency and a 54 percent decrease in the high end. Approach one assumes that the sample time weighted average is reflective of full-shift exposures. With all samples considered, the dataset can include worker monitoring taken solely for STEL comparison purposes, where EPA expects that compliance officers target times or tasks during the shift expected to have the highest formaldehyde exposures. These shorter term, high exposure events may not be reflective of the entire 8-hour shift. Approach two with the 8-hour TWA adjustment will comparatively underestimate exposure estimates, with a significant portion of the work shift assuming no formaldehyde exposure. This discrepancy becomes more significant for specific scenarios dependent on the number of shorter term samples identified for the exposure scenario. The scenarios most impacted by the change in the 8-hour TWA calculation approach included the following[5]:

- Industrial use of lubricants;
- Processing of formaldehyde into formulations, mixtures, or reaction products;
- Use of packaging, paper, and hobby products;
- Manufacturing of formaldehyde;
- Use of explosive materials;
- Use of formulations containing formaldehyde in fuels; and
- Use of formulations containing formaldehyde in automotive care products.

[5] These scenarios are **bolded** in the OES column of Table_Apx E-1.

The approach to sampling data utilized by the EPA for assessing full-shift data from OSHA CEHD implemented a cutoff threshold of 5.5 hours of sampling time. Table_Apx E-2 shows the calculated sample concentrations from the OSHA data for sampling times above the 5.5-hour cutoff. The central tendency and high-end result are shown for the approach with no 8-hour adjustment, and the approach EPA utilized with an 8-hour adjustment.

Table_Apx E-2. Analysis of OSHA CEHD Formaldehyde Data from 1992 to 2020 (Total Samples Times >330 Minutes) [a]

Occupational Exposure Scenario (OES)	Number of Samples	Sample Concentrations (ppm)			
		Central Tendency	High-End	Central Tendency (8-Hour TWA)	High-End (8-Hour TWA)
Manufacturing of formaldehyde	6	0.100	1.403	0.079	1.394
Processing as a reactant	51	0.236	1.583	0.213	1.483
Use of formulations containing formaldehyde for spray applications (*e.g.*, spray or roll)	273	0.081	0.580	0.075	0.549
Rubber product manufacturing	37	0.010	0.087	0.009	0.080
Composite wood product manufacturing	165	0.100	0.808	0.091	0.682
Other composite material manufacturing (*e.g.*, roofing, etc.)	74	0.108	0.385	0.092	0.358
Plastic product manufacturing	167	0.082	0.377	0.071	0.344
Paper manufacturing	67	0.053	0.429	0.043	0.394
Processing of formaldehyde into formulations, mixtures, or reaction products	59	0.073	0.876	0.068	0.765
Processing aid	43	0.039	0.224	0.036	0.213
Use of formaldehyde for oilfield well production	5	0.008	0.250	0.008	0.227
Storage and retail of articles	58	0.164	0.710	0.16	0.634
Furniture manufacturing	152	0.099	0.827	0.096	0.744
Repackaging	9	0.094	0.173	0.090	0.158
Foundries	464	0.094	0.492	0.086	0.453
Use of electronic and metal products	29	0.067	0.510	0.055	0.510
Textile finishing	121	0.076	0.467	0.066	0.411
Installation and demolition of formaldehyde-based furnishings and building/construction materials in	28	0.103	0.365	0.095	0.352

Occupational Exposure Scenario (OES)	Number of Samples	Sample Concentrations (ppm)			
		Central Tendency	High-End	Central Tendency (8-Hour TWA)	High-End (8-Hour TWA)
residential, public, and commercial buildings, and other structures					
Use of automotive lubricants	11	0.027	0.176	0.024	0.159
Industrial use of lubricants	0	–	–	–	–
Use of explosive materials	9	0.040	0.074	0.038	0.074
Use of formulations containing formaldehyde in automotive care products	0	–	–	–	–
Use of formulations containing formaldehyde in fuels	3	0.279	0.381	0.262	0.352
Leather tanning	0	–	–	–	–
Use of printing ink, toner, and colorant products containing formaldehyde	6	0.069	0.104	0.064	0.097
Photo processing using formulations containing formaldehyde	6	0.040	0.048	0.033	0.040
Worker handling of wastes	4	0.025	0.049	0.024	0.049
General laboratory use	138	0.100	0.644	0.086	0.622
Use of packaging, paper, and hobby products	2	0.020	0.027	0.015	0.020

[a] EPA applied the cut-off of 330 minutes for this supplemental analysis. Note that during the analysis, EPA considered samples below the cut-off that were marked as "eight-hour calculation used" in OSHA CEHD database.

In general, EPA found that when central tendency and high-end TWAs were calculated only using sampling time data above the 5.5-hour threshold, the average percentage difference across all OESs between the two different methodologies for TWA calculation was a 10 percent decrease in the central tendency and a 9 percent decrease in the high end. This is a substantially more marginal discrepancy between the two calculation methodologies when compared to the discrepancy utilizing all of the sampling data. This is consistent with EPA expectations for the impact of the assumption of no exposure during unsampled time, as the samples with durations greater than 5.5 hours will be more representative of full-shift exposure. The difference between the approaches is illustrated further by Table_Apx E-3 and Table_Apx E-4 below which show the central tendency and high-end TWA results for both TWA calculation approaches as well as both sampling duration methodologies for the processing of formaldehyde into formulations, mixtures, or reaction products and the paper manufacturing OESs. Generally, there are about 309 samples between the 5.5-hour cutoff and the half of a typical shift (*i.e.*, 4 hours). EPA believes the 5.5-hour threshold helps reduce the level of uncertainty in the exposure estimates.

Table_Apx E-3. Sampling Concentration Results for Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products

Total Sampled Duration	Central Tendency (ppm)	High-end (ppm)	8-Hour Adjustment
All	0.098	2.095	No
>330 minutes	0.073	0.876	No
All	0.018	0.593	Yes
>330 minutes	**0.068**	**0.765**	**Yes**

Note: EPA excluded 98 of 157 OSHA CEHD data samples mapped to ‘processing of formaldehyde into formulations, mixtures, or reaction products’ for integration into the full-shift exposure estimates as the totaled sample time was less than 330 minutes. To reduce the levels of uncertainty, the EPA only integrated 59 OSHA CEHD samples with other data to provide full-shift exposure estimates.

Table_Apx E-4. Sampling Concentration Results for Paper Manufacturing

Total Sampled Duration	Central Tendency (ppm)	High-End (ppm)	8-Hour Adjustment
All	0.064	0.446	No
>330 minutes	0.053	0.429	No
All	0.015	0.352	Yes
>330 minutes	**0.043**	**0.394**	**Yes**

Note: EPA excluded 63 of 130 OSHA CEHD data samples mapped to “processing of formaldehyde into formulations, mixtures, or reaction products” for integration into the full-shift exposure estimates as the totaled sample time was less than 330 minutes. To reduce the levels of uncertainty, the EPA only integrated 67 OSHA CEHD samples with other data to provide full-shift exposure estimates.

Three OESs had no OSHA sampling data with sampling durations greater than 5.5 hours: leather tanning, industrial use of lubricants and use of formulations containing formaldehyde in automotive care products. While this could potentially be reflective of the type of worker activities with exposure to formaldehyde, it could also be a result of the low number of OSHA samples for these scenarios in general as industrial use of lubricants and use formulations containing formaldehyde in automotive care products had just 2 and 3 total samples respectively. For two of the three scenarios, EPA did not utilize any OSHA data in the formaldehyde occupational exposure assessment.

Appendix F CONSIDERATION OF ENGINEERING CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT

OSHA and NIOSH recommend employers utilize the hierarchy of controls to address hazardous exposures in the workplace. The hierarchy of controls strategy outlines, in descending order of priority, the use of elimination, substitution, engineering controls, administrative controls, and lastly PPE. The hierarchy of controls prioritizes the most effective measures first, which is to eliminate or substitute the harmful chemical (*e.g.*, use a different process, substitute with a less hazardous material), thereby preventing or reducing exposure potential. Following elimination and substitution, the hierarchy recommends engineering controls to isolate employees from the hazard (*e.g.*, source enclosure, local exhaust ventilation systems), followed by administrative controls (*e.g.*, a rule/policy that directs employees to not open machine doors when running), or changes in work practices (*e.g.*, maintenance plan to check equipment to ensure no leaks) to reduce exposure potential. Administrative controls are policies and procedures instituted and overseen by the employer to limit worker exposures. Under CFR 1910.1000, OSHA requires the use of engineering or administrative controls to bring exposures to the levels permitted under the air contaminants standard. PPE such as respirators do not replace engineering controls and they are implemented in addition to feasible engineering controls (29 CFR 910.134(a)(1). The PPE (*e.g.*, respirators, gloves) could be used as the last means of control, when the other control measures cannot reduce workplace exposure to the air contaminants standard.

Formaldehyde has an OSHA Standard 29 CFR 1910.1048. The PEL is 0.75 parts per million (ppm) over an 8-hour workday, TWA and a STEL of 2 ppm. The OSHA standard also includes but is not limited to requirements for exposure monitoring, dermal protection, recordkeeping, PPE if other exposure controls are not feasible, and hazard communication. OSHA has an action level of 0.5 ppm for formaldehyde and if exposures occur at or above the action level, at which an organization must have a program, provide medical surveillance, periodically monitor, and other aspect of 1910.1048).

The remainder of this section discusses respiratory protection and glove protection, including protection factors for various respirators and dermal protection strategies. EPA's estimates of occupational exposure presented in this document do not assume the use of engineering controls or PPE; however, the effect of respiratory and dermal protection factors on EPA's occupational exposure estimates can be explored in *Draft Risk Evaluation for Formaldehyde – Supplemental Information File: Risk Calculator for Occupational Exposures.*

F.1 Respiratory Protection

OSHA's Respiratory Protection Standard (29 CFR 1910.134) requires employers in certain industries to address workplace hazards by implementing engineering control measures and, if these are not feasible, provide respirators that are applicable and suitable for the purpose intended. Engineering and administrative controls must be implemented whenever employees are exposed above the PEL. If engineering and administrative controls do not reduce exposures to below the PEL, respirators must be worn. Respirator selection provisions are provided in CFR 1910.134(d) and require that appropriate respirators are selected based on the respiratory hazard(s) to which the worker will be exposed and workplace and user factors that affect respirator performance and reliability. Assigned protection factors (APFs) are provided in Table 1 under CFR 1910.134(d)(3)(i)(A) (see below in Table 2-1) and refer to the level of respiratory protection that a respirator or class of respirators could provide to employees when the employer implements a continuing, effective respiratory protection program. Implementation of a full respiratory protection program requires employers to provide training, appropriate selection, fit

testing, cleaning, and change-out schedules in order to have confidence in the efficacy of the respiratory protection.
If respirators are necessary in atmospheres that are not immediately dangerous to life or health, workers must use NIOSH-certified air-purifying respirators or NIOSH-approved supplied-air respirators with the appropriate APF. Respirators that meet these criteria may include air-purifying respirators with organic vapor cartridges. Respirators must meet or exceed the required level of protection listed in Table_Apx F-1. Based on the APF, inhalation exposures may be reduced by a factor of 5 to 10,000 if respirators are properly worn and fitted.

For atmospheres that are immediately dangerous to life and health, workers must use a full facepiece pressure demand self-contained breathing apparatus (SCBA) certified by NIOSH for a minimum service life of 30 minutes or a combination full facepiece pressure demand supplied-air respirator (SAR) with auxiliary self-contained air supply. Respirators that are provided only for escape from an atmosphere that is immediately dangerous to life and health must be NIOSH-certified for escape from the atmosphere in which they will be used.

Table_Apx F-1. Assigned Protection Factors for Respirators in OSHA Standard 29 CFR 1910.134

Type of Respirator	Quarter Mask	Half Mask	Full Facepiece	Helmet/ Hood	Loose-Fitting Facepiece
1. Air-Purifying Respirator	5	10	50		
2. Power Air-Purifying Respirator (PAPR)		50	1,000	25/1,000	25
3. Supplied-Air Respirator (SAR) or Airline Respirator					
• Demand mode		10	50		
• Continuous flow mode		50	1,000	25/1,000	25
• Pressure-demand or other positive-pressure mode		50	1,000		
4. Self-Contained Breathing Apparatus (SCBA)					
• Demand mode		10	50	50	
• Pressure-demand or other positive-pressure mode (*e.g.*, open/closed circuit)			10,000	10,000	
Source: 29 CFR 1910.134(d)(3)(i)(A).					

NIOSH and the U.S. Department of Labor's Bureau of Labor Statistics (BLS) conducted a voluntary survey of U.S. employers regarding the use of respiratory protective devices between August 2001 and January 2002. The survey was sent to a sample of 40,002 establishments designed to represent all private sector establishments. The survey had a 75.5 percent response rate (NIOSH, 2003b). A voluntary survey may not be representative of all private industry respirator use patterns as some establishments with low or no respirator use may choose to not respond to the survey. Therefore, results of the survey may potentially be biased towards higher respirator use.

NIOSH and BLS estimated about 619,400 U.S. establishments used respirators for voluntary or required purposes (including emergency and non-emergency uses). About 281,800 establishments (45 percent) were estimated to have had respirator use for required purposes in the 12 months prior to the survey. The 281,800 U.S. establishments were estimated to represent approximately 4.5 percent of all private industry establishments in the United States at the time (NIOSH, 2003b).

The survey found that the establishments that required respirator use had the following respirator program characteristics (NIOSH, 2003b):

- 59 percent provided training to workers on respirator use;
- 34 percent had a written respiratory protection program;
- 47 percent performed an assessment of the employees' medical fitness to wear respirators; and
- 24 percent included air sampling to determine respirator selection.

Note that the survey report does not provide a result for respirator fit testing or identify if fit testing was included in one of the other program characteristics.

Of the establishments that had respirator use for a required purpose within the 12 months prior to the survey, NIOSH and BLS found (NIOSH, 2003b) that

- non-powered air purifying respirators were most common, 94 percent overall and varying from 89 to 100 percent across industry sectors;
- powered air-purifying respirators represented a minority of respirator use, 15 percent overall and varying from 7 to 22 percent across industry sectors; and
- supplied air respirators represented a minority of respirator use, 17 percent overall and varying from 4 to 37 percent across industry sectors.

Of the establishments that used non-powered air-purifying respirators for a required purpose within the 12 months prior to the survey, NIOSH and BLS found (NIOSH, 2003b) that a

- large majority used dust masks, 76 percent overall and varying from 56 to 88 percent across industry sectors;
- varying fraction use half-mask respirators, 52 percent overall and varying from 26 to 66 percent across industry sectors; and
- varying fraction use full-facepiece respirators, 23 percent overall and varying from 4 to 33 percent across industry sectors.

Table_Apx F-2 summarizes the number and percent of all private industry establishments and employees that used respirators for a required purpose within the 12 months prior to the survey and includes a breakdown by industry sector (NIOSH, 2003b):

Table_Apx F-2. Number and Percent of Establishments and Employees Using Respirators within 12 Months Prior to Survey

Industry	Establishments		Employees	
	Number	Percent of All Establishments	Number	Percent of All Employees
Total Private Industry	281,776	4.5	3,303,414	3.1
Agriculture, Forestry, and Fishing	13,186	9.4	101,778	5.8
Mining	3,493	11.7	53,984	9.9
Construction	64,172	9.6	590,987	8.9
Manufacturing	48,556	12.8	882,475	4.8
Transportation and Public Utilities	10,351	3.7	189,867	2.8
Wholesale Trade	31,238	5.2	182,922	2.6
Retail Trade	16,948	1.3	118,200	0.5
Finance, Insurance, and Real Estate	4,202	0.7	22,911	0.3
Services	89,629	4.0	1,160,289	3.2

F.2 Glove Protection

OSHA's hand protection standard (29 CFR 1910.138) requires employers select and require employees to use appropriate hand protection when expected to be exposed to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations; severe abrasions; punctures; chemical burns; thermal burns; and harmful temperature extremes. Dermal protection selection provisions are provided in CFR 1910.138(b) and require that appropriate hand protection is selected based on the performance characteristics of the hand protection relative to the task(s) to be performed, conditions present, duration of use, and the hazards to which employees will be exposed.

Unlike respiratory protection, OSHA standards do not provide protection factors (PFs) associated with various hand protection PPE, such as gloves, and data about the frequency of effective glove use—that is, the proper use of effective gloves—is very limited in industrial settings. Initial literature review suggests that there is unlikely to be sufficient data to justify a specific probability distribution for effective glove use for a chemical or industry. Instead, the impact of effective glove use is explored by considering different percentages of effectiveness.

Gloves only offer barrier protection until the chemical breaks through the glove material. Using a conceptual model, Cherrie (Cherrie et al., 2004) proposed a glove workplace protection factor—the ratio of estimated uptake through the hands without gloves to the estimated uptake though the hands while wearing gloves: this protection factor is driven by flux, and thus varies with time. The European Centre for Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment (ECETOC TRA) model represents the protection factor of gloves as a fixed, assigned protection factor equal to 5, 10, or 20 (Marquart et al., 2017) where, similar to the APF for respiratory protection, the inverse of the protection factor is the fraction of the chemical that penetrates the glove. It should be noted that the described PFs are not based on experimental values or field investigations of PPE effectiveness, but rather professional judgements used in the development of the ECETOC TRA Model. EPA did not identify reasonably available information on PPE usage to corroborate the PFs used in this model.

As indicated in Table_Apx F-3, use of protection factors above 1 is recommended only for glove materials that have been tested for permeation against the formaldehyde-containing liquids associated with the COU. EPA has not found information that would indicate specific activity training (*e.g.*, procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur in a majority of sites in industrial only OESs, so the PF of 20 would usually not be expected to be achieved.

Table_Apx F-3. Glove Protection Factors for Different Dermal Protection Strategies from ECETOC TRA V3

Dermal Protection Characteristics	Affected User Group	Indicated Efficiency (%)	Protection Factor, PF
a. Any glove/gauntlet without permeation data and without employee training	Both industrial and professional users	0	1
b. Gloves with available permeation data indicating that the material of construction offers good protection for the substance		80	5
c. Chemically resistant gloves (*i.e.*, as b above) with "basic" employee training		90	10
d. Chemically resistant gloves in combination with specific activity training (*e.g.*, procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur	Industrial users only	95	20

Appendix G FACILITY ESTIMATES AND NUMBER OF WORKERS

This appendix presents the number of facilities and worker estimates for each OES. In general, sites were identified from 2016 and 2020 CDR, 2016 to 2021 TRI, 2015 to 2022 DMR, and 2017 NEI. If reporting data was not available for a given OES, the number of facilities was determined using U.S. economic and market data. For further information on the approach and methodology for estimating the number of facilities, see Section 2.2. Number of workers and ONUs were estimated using Bureau of Labor Statistics (BLS) and the U.S. Census' Statistics of US Businesses (SUSB) data specific to the OES (U.S. BLS, 2016; U.S. Census Bureau, 2015).

G.1 Manufacturing of Formaldehyde

In the 2016 CDR, 31 reporters domestically manufactured formaldehyde, one reporter both domestically manufactured and imported formaldehyde, and the manufacture/import activity for six reporters was claimed as CBI or withheld (U.S. EPA, 2016). In the 2020 CDR, 37 facilities domestically manufactured formaldehyde, one facility both domestically manufactured and imported formaldehyde, and the manufacture/import activity for two facilities was claimed as CBI or withheld (U.S. EPA, 2020a). Out of the 37 manufacturing facilities, 21 of the facilities also reported to the 2016 CDR.

The 2019 Nationally Aggregated PV reported in 2020 CDR was 1,000,000,000 to less than 5,000,000,000 lb. Two facilities claimed activities as CBI or withheld (U.S. EPA, 2020a). EPA did not identify data on facility operating schedules; therefore, EPA assumes 350 days/yr of operation.

To determine the number of workers, EPA used a combination of CDR and BLS data. In the 2016 and 2020 CDR, data on the number of workers was available for 39 manufacturing sites. There were six additional manufacturing sites in CDR where data on the number of workers was unavailable. EPA used the average of the ranges reported in the 2016 and 2020 CDR for 39 sites where data was available, and the ratio of workers to ONUs from the BLS analysis for the other 6 sites. For the BLS analysis, EPA used the most commonly reported NAICS code among the manufacturers, which is 325199 – All Other Basic Organic Chemical Manufacturing. As described in Appendix H, EPA reviewed the occupation descriptions under this NAICS code and determined that approximately 68 percent of the exposed personnel are workers and 32 percent are ONUs. CDR data does not differentiate between workers and ONUs; therefore, EPA assumed the ratio of workers to ONUs would be similar as determined from the BLS occupation descriptions (U.S. BLS, 2023). This resulted in approximately 41 workers per site and 19 ONUs per site. Based on 45 manufacturing sites reported in either 2016 or 2020 CDR, the total number of workers expected for this OES is 1,827 and the number of ONUs is 860. Totals have been rounded to two significant figures and may not add exactly due to rounding (see Table_Apx G-1).

Table_Apx G-1. Number of Workers for Manufacturing

	Number of Sites	Average Number of Employees per Site	Average Number of Workers per Site	Total Number of Workers	Average Number of ONUs per Site	Total Number of ONUs
Site with a known number of workers from CDR	39	60	41	1,595	19	751
Sites with an unknown number of workers from CDR	6	–	39	232	18	109
Total	45	–	–	1,827	–	860

G.2 Import and/or Repackaging of Formaldehyde

In the 2016 CDR, five reporters imported formaldehyde, and the manufacture/import activity for six reporters was claimed as CBI (U.S. EPA, 2016). In the 2020 CDR, four facilities imported formaldehyde and two facilities claimed formaldehyde activities as CBI or withheld (U.S. EPA, 2020a).

In the 2020 CDR, two manufacturers reported 80 percent of their PV to liquid formaldehyde repackaging for use as a laboratory chemical in medical diagnostics with a reported PV of 391,614 lb (U.S. EPA, 2020a). Both reported less than 10 industrial sites (U.S. EPA, 2020a). EPA assumes a shift length of 8 hours per day for repackaging facilities, as well as 260 annual operating days. The Agency estimates an annual throughput for repackaging ranges from 1 to 315,479 kg/site-year (U.S. EPA, 2022a). The 50th and 95th percentiles are 7,000 and 42,000 kg/site-year, respectively (U.S. EPA, 2022a).

Using TRI release data, EPA identified 49 facilities that reported repackaging of formaldehyde under use information. Within other release databases, EPA identified 188 facilities that may be repackaging formaldehyde based on their industrial sectors. These sites operated under NAICS code 493190 Other Warehousing and Storage, 424690 Other Chemical and Allied Product Merchant Wholesaler, 493110 General Warehousing and Storage, 4931 Warehousing and Storage, and 42469 Other Chemical and Allied Products Merchant Wholesaler.

EPA used data from the BLS and the SUSB specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during repackaging (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Appendix H 286includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA used NAICS codes in Sectors 325 – Chemical Manufacturing, 327 – Nonmetallic Mineral Product Manufacturing, 424 – Merchant Wholesalers, Nondurable Goods, 493 – Warehousing and Storage, and 562 – Waste Management and Remediation Services based on facilities identified as discussed earlier. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-2. The estimated number of workers per site for import/repackaging is five. Based on an estimated number of sites of 237 for this OES, the total number of workers expected for this OES is 1,153. The estimated number of ONUs per site for this OES is 2, with a total number of ONUs of 445.

Table_Apx G-2. Number of Workers for Import and/or Repackaging of Formaldehyde

NAICS Code	Total Number of Sites	Number of Workers/ Site	Total Number of Workers	Number of ONUs/ Site	Total Number of ONUs
493190	48	1	68	0.3	13
424690	44	1	56	0.4	20
493110	55	4	202	1	37
4931	8	3	25	1	5
42469	3	1	4	0.4	1
424690	45	1	57	0.4	20
325413	1	43	43	26	26
325193	27	22	581	10	273
325199	2	39	77	18	36
327310	1	22	22	3	3
562211	2	9	18	5	10
424710	1	1	1	0.2	0.2
Total			1,153		445

G.3 Processing as a Reactant

Between 2016 and 2021, 240 facilities reported processing of formaldehyde as a reactant to TRI. As not all sites may be required to submit to TRI, EPA also considered NEI, DMR, and TRI form A submissions for specific NAICS codes related to 325 – Chemical Manufacturing. EPA estimates that potentially 2,513 sites may process formaldehyde as a reactant.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during processing as a reactant (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned NAICS codes in Sectors 31 to 33 (Manufacturing) for this OES based on mapping from TRI reporting data. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-3. The estimated number of workers per site for processing as a reactant is 25. Based on an estimated number of sites of 2,513 for this OES, the total number of workers expected for this OES is 62,881. The estimated number of ONUs per site for this OES is 11, with a total number of ONUs of 27,714.

7275 **Table_Apx G-3. Number of Workers for Processing as a Reactant**

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
325998	165	14	2,323	5	767
326130	12	15	184	4	52
325199	191	39	7,374	18	3,472
314994	9	6	56	18	160
325211	241	27	6,621	12	2,909
325110	109	64	6,945	30	3,270
325520	39	18	704	7	264
325613	31	22	675	5	155
325411	30	24	730	15	448
332813	134	8	1,061	2	241
325311	40	17	700	5	204
322299	14	19	272	2	35
325314	21	10	216	3	63
325180	112	25	2,819	12	1,327
321999	72	4	272	1	47
313110	11	16	181	10	115
321219	76	30	2,275	6	432
327993	38	28	1,083	6	216
313310	55	7	376	3	185
322220	84	35	2,959	5	380
311119	136	8	1,081	1	114
336413	33	41	1,357	35	1,144
334413	87	50	4,386	45	3,943
331492	24	14	340	4	107
325130	35	26	900	12	424
325320	29	25	739	7	215
334417	4	41	165	37	148
334412	24	21	506	19	455
326150	24	15	351	4	99
325611	28	19	521	4	119
325194	29	34	992	16	467
325991	25	20	505	7	167
325412	124	44	5,442	27	3,340
327910	19	24	460	5	92

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
331523	29	19	556	8	224
324122	46	23	1,036	10	459
321212	38	58	2,213	11	420
339113	16	20	326	6	102
321113	197	6	1,118	1	244
327212	30	18	531	3	87
3251	7	29	200	13	94
325312	12	41	493	12	144
325212	19	25	469	11	206
32519	3	35	104	16	49
32532	3	25	76	7	22
32552	2	18	36	7	14
32513	5	26	129	12	61
32521	1	27	27	12	12
Total	2,513		62,881		27,714

G.4 Composite Wood Product Manufacturing

Between 2016 and 2021, five facilities reported incorporation into an article from within the wood product manufacturing industry to TRI. As not all sites may be required to submit to TRI, EPA also considered NEI, DMR, and TRI form A submissions for specific NAICS codes related to 321 – Wood Product Manufacturing. EPA estimates that potentially 577 sites may process formaldehyde for this particular OES.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during processing as a reactant (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned NAICS codes in Sectors 31 to 33 (Manufacturing) for this OES based on mapping from TRI reporting data. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-4. The estimated number of workers per site for processing as a reactant is 25. Based on an estimated number of sites of 2,513 for this OES, the total number of workers expected for this OES is 62,881. The estimated number of ONUs per site for this OES is 11, with a total number of ONUs of 27,714.

Table_Apx G-4. Number of Workers for Composite Wood Product Manufacturing

NAICS Code	Total Number of Unique Sites	Number of Workers/ Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
321219	58	30	1736	6	330
321213	9	15	136	3	26
321999	71	4	269	1	47
321211	33	22	710	4	135
321113	196	6	1,112	1	242
321212	37	58	2,154	11	409
321911	30	15	461	3	80
321912	36	9	325	2	56
321920	19	7	124	1	22
321918	48	7	314	1	54
3219	3	8	23	1	4
321114	21	5	113	1	25
321214	1	13	13	2	2
32199	2	6	13	1	2
32121	1	20	20	4	4
32111	1	6	6	1	1
321991	6	27	162	5	28
32192	3	7	20	1	3
32191	2	10	20	2	3
Total	577	13	7,731	3	1,474

G.5 Other Composite Material Manufacturing (*e.g.*, Roofing)

EPA assigned NAICS codes in Subsectors 324 – Petroleum and Coal Products Manufacturing, 327 – Nonmetallic Mineral Product Manufacturing, and 332 – Fabricated Metal Product Manufacturing for this OES based on mapping from TRI and NEI reporting data. The estimated number of unique sites for this OES is 608.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during other composite material manufacturing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned NAICS codes in Subsectors 324 – Petroleum and Coal Products Manufacturing, 327 - Nonmetallic Mineral Product Manufacturing, and 332 - Fabricated Metal Product Manufacturing for this OES based on mapping from TRI reporting data. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-5. The estimated number of workers per site for other composite material manufacturing is 21. Based on an estimated number of sites of 608 for this OES, the total number of workers expected for this OES is 12,678. The estimated number of ONUs per site for this OES is 4, with a total number of ONUs of 82.

7313 **Table_Apx G-5. Number of Workers for Other Composite Material Manufacturing**

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
332618	11	9	97	2	25
324122	46	23	1,036	10	459
327215	17	22	376	4	62
327993	32	28	912	6	182
327910	20	24	484	5	96
327993	32	28	912	6	182
327910	20	24	484	5	96
327310	65	22	1,417	3	218
327215	17	22	376	4	62
32741	3	23	68	5	14
327120	45	24	1,068	4	182
32791	3	24	73	5	14
327993	32	28	912	6	182
327320	152	5	817	1	126
32731	10	22	218	3	34
327992	28	17	478	3	95
327999	26	13	342	3	68
327213	29	87	2,528	14	414
32712	2	24	47	4	8
32732	10	5	54	1	8
327410	15	23	341	5	68
327390	38	11	413	2	64
327331	15	8	125	1	19
32742	13	19	252	4	50
327212	29	18	513	3	84
327211	18	50	900	8	147
327991	8	8	67	2	13
327332	5	11	55	2	9
327420	30	19	582	4	115
327110	13	13	172	2	29
32739	2	11	22	2	3
3274	1	20	20	4	4
32733	1	9	9	1	1
32799	1	12	12	2	2
Total	608	21	12678	4	82

G.6 Textile Finishing

EPA did not identify facilities reporting use of formaldehyde for textile finishing in the 2020 CDR. However, three reporters to the 2016 CDR reported use of formaldehyde in the textiles, apparel, and leather industry (U.S. EPA, 2016).

Using TRI, NEI, and DMR release data, EPA identified 195 facilities that use formaldehyde for textile finishing.

Due to CBI claims in the 2016 CDR, the PV is unknown. According to literature, the total number of garments produced every week may range from 7,000 to 15,000 garments (Echt, 1993; NIOSH, 1983b). Per the OECD ESD on the Use of Textile Dyes, EPA assumes textile finishing facilities may operate between 31 to 295 days per year (OECD, 2017).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during textile finishing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned NAICS codes in Subsectors 313 – Textile Mills, 314 – Textile Product Mills, 315 – Apparel Manufacturing, and 316 - Leather and Allied Product Manufacturing for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-6. The estimated number of workers per site for textile finishing is 11. Based on an estimated number of sites of 195 for this OES, the total number of workers expected for this OES is 2,118. The estimated number of ONUs per site for this OES is 11, with a total number of ONUs of 2,065.

Table_Apx G-6. Number of Workers for Textile Finishing

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
313320	17	9	151	4	74
313230	8	19	151	14	114
314999	5	2	9	5	27
313220	3	7	22	6	17
313310	54	7	369	3	182
315110	6	20	118	14	82
31332	6	9	53	4	26
314910	1	2	2	6	6
313110	8	16	131	10	84
315240	5	3	15	14	70
31321	16	14	219	10	165
315280	2	3	5	12	24
315190	1	6	6	4	4
314120	1	3	3	4	4
315990	2	2	4	9	18

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
316210	5	11	57	23	117
315220	2	4	7	17	33
313210	7	14	96	10	72
31411	5	20	98	33	163
31323	9	19	170	14	128
314110	15	20	295	33	488
3133	2	7	14	4	7
314994	5	6	31	18	89
315210	1	1	1	6	6
3132	4	13	51	10	39
31331	3	7	21	3	10
3131	1	16	16	10	10
31499	1	2	2	6	6
Total	195	11	2,118	11	2,065

G.7 Leather Tanning

EPA identified limited information on the number of facilities that may use formaldehyde in leather tanning. In NEI, EPA identified six sites with NAICS code 31611 – Leather and Hide Tanning and Finishing.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during leather tanning (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code 316110 – Leather and Hide Tanning and Finishing for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-7. The estimated number of workers per site for leather tanning is 6. Based on an estimated number of sites of 6 for this OES, the total number of workers expected for this OES is 36. The estimated number of ONUs per site for this OES is 6, with a total number of ONUs of 33.

Table_Apx G-7. Number of Workers for Leather Tanning

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
31611	1	6	6	6	6
316110	5	6	30	6	28
Total	6		36		33

G.8 Rubber Product Manufacturing

EPA did not identify any TRI sub-use information to indicate sites that may incorporate formaldehyde into an article within industries expected to produce rubber products. EPA considered the relevant NAICS codes where formaldehyde may be potentially used in rubber product manufacturing. From the 2017 NEI, there are 122 sites under the 4-digit NAICS code 3262 – Rubber Product Manufacturing.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during rubber product manufacturing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsector 326 – Plastics and Rubber Products Manufacturing for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-8. The estimated number of workers per site for rubber product manufacturing is 101. Based on an estimated number of sites of 122 for this OES, the total number of workers expected for this OES is 12,351. The estimated number of ONUs per site for this OES is 16, with a total number of ONUs of 1,984.

Table_Apx G-8. Number of Workers for Rubber Product Manufacturing

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
326299	48	27	1,317	4	212
326291	12	43	511	7	82
326211	44	225	9,888	36	1,589
32622	2	43	85	7	14
326212	4	10	39	2	6
326220	12	43	511	7	82
Total	122		12,351		1,984

G.9 Paper Manufacturing

EPA identified three sites with TRI sub-use information to indicate sites that may incorporate formaldehyde into an article within industries expected to produce paper products. In addition, EPA considered the relevant NAICS codes where formaldehyde may be potentially used in paper product manufacturing. From the 2017 NEI, there are 462 sites under the 3-digit NAICS code 322 – Paper Product Manufacturing.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during paper manufacturing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code Subsector 322 – Paper Manufacturing for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-9. The estimated number of workers per site for paper manufacturing is 81. Based on an estimated number of sites of 465 for this OES, the total number of workers expected for this OES is 37,593. The estimated number of ONUs per site for this OES is 12, with a total number of ONUs of 5,511.

Table_Apx G-9. Number of Workers for Paper Manufacturing

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
322220	84	35	2,959	5	380
322130	55	120	6,626	18	1,013
322110	19	100	1,909	15	292
322121	106	154	16,283	23	2,489
322122	6	91	548	14	84
32211	5	100	502	15	77
32213	11	120	1,325	18	203
32212	3	150	450	23	69
3221	3	133	400	20	61
322291	15	69	1,041	9	134
322211	117	36	4,154	5	533
322299	12	19	234	2	30
322212	15	46	692	6	89
322230	3	24	72	3	9
32222	6	35	211	5	27
322219	5	37	183	5	24
Total	465		37,593		5,511

G.10 Plastic Product Manufacturing

EPA identified five sites with TRI sub-use information to indicate sites that may incorporate formaldehyde into an article within industries expected to produce plastic products. EPA considered the relevant NAICS codes where formaldehyde may be potentially used in plastic product manufacturing. From the 2017 NEI, there are 469 sites under specific NAICS code within the Subsectors 325 – Chemical Manufacturing, 326 – Plastics and Rubber Products Manufacturing, and 339 – Miscellaneous Manufacturing.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during plastic product manufacturing (U.S. BLS, 2016; U.S.

Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code Subsectors 325 - Chemical Manufacturing, 326 – Plastics and Rubber Products Manufacturing, and 339 – Miscellaneous Manufacturing for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-10. The estimated number of workers per site for plastic product manufacturing is 17. Based on an estimated number of sites of 474 for this OES, the total number of workers expected for this OES is 7,917. The estimated number of ONUs per site for this OES is 5, with a total number of ONUs of 2,202.

Table_Apx G-10. Number of Workers for Plastic Product Manufacturing

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
339999	36	5	189	1	43
326121	21	15	325	4	92
326199	100	18	1,811	5	513
32612	4	15	61	4	17
339994	1	20	20	5	5
339920	13	9	115	2	26
326140	50	18	907	5	257
32613	4	15	61	4	17
339991	15	21	316	5	72
326150	22	15	322	4	91
32615	17	15	249	4	70
326111	10	27	272	8	77
326113	49	22	1,080	6	306
3261	8	18	147	5	42
3399	18	7	121	2	28
326191	8	14	110	4	31
326130	12	15	184	4	52
339930	2	5	9	1	2
326112	27	25	687	7	194
339940	4	9	37	2	8
32614	17	18	309	5	87
32619	17	18	304	5	86
339993	5	13	63	3	14
326122	5	15	74	4	21
3391	3	11	34	4	11
326160	2	21	43	6	12
33994	1	9	9	2	2

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
33993	1	5	5	1	1
325211	2	27	55	12	24
Total	474		7,917		,2,202

G.11 Processing of Formaldehyde into Formulations, Mixtures, or Reaction Products

Between 2016 and 2021, 189 facilities reported processing of formaldehyde into a formulation to TRI. As not all sites may be required to submit to TRI, EPA also considered NEI, DMR, and TRI form A submissions for specific NAICS codes related to NAICS codes in Sectors 31 to 33 (Manufacturing) and 424 – Merchant Wholesalers, Nondurable Goods. EPA estimates that potentially 1,587 sites may process formaldehyde into a formulation, mixture, or reaction products.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during processing into formulations, mixtures, or reaction products (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned NAICS codes in Sectors 31 to 33 (Manufacturing) and 424 – Merchant Wholesalers, Nondurable Goods for this OES based on the mapping of OSHA data described in C.2. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-11. The estimated number of workers per site for processing into formulations, mixtures or reaction products is 5. Based on an estimated number of sites of 1,587 for this OES, the total number of workers expected for this OES is 7,543. The estimated number of ONUs per site for this OES is 2, with a total number of ONUs of 2,875.

Table_Apx G-11. Number of Workers for Processing of Formaldehyde into Formulations, Mixture, or Reaction Products

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
325180	111	25	2,794	12	1315
325510	83	14	1,186	5	444
324121	746	6	4,142	2	1835
325412	122	44	5,354	27	3286
325910	11	13	143	4	47
327910	21	24	508	5	101
325411	28	24	681	15	418
325314	20	10	206	3	60
324191	23	20	465	9	206
324199	34	17	591	8	262
32518	5	25	126	12	59
32551	10	14	143	5	54

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
324122	47	23	1,059	10	469
325611	31	19	577	4	132
32591	1	13	13	4	4
325991	25	20	505	7	167
325414	28	54	1,524	33	936
325612	10	17	166	4	38
325920	5	32	158	10	52
325992	10	19	191	6	63
325613	26	22	566	5	130
325620	13	28	360	6	83
32412	4	8	31	3	14
32562	4	28	111	6	25
3254	1	41	41	25	25
325413	6	43	256	26	157
32592	1	32	32	10	10
326130	4	15	61	4	17
424690	4	1	5	0.4	2
325211	22	27	604	12	266
325199	21	39	811	18	382
325998	23	14	324	5	107
322220	7	35	247	5	32
325311	10	17	175	5	51
313320	1	9	9	4	4
337110	1	3	3	2	2
322299	2	19	39	2	5
311613	3	9	26	2	5
311119	6	8	48	1	5
313110	1	16	16	10	10
332813	2	8	16	2	4
321219	13	30	389	6	74
333922	1	12	12	6	6
336350	1	67	67	20	20
313230	3	19	57	14	43
322121	3	154	461	23	70
321999	2	4	8	1	1

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
327993	5	28	142	6	28
332321	1	18	18	5	5
336360	1	74	74	22	22
314994	1	6	6	18	18
325320	5	25	127	7	37
325130	1	26	26	12	12
334412	1	21	21	19	19
327120	1	24	24	4	4
325520	1	18	18	7	7
321911	1	15	15	3	3
326150	2	15	29	4	8
325194	3	34	103	16	48
327215	1	22	22	4	4
311710	1	10	10	2	2
339999	1	5	5	1	1
327212	3	18	53	3	9
339113	1	20	20	6	6
321213	1	15	15	3	3
Total	1,587		7,543		2,875

G.12 Recycling

As previously mentioned, the recycling of formaldehyde or formaldehyde products was not reported in the 2020 or 2016 CDR. Using TRI, NEI, and DMR release data, EPA identified 20 facilities that recycle formaldehyde or formaldehyde products.

EPA did not identify data related to formaldehyde PV or facility throughputs. EPA assumes recycling facilities operate 5 days/week, 50 weeks/year, or 250 days/year.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during recycling (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code 423930 – Recyclable Material Merchant Wholesalers for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-12. The estimated number of workers per site for recycling is 1. Based on an estimated number of sites of 20 for this OES, the total number of workers expected for this OES is 25. The estimated number of ONUs per site for this OES is 0.2, with a total number of ONUs of 3.

Table_Apx G-12. Number of Workers for Recycling

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
423930	15	1	18	0.2	3
42393	5	1	6	0.2	1
Total	20		25		3

G.13 Storage and Retail Stores

This COU was not reported in the 2020 or 2016 CDR. Using TRI, NEI, and DMR release data, EPA identified 502 facilities that distribute formaldehyde or formaldehyde products.

EPA did not identify data on facility operating schedules, annual throughputs, or daily throughputs but assumes that the number of days spent in transit and volumes distributed can vary depending on the needs of the downstream site receiving formaldehyde. Transit may occur daily or occasionally depending on downstream user needs. EPA assumes distribution in commerce may occur 365 days/yr.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during distribution in commerce (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 423 – Merchant Wholesalers, Durable Goods, 424 – Merchant Wholesalers, Nondurable Goods, 425 - Wholesale Trade Agents and Brokers, 444 – Building Material and Garden Equipment and Supplies, 448 – Clothing and Clothing Accessories Stores, 484 – Truck Transportation, and 532 – Rental and Leasing Services for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-13. The estimated number of workers per site for distribution in commerce is 1. Based on an estimated number of sites of 502 for this OES, the total number of workers expected for this OES is 590, and the total number of ONUs is 122.

Table_Apx G-13. Number of Workers in Storage and Retail Stores

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site[a]	Total Number of ONUs
42331	3	2	5	0.2	1
444190	4	0.3	1	0.04	0.1
423990	1	1	1	0.1	0.1
423310	6	2	9	0.2	1
424210	6	1	6	0.3	2
424930	4	1	3	0.1	1
423120	7	2	15	0.3	2
484220	4	0.4	2	0.03	0.1
42332	2	1	2	0.1	0.3
423320	9	1	8	0.1	1

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site[a]	Total Number of ONUs
423110	7	3	19	0.4	3
442110	4	0.1	1	0.1	0.2
423840	3	2	7	0.4	1
423810	8	4	29	0.7	6
424470	2	1	2	0.2	0.3
4481	1	0.01	0.01	0.1	0.1
423210	1	1	1	0.1	0.1
424910	11	1	6	0.1	1
423830	9	2	22	0.5	4
423510	6	1	6	0.4	2
424410	9	2	22	0.4	4
444110	33	4	116	0.4	14
423140	4	1	6	0.2	1
423610	20	1	19	0.4	8
423820	3	3	8	0.5	2
425120	7	1	7	0.4	3
423860	2	3	6	0.5	1
424610	1	1	1	0.4	0.4
42312	1	2	2	0.3	0.3
532210	2	0.4	1	0.1	0.1
423910	3	1	3	0.1	0.4
451110	4	1	3	0.1	0.4
444130	5	0.3	2	0.04	0.2
423620	6	1	8	0.5	3
423720	7	1	7	0.2	2
444210	8	1	6	0.04	0.3
443142	9	1	7	0.1	1
423450	10	2	24	0.6	6
4442	11	1	10	0.1	1
423490	12	2	21	0.4	5
423130	13	2	25	0.3	3
484210	14	1	9	0.1	1
423430	15	2	37	0.6	9
451120	16	1	18	0.2	2
448190	17	0.01	0.2	0.1	1

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site[a]	Total Number of ONUs
442299	18	1	15	0.1	1
424330	19	0.2	4	0.3	5
424990	20	0.3	7	0.1	1
424950	21	0.5	10	0.1	2
448120	22	0.01	0.2	0.1	2
448130	23	0.01	0.3	0.1	2
423420	24	2	45	0.5	11
448150	25	0.01	0.2	0.1	1
Total	502		590		1

[a] Number of workers and occupational non-users per site are calculated by dividing the exposed number of workers or occupational non-users by the number of establishments. The number of workers per site is rounded to the nearest integer. The number of occupational non-users per site is shown as 0.2, as it rounds down to zero.

G.14 Furniture Manufacturing

Formaldehyde use for furniture manufacturing was not reported in the 2020 or 2016 CDR. Using TRI, NEI, and DMR release data, EPA identified 338 facilities that use formaldehyde in furniture manufacturing.

Facilities typically use coatings for metal and wooden furniture at a rate of 20 to 1,786 L/day and 17.4 L/day, respectively (U.S. EPA, 2004b). The daily use rate of formaldehyde in furniture coatings is unknown. Typically, facilities operate for 250 days per year (U.S. EPA, 2004b).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during furniture manufacturing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 337 – Furniture and Related Product Manufacturing, 339 – Miscellaneous Manufacturing, and 811 – Repair and Maintenance for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-14. The estimated number of workers per site for furniture manufacturing is 6. Based on an estimated number of sites of 338 for this OES, the total number of workers expected for this OES is 2,180. The estimated number of ONUs per site for this OES is 4, with a total number of ONUs of 1,340.

Table_Apx G-14. Number of Workers for Furniture Manufacturing

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
337211	32	9	298	4	128
337110	76	3	257	2	189
339995	6	14	86	3	20
337122	78	3	250	2	184

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
337125	3	4	12	3	9
337215	19	8	155	4	67
337121	34	13	458	10	336
337920	1	15	15	7	7
33711	26	3	88	2	65
337127	27	9	242	7	178
33721	3	7	22	3	9
337124	3	8	24	6	17
337214	6	22	130	9	56
33712	5	7	35	5	25
337212	11	5	52	2	22
337910	2	24	48	10	21
811420	2	1	2	1	2
3371	1	5	5	4	4
811490	3	1	3	1	2
Total	338		2,180		1,340

G.15 Processing Aid

The use of formaldehyde as a processing aid was not reported to the 2020 or 2016 CDR. Based on the Emission Scenario Document (ESD) on Chemical Vapor Deposition in the Semiconductor Industry, it is estimated that semiconductor manufacturing sites use precursor chemicals at an annual rate of 50 to 1,000 kg/site-year (OECD, 2015a). The ESD on the Semiconductor Industry estimates that semiconductor facilities will operate 360 days/year (OECD, 2015a). EPA assumes facilities operate 300 days/yr based on the assumption of operations over 7 days/week over some portion of the year since the chemical may not be processed throughout the entire year.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during processing aid (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code sectors 31-33 (Manufacturing) and subsector 424 – Merchant Wholesalers, Nondurable Goods and 562 - Waste Management and Remediation Services for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-15. The estimated number of workers per site for processing aid is 27. Based on an estimated number of sites of 544 for this OES, the total number of workers expected for this OES is 14,699. The estimated number of ONUs per site for this OES is 19, with a total number of ONUs of 10,246.

7526 **Table_Apx G-15. Number of Workers for Processing Aid**

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
33431	2	10	21	7	14
334511	17	53	907	55	935
334413	87	50	4,386	45	3,943
334416	4	22	87	20	78
332813	139	8	1,100	2	250
33421	1	9	9	9	9
334419	30	20	591	18	532
339910	13	5	64	1	15
334519	6	10	59	10	60
334412	34	21	717	19	644
334417	4	41	165	37	148
334515	1	9	9	10	10
334512	4	9	37	10	38
334514	9	18	166	19	172
334513	12	11	128	11	132
334418	6	28	170	25	153
334220	23	17	397	18	415
334614	8	5	40	5	42
334112	10	42	424	62	616
334290	4	7	29	8	30
334310	3	10	31	7	21
334210	8	9	71	9	74
334111	15	15	232	23	338
334516	9	15	136	16	140
33422	3	17	52	18	54
334510	6	21	124	21	127
334517	2	22	44	23	45
334118	5	17	83	24	121
334613	1	3	3	3	3
33991	2	5	10	1	2
3344	3	30	89	27	80
325998	3	14	42	5	14
424690	1	1	1	0.4	0.4
322121	6	154	922	23	141
332812	3	7	22	2	5

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
337214	2	22	43	9	19
339113	2	20	41	6	13
337110	1	3	3	2	2
322299	2	19	39	2	5
311613	2	9	17	2	3
336350	1	67	67	20	20
313110	2	16	33	10	21
325110	1	64	64	30	30
326130	1	15	15	4	4
327993	2	28	57	6	11
313310	1	7	7	3	3
325311	3	17	52	5	15
324110	1	170	170	75	75
331492	1	14	14	4	4
325199	6	39	232	18	109
322130	1	120	120	18	18
336111	1	342	342	45	45
332431	9	31	283	11	98
322110	2	100	201	15	31
325412	2	44	88	27	54
321219	1	30	30	6	6
311221	2	39	78	9	18
325220	1	47	47	21	21
336112	1	863	863	114	114
321211	1	22	22	4	4
326211	1	225	225	36	36
331315	1	64	64	18	18
331511	1	22	22	9	9
321999	1	4	4	1	1
332439	1	12	12	4	4
331221	1	18	18	5	5
562211	1	9	9	5	5
325411	1	24	24	15	15
424910	1	1	1	0.1	0.1
326150	1	15	15	4	4
311119	1	8	8	1	1

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
Total	544		14,699		10,246

G.16 Use of Formaldehyde for Oilfield Well Production

In the 2020 CDR, five reporters reported the use of formaldehyde in the oil and gas drilling, extraction, and support activities industry (U.S. EPA, 2020a). One reporter indicated less than 10 industrial sites, another reporter indicated 25 to 99 industrial sites, and the other 3 reporters had an unknown number of industrial sites. In the 2016 CDR, one manufacturer reported use of formaldehyde as a processing aid in the oil and gas industry in a non-incorporative function (U.S. EPA, 2016). Using TRI, NEI, and DMR release data, EPA identified 2,875 facilities that potentially use formaldehyde for oilfield well production based on their NAICS code.

EPA does not possess information regarding the annual operating days for petroleum production. The ESD on Oil Well Production indicates that facilities typically operate 350 days/year (OECD, 2012). The Draft ESD on Hydraulic Fracturing indicates that facilities typically operate 350 days/year (U.S. EPA, 2022d).

The daily petroleum production is generally 5.14 million barrels per day, with a total number of wells as 504,000 in the United States (OECD, 2012). One reporter in the 2020 CDR reported a PV of 1,240,000 lb (U.S. EPA, 2020a). FracFocus 3.0 reports 3,022 sites utilize formaldehyde in hydraulic fracturing fluids across the United States (GWPC and IOGCC, 2022).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during oilfield well production (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 211 – Oil and Gas Extraction and 213 – Support Activities for Mining for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-16. The estimated number of workers per site for oilfield well production is 2. Based on an estimated number of sites of 2,875 for this OES, the total number of workers expected for this OES is 6,132. The estimated number of ONUs per site for this OES is 4, with a total number of ONUs of 12,408.

Table_Apx G-16. Use of Formaldehyde for Oilfield Well Production

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
2111	773	2	1,632	4	3,470
213112	90	3	273	2	197
211130	1,521	2	3,129	4	6,653
211120	418	2	860	4	1828
213111	23	4	102	3	74
21112	28	3	77	4	104
21113	22	3	60	4	82

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
Total	2,875		6,132		12,408

G.17 Use of Coatings, Paints, Adhesives, or Sealants (non-spray applications)

In the 2020 CDR, one reporter reported 30 percent of its PV to use formaldehyde for two-component glues and adhesives with a maximum concentration of 1 to 30 percent (U.S. EPA, 2020a). One reporter to the 2020 CDR reported a PV of 4,860,000 lb (U.S. EPA, 2020a). Using TRI, NEI, and DMR, EPA identifies 18 sites potentially using formaldehyde in coatings, paints, adhesives, or sealants in non-spray applications. As spray applications is expected to have higher exposures, EPA conservatively assesses many coating-related industries as potentially including spray operations. According to the ESD on the Use of Adhesives, facilities may operate 200 to 365 days/year with a general throughput of 1,500 to 9,100,000 kg/site-year, depending on the method of application and type of substrate (OECD, 2015b).

In the 2020 CDR, two reporters reported the use of formaldehyde in paints and coatings (U.S. EPA, 2020a). One reporter reported 20 percent of its PV was used for formaldehyde in lacquers, stains, varnishes, and floor finish with a maximum concentration of 1 to 30 percent (U.S. EPA, 2020a). The other reporter reported 3 percent of its PV was used for formaldehyde in solvent-based paint with a concentration ranging from 30 to 60 percent (U.S. EPA, 2020a).

Due to CBI in CDR, the exact volume of formaldehyde in paints and coatings is unknown; however, the PV of one reporter is 3,240,000 lb (U.S. EPA, 2020a). According to the ESD on Radiation Curable Coatings, Inks, and Adhesives, facilities typically operate 250 days/year with an annual coating use rate of 137,000 kg/site-year (OECD, 2011b).

In the 2020 CDR, one reporter reported 20 percent of its PV to the incorporation of formaldehyde into a formulation, mixture, or reactant product in the transportation equipment manufacturing industry (U.S. EPA, 2020a). Due to CBI claims in the CDR, the volume of formaldehyde used in the transportation equipment manufacturing industry is unknown. EPA assumes facilities operate 5 days/week, 50 weeks/year, or 250 days/year.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of coatings, paints, adhesives, or sealants (non-spray applications) (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsector 339 – Miscellaneous Manufacturing for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-17. The estimated number of workers per site for use of coatings, paints, adhesives, or sealants (non-spray applications) is nine. Based on an estimated number of sites of 18 for this OES, the total number of workers expected for this OES is 156. The estimated number of ONUs per site for this OES is 2, with a total number of ONUs of 42.

Table_Apx G-17. Number of Workers for Use of Coatings, Paints, Adhesives, or Sealants

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
339115	3	20	60	6	19
339950	9	5	49	1	11
339992	3	7	22	2	5
33995	1	5	5	1	1
339114	1	10	10	3	3
332196	1	10	10	3	3
Total	18		156		42

G.18 Industrial Use of Lubricants

Using TRI, NEI, and DMR, EPA identified 10 sites potentially using formaldehyde in lubricants. Due to a lack of information, EPA did not identify annual or daily site throughputs. EPA assumes facilities use lubricants 5 days/week, 50 weeks/year, or 250 days/year.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during the industrial use of lubricants (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS codes 811310 - Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance and 324110 – Petroleum Refineries for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-18. The estimated number of workers per site for industrial use of lubricants is 17. Based on an estimated number of sites of 10 for this OES, the total number of workers expected for this OES is 170. The estimated number of ONUs per site for this OES is 8, with a total number of ONUs of 75.

Table_Apx G-18. Number of Workers for Industrial Use of Lubricants

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
811310	9	0	0	0	0
324110	1	170	170	75	75
Total	10		170		75

G.19 Foundries

According to BLS, there are currently 2,611 foundries in the United States (U.S. BLS, 2023). Using TRI, NEI, and DMR, EPA identified 571 sites with NAICS codes associated with foundries. Large foundries may produce 75,000 tons per year, while smaller facilities may produce 500 to 1,000 tons per year (Westberg et al., 2005). EPA assumes facilities use formaldehyde resins for foundry casting 5 days/week, 50 weeks/year, or 250 days/year.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during foundry activities (U.S. BLS, 2016; U.S. Census

Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 331 – Primary Metal Manufacturing and 332 – Fabricated Metal Product Manufacturing for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-19. The estimated number of workers per site for foundries is 28. Based on an estimated number of sites of 571 for this OES, the total number of workers expected for this OES is at least 15,718. The estimated number of ONUs per site for this OES is 9, with a total number of ONUs of 5,162.

Table_Apx G-19. Number of Workers for Foundries

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
331314	33	22	732	6	201
331524	27	11	288	4	116
331318	21	37	785	10	216
33211	3	10	31	4	11
331492	23	14	326	4	102
331511	90	22	2,012	9	810
331315	19	64	1,219	18	336
331110	82	53	4,349	18	1,446
331529	12	8	94	3	38
331523	28	19	537	8	216
332111	28	13	364	5	130
331222	12	23	282	6	69
332119	22	8	179	3	64
331491	21	21	436	7	137
331221	20	18	366	5	90
331420	24	32	760	10	239
332117	8	15	121	5	43
33142	2	32	63	10	20
331210	18	39	693	9	170
331513	25	19	468	8	189
33111	7	53	371	18	123
331313	8	37	296	10	81
33121	3	39	116	9	28
331512	6	29	171	12	69
331410	16	19	303	6	95
332112	8	27	216	10	77
33131	2	40	79	11	22

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
33141	2	19	38	6	12
33151	1	22	22	9	9
Total	571		15,718		5,162

G.20 Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public, and Commercial Buildings, and Other Structures

In the 2020 CDR, one manufacturer reported 50 percent of its PV to downstream use of formaldehyde in furniture and furnishings including plastic and leather articles (U.S. EPA, 2020a). Twelve reporters reported downstream use of formaldehyde in construction and building materials covering large surfaces, including wood, metal, cement, stone, and other articles (U.S. EPA, 2020a). Demolition debris of wood products from buildings was equal to 36,090 thousand tons in 2015. Total demolition debris generated in 2015 was 518,242 thousand tons (U.S. EPA, 2003). The number and location of sites that install furniture and furnishings containing formaldehyde are unknown. Due to a lack of information, EPA does not present daily or annual site throughputs. EPA expects facilities to install furnishings and construction/building materials 250 days per year.

According to public comment, approximately 8 billion lb of formaldehyde are produced annually in the United States, with formaldehyde resins for the building products market comprising 60 to 70 percent of this total (Solenis, 2020). According to the GS on Spray Foam Insulation, 55 million and 365 million lb of one-component and two-component spray foam are used per year, respectively (U.S. EPA, 2021a). The daily use rate of formaldehyde in foam is unknown; however, EPA believes the use of formaldehyde in spray foam has significantly reduced. The GS indicates that construction crews typically operate 260 days per year (U.S. EPA, 2021a).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during installation and demolition of formaldehyde-based furnishings (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code sector 23 – Construction and the subsector 336 – Transportation Equipment Manufacturing for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-20. The estimated number of workers per site for installation and demolition of formaldehyde-based furnishing is 24. Based on an estimated number of sites of 240 for this OES, the total number of workers expected for this OES is 5,704. The estimated number of ONUs per site for this OES is 6, with a total number of ONUs of 1,500.

Table_Apx G-20. Number of Workers for Installation and Demolition of Formaldehyde-Based Furnishings and Building/Construction Materials in Residential, Public, Commercial Buildings, and Other Structures

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
336611	36	61	2,199	19	671
336612	29	16	458	5	140
237310	39	20	774	4	173
237210	12	1	16	1	11
237130	5	14	70	4	19
238910	8	6	49	1	7
237120	9	35	312	10	86
238210	14	7	101	1	13
238320	7	4	30	0.4	3
236210	11	16	176	8	88
237110	10	6	61	2	17
336213	10	108	1,075	14	142
236220	18	8	142	4	71
236116	6	7	42	2	12
236117	9	5	44	1	12
238220	2	7	13	1	2
238140	1	5	5	1	1
236118	1	2	2	1	1
238990	2	5	10	1	1
236115	3	2	6	1	2
237990	4	13	53	3	14
238160	1	7	7	1	1
238120	1	16	16	2	2
3366	1	36	36	11	11
238110	1	8	8	1	1
Total	240		5,704		1,500

G.21 Use of Formulations Containing Formaldehyde for Water Treatment

Due to CBI claims in CDR, the volume of formaldehyde present in water treatment products is unknown. According to BLS data, there are a total of 4,228 sites under the NAICS code 221310 – Water Supply and Irrigation Systems (U.S. BLS, 2023). The number of sites that use formaldehyde was estimated using TRI, NEI, and DMR. EPA assigned the NAICS code 221310 for this OES based on mapping from TRI reporting data. The Agency estimated the number of sites as 388. Water treatment plants operate on a continuous, year-round schedule; however, formaldehyde may not be used every day (U.S. EPA, 1994c).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during water treatment (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code 221310 – Water Supply and Irrigation Systems for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-21. The estimated number of workers per site for water treatment is 2. Based on an estimated number of sites of 388 for this OES, the total number of workers expected for this OES is 824. The estimated number of ONUs per site for this OES is 1, with a total number of ONUs of 333.

Table_Apx G-21. Number of Workers for Use of Formulations Containing Formaldehyde for Water Treatment

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
221310	388	2	824	1	333
Total	388		824		333

G.22 Use of Formulations Containing Formaldehyde in Laundry and Dishwashing Products

The volume of formaldehyde present in industrial or institutional laundry detergents or the number of sites that use formaldehyde is unknown. U.S. Census Bureau data cited in the ESD on Water Based Washing Operations at Industrial and Institutional Laundries indicates 4,338 industrial and 95,533 institutional laundries (OECD, 2011c). According to the ESD, industrial laundry facilities operate over a range of 20 to 365 days/year while institutional laundry facilities operate over a range of 250 to 365 days/year (OECD, 2011c).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during laundry and dishwashing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsector 812 – Personal and Laundry Services for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-22. The estimated number of workers per site for laundry and dishwashing is 4. Based on an estimated number of sites of 15 for this OES, the total number of workers expected for this OES is 54. The estimated number of ONUs per site for this OES is 0.4, with a total number of ONUs of 6.

Table_Apx G-22. Number of Workers for Use of Formulations containing Formaldehyde in Laundry and Dishwashing Products

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
812320	15	4	54	0.4	6
Total	15		54		6

G.23 Use of Formulations Containing Formaldehyde for Spray Applications (*e.g.*, spray or roll)

Spray application of paints and coatings was not reported in the 2016 or 2020 CDR. In 2004, there were 36,296 automotive refinishing facilities in the United States (OECD, 2011a). Using TRI, NEI, and DMR, EPA estimates that 4,417 sites potentially use formaldehyde for spray applications. Facilities generally use 45 to 452 gallons of coating formulation per year, which corresponds to a total daily use rate of 0.9 gal/site day. Facilities typically operate 250 days per year (OECD, 2011a).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during spray applications (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code sectors 332 – Fabricated Metal Product Manufacturing, 333 – Machinery Manufacturing, 336 – Transportation Equipment Manufacturing, 339 – Miscellaneous Manufacturing, 561 – Administrative and Support Services, and 811 – Repair and Maintenance for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-23. The estimated number of workers per site for spray applications is 43. Based on an estimated number of sites of 4,421 for this OES, the total number of workers expected for this OES is 188,017. The estimated number of ONUs per site for this OES is 17, with a total number of ONUs of 75,249.

Table_Apx G-23. Number of Workers for Use of Formulations Containing Formaldehyde for Spray Applications (*e.g.*, Spray or Roll)

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
332431	69	31	2,171	11	749
336111	41	342	14,007	45	1,851
336112	9	863	7763	114	1,026
336350	12	67	801	20	237
332420	8	16	124	5	43
336390	93	45	4,187	13	1,239
333922	3	12	35	6	18
332312	31	11	356	3	95
332321	15	18	263	5	70
332999	63	6	353	2	136

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
336413	32	41	1,316	35	1,110
339112	22	34	752	11	236
33911	4	11	45	4	14
336212	18	45	815	6	108
333618	35	37	1,300	20	705
811121	225	3	746	0.3	74
332812	186	7	1,343	2	306
336370	11	60	658	18	195
336211	43	33	1,426	4	189
333111	25	16	402	7	187
336510	11	35	385	15	162
339113	15	20	305	6	96
332216	11	7	77	3	30
333991	2	14	28	7	14
333249	17	7	122	6	95
333994	5	9	43	4	21
336992	9	45	405	11	103
333996	2	18	35	9	18
332996	1	12	12	5	5
333612	2	18	37	10	20
333611	3	40	119	21	64
33641	4	75	302	64	255
333318	5	15	75	7	35
332311	6	14	85	4	23
332721	7	4	27	2	14
33636	8	74	592	22	175
336411	9	184	1,653	155	1,394
332991	10	39	390	15	150
332618	11	9	97	2	25
333131	12	14	168	6	78
332811	13	10	128	2	29
332919	14	18	254	7	98
333923	15	16	247	8	124
336320	16	43	686	13	203
333120	17	23	399	11	186
333912	18	19	347	10	174

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
332710	19	2	33	1	17
333999	20	9	175	4	88
333914	21	17	366	9	183
333515	22	4	97	3	73
333924	23	19	446	10	224
333242	24	23	540	18	421
333413	25	21	521	6	141
332322	26	9	244	2	65
333519	27	7	176	5	132
333995	28	20	557	10	280
333613	29	18	536	10	290
333921	30	11	342	6	172
336991	31	12	383	3	97
336999	32	15	483	4	123
332911	34	22	745	8	287
333415	34	43	1,472	12	397
33312	35	23	822	11	382
332722	36	6	221	3	116
332323	37	5	201	1	53
336360	38	74	2,812	22	832
332215	39	8	304	3	118
33242	40	16	621	5	214
332510	41	12	489	4	146
332313	42	10	420	3	112
333414	43	17	720	5	194
333243	44	9	382	7	298
333514	45	4	160	3	120
333244	46	6	273	5	213
332913	47	19	872	7	336
336214	48	40	1,896	5	251
336330	49	67	3,272	20	969
333314	50	13	655	6	306
33635	51	67	3,404	20	1,008
333517	52	5	261	4	196
332912	53	28	1468	11	566

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
33361	54	29	1578	16	855
332613	55	13	739	3	192
333112	56	29	1,635	14	760
333997	57	10	585	5	294
333132	58	21	1,243	10	577
333241	59	9	503	7	392
336120	60	320	19,181	42	2,534
336419	61	30	1,819	25	1,534
336415	62	132	8,162	111	6,884
33633	63	67	4,207	20	1,245
33324	64	8	530	6	413
33251	65	12	775	4	232
33639	66	45	2,971	13	879
333992	67	11	732	5	367
33651	68	35	2,381	15	999
33637	69	60	4,129	18	1,222
33612	70	320	22,377	42	2,957
333316	71	7	514	3	240
336414	72	372	26,812	314	22,613
333511	73	4	315	3	236
33221	74	7	531	3	207
3335	75	4	322	3	241
33299	76	9	694	4	268
3364	77	75	5,813	64	4,903
33331	78	14	1,072	6	501
3339	79	13	1,009	6	507
3329	80	12	935	5	360
561720	81	1	52	0.1	8
3363	82	51	4,147	15	1,228
Total	4,421		188,017		75,249

G.24 Use of Electronic and Metal Products

The volume of formaldehyde present in electronic and metal products is unknown. Using TRI, NEI, and DMR, EPA estimates 134 sites potentially using formaldehyde for this OES. Due to a lack of information, EPA does not present annual or daily site throughputs. The Agency assumes facilities use electronic and metal products 250 days/year, although it is uncertain that formaldehyde is used every day.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of electronic and metal products (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsector 335 – Electrical Equipment, Appliance, and Component Manufacturing for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-24. The estimated number of workers per site for use of electronic and metal products is 41. Based on an estimated number of sites of 126 for this OES, the total number of workers expected for this OES is 5,225. The estimated number of ONUs per site for this OES is 14, with a total number of ONUs of 1,708.

Table_Apx G-24. Number of Workers for Use of Electronics and Metal Products

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
335312	26	34	889	15	387
335999	6	13	79	5	28
335991	17	21	365	8	132
335931	5	25	123	9	44
335313	11	32	355	14	154
335912	2	32	65	12	23
335311	6	39	231	17	100
335121	5	10	50	3	14
335911	16	54	867	20	313
335932	5	35	174	13	63
335314	4	19	77	8	33
335929	4	30	119	11	43
33521	1	53	53	10	10
335210	4	53	213	10	41
335129	1	21	21	6	6
335921	1	20	20	7	7
335220	7	180	1,259	35	245
335122	3	19	58	5	16
33522	1	180	180	35	35
33531	1	28	28	12	12
Total	126		5,225		1,708

G.25 Use of Formulations Containing Formaldehyde in Fuels

Using specific codes within the NAICS code subsectors 221 – Utilities, 324 – Petroleum and Coal Products Manufacturing, 325 – Chemical Manufacturing, 327 – Nonmetallic Mineral Product Manufacturing, 336 – Transportation Equipment Manufacturing, 424 – Merchant Wholesalers, Nondurable Goods, and 447 – Gasoline Stations, EPA estimates number of sites of 139 for this OES.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use in fuels (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 221 – Utilities, 324 – Petroleum and Coal Products Manufacturing, 325 – Chemical Manufacturing, 327 – Nonmetallic Mineral Product Manufacturing, 336 – Transportation Equipment Manufacturing, 424 – Merchant Wholesalers, Nondurable Goods, and 447 – Gasoline Stations for this OES based on based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-25. The estimated number of workers per site for use in fuels is 11. Based on an estimated number of sites of 139 for this OES, the total number of workers expected for this OES is 1,551. The estimated number of ONUs per site for this OES is 2, with a total number of ONUs of 347.

Table_Apx G-25. Number of Workers for Use of Formulations Containing Formaldehyde in Fuels

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
424710	106	1	152	0.2	18
447110	20	0.2	4	0.01	0.3
221112	2	6	11	8	15
324110	2	170	340	75	151
327992	2	17	34	3	7
325193	1	22	22	10	10
327310	4	22	87	3	13
325199	1	39	39	18	18
336112	1	863	863	114	114
Total	139	11	1,551	2	347

G.26 Use of Automotive Lubricants

The ESD on Automotive Lubricants indicates there are 93,270 automotive service sites based on 2012 U.S. Census data (OECD, 2020). The volume of formaldehyde in automotive lubricants is unknown. Using TRI, NEI, and DMR, EPA estimates a number of sites of 72. Facilities typically use automotive lubricants 253 days per year with an average annual use rate of 40,000 kg lubricant/site-yr (OECD, 2020).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of automotive lubricants (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsector 336 – Transportation Equipment Manufacturing and NAICS codes 332410 – Power Boiler and Heat Exchanger Manufacturing and 811111 – General Automotive Repair for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-26. The estimated number of workers per site for use of automotive lubricants is 31. Based on an estimated number of sites of 72 for this OES, the total number of workers expected for this OES is 2,260. The estimated number of ONUs per site for this OES is 18, with a total number of ONUs of 1,283.

Table_Apx G-26. Number of Workers for Use of Automotive Lubricants

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
336412	24	47	1,118	39	943
811111	18	2	39	0.2	4
336340	4	55	221	16	65
332410	7	27	190	9	66
336310	15	31	472	9	140
33634	4	55	221	16	65
Total	72	31	2,260	18	1,283

G.27 Use of Formulations Containing Formaldehyde in Automotive Care Products

Five reporters in the 2016 CDR reported the use of formaldehyde in liquid automotive care products (U.S. EPA, 2016). Three of the reporters reported a maximum formaldehyde concentration of 1 to 30 percent by weight, and two reporters indicated a concentration of less than 1 percent by weight (U.S. EPA, 2016). In the 2020 CDR, four reporters reported the use of formaldehyde as a binder in exterior car waxes, polishes, and coatings. One of these reporters indicated 100 percent of its PV was used for exterior car waxes, polishes, and coatings, with a concentration of 1 to 30 percent (U.S. EPA, 2020a).

Due to CBI claims in the CDR, the exact volume of formaldehyde is unknown. According to 2019 U.S. Census Bureau data indicated in the MRD, there are 147,152 automotive detailing sites (U.S. EPA, 2022b). Using TRI, NEI, and DMR, EPA assumes a total number of sites of 26. The MRD assumes automotive detailing facilities operate 260 days per year; however, EPA does not expect formaldehyde to be used every day at automotive detailing sites (U.S. EPA, 2022b).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of automotive care products (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA identified 26 sites in NEI that potentially use formaldehyde for automotive care products; however, EPA does not expect this to cover all uses of formaldehyde for this exposure scenario. Therefore, EPA applied a bounding estimate using the NAICS codes 441110 – New Car Dealers and 811192 – Car Washes to estimate a total of 37,346 sites, 339,218 workers, and 35,031 ONUs. Market data was not available on formaldehyde use in automotive care products; therefore, this may overestimate the number of sites and workers that actually use formaldehyde. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-27.

Table_Apx G-27. Number of Workers for Use of Formulations Containing Formaldehyde in Automotive Care Products

NAICS Code	Total Number of Establishments	Total Number of Workers	Total Number of ONUs	Number of Workers/Site	Number of ONUs/Site
441110	21,444	261,018	27,282	12	1
811192	15,902	78,199	7,749	5	0.5
Total	37,346	339,218	35,031	–	–

G.28 Use of Fertilizers Containing Formaldehyde in Outdoors Including Lawns

Three reporters reported processing formaldehyde as a reactant for fertilizers. Two reporters indicated a commercial/consumer use of formaldehyde as an agricultural product. One of these facilities reported 3 percent of their PV for this use with a maximum concentration of 30 to 60 percent formaldehyde. The other facility reported 32 percent of their PV for this use; however, the concentration is not known or reasonably ascertainable (U.S. EPA, 2020a).

Due to CBI claims in CDR, the exact volume of formaldehyde is unknown; however, one site reported a PV of 260,000 lb formaldehyde for incorporation into formulation in the agriculture, forestry, fishing, and hunting industry sector (U.S. EPA, 2020a). Facility operating schedules may be highly variable due to crop type, season, and climate.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of fertilizer (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA did not identify sites that use fertilizers containing formaldehyde in release data; therefore, EPA applied a bounding estimate using the NAICS code 115112 – Soil Preparation, Planting, and Cultivating to estimate a total of 2,157 sites, 2,914 workers, and 274 ONUs. Market data was not available on formaldehyde use in fertilizers; therefore, this may overestimate the number of sites and workers that actually use formaldehyde. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-28.

Table_Apx G-28. Number of Workers for Use of Fertilizers containing Formaldehyde in Outdoors including Lawns

NAICS Code	Total Number of Establishments	Total Number of Workers	Total Number of ONUs	Number of Workers/Site	Number of ONUs/Site
115112	2,157	2,914	274	1	0.1
Total	2,157	2,914	274	–	–

G.29 Use of Explosive Materials

The volume of formaldehyde present in explosive materials is unknown. Additionally, the number and location of sites that use explosive materials containing formaldehyde are unknown. Using primarily NAICS code 928110 – National Security, EPA estimates 344 sites. Due to a lack of information, EPA does not present annual or daily site throughputs.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of explosive materials (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsector 3329 – Other Fabricated Metal Product Manufacturing and NAICS code 928110 – National Security for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-29. The estimated number of workers per site for use of explosive materials is 32. Based on an estimated number of sites of 207 for this OES, the total number of workers expected for this OES is 6,574. The estimated number of ONUs per site for this OES is 12, with a total number of ONUs of 2,534.

Table_Apx G-29. Number of Workers for Use of Explosive Materials

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
928110	161	33	5,239	13	2,019
92811	24	33	781	13	301
332993	5	63	315	24	121
332994	13	11	145	4	56
332992	4	24	94	9	36
Total	207		6,574		2,534

G.30 Use of Packaging, Paper, Plastics, and Hobby Products

The facility in the 2020 CDR reported a PV of 46,119 lb formaldehyde for commercial/consumer use in paper articles (U.S. EPA, 2020a). EPA uses site data from TRI, NEI, and DMR for NAICS code 453998 – All Other Miscellaneous Store Retailers (Except Tobacco Stores), 491110 – Postal Service, 492110 – Local Messengers and Local Delivery, and 561910 – Packaging and Labeling Services to estimate a number of sites of 28 for this OES. EPA assumes facilities that use these products typically operate 5 days/week, 50 weeks/year, or approximately 250 days/year.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of packaging, paper, and hobby products (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code 453998 – All Other Miscellaneous Store Retailers (except Tobacco Stores), 491110 – Postal Service, 492110 – Local Messengers and Local Delivery, and 561910 – Packaging and Labeling Services for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-30. The estimated number of workers per site for use of packaging, paper, and hobby products is 2. Based on an estimated number of sites of 28 for this OES, the total number of workers expected for this OES is 42. The estimated number of ONUs per site for this OES is 0.2, with a total number of ONUs of 7.

Table_Apx G-30. Number of Workers for Use of Packaging, Paper, Plastics, and Hobby Products

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
561910	6	3	19	0.4	3
492110	5	1	4	0.2	1
491110	12	1	17	0.2	3
453998	5	0.4	2	0.03	0.1
Total	28	–	42	–	7

G.31 Use of Craft Materials

The volume of formaldehyde present in craft materials is unknown. Additionally, the number and location of sites that use paints, coatings, and adhesives containing formaldehyde are unknown. Using NAICS codes 611110 – Elementary and Secondary Schools and 611610 – Fine Art Schools, EPA estimates 190 sites reported in NEI. The Agency does not present daily or annual site throughputs. Using the ESD on Automotive Spray Coating, facilities typically operate 250 days/year (OECD, 2011a).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of craft materials (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS codes 611110 – Elementary and Secondary Schools and 611610 – Fine Art Schools for this OES based on the mapping of OSHA data described in Appendix C. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-31. The estimated number of workers per site for use of craft materials is 4. Based on an estimated number of sites of 190 for this OES, the total number of workers expected for this OES is 771. The estimated number of ONUs per site for this OES is 0.4, with a total number of ONUs of 76. Due to a lack of readily available information, this estimate may not cover all sites that use formaldehyde in craft materials.

Table_Apx G-31. Number of Workers for Use of Craft Materials

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
611110	188	4	771	0.4	76
611610	2	0.03	0.1	0.002	0.003
Total	190	–	771	–	76

G.32 Use of Printing Ink, Toner, and Colorant Products Containing Formaldehyde

The GS on Manufacture and Use of Printing Inks indicates 29,738 use sites in 2007. According to the GS, facilities typically operate 250 days/year (U.S. EPA, 2010). The daily use rate of ink used for flexographic printing is 1,800 kg/site-day, and facilities generally operate 300 days per year (U.S. EPA, 1999).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during use of printing ink, toner, and colorant products (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site.

EPA identified 239 sites in NEI that potentially use printing ink, toner, and colorant products containing formaldehyde; however, EPA does not expect this to cover all uses of formaldehyde for this exposure scenario. Therefore, EPA applied a bounding estimate using the NAICS subsectors 323 – Printing and Related Support Activities and 511 – Publishing Industries (except Internet) to estimate a total of 71,648 sites, 112,842 workers, and 53,253 ONUs. Market data was not available on formaldehyde use in these products; therefore, this may overestimate the number of sites and workers that actually use formaldehyde-containing products. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-32.

Table_Apx G-32. Number of Workers for Use of Printing Ink, Toner, and Colorant Products

NAICS Code	Total Number of Establishments	Total Number of Workers	Total Number of ONUs	Number of Workers/Site	Number of ONUs/site
323111	18,687	39,836	19,010	2	1
511110	7,165	3,850	1,621	1	0.2
323113	4,956	7,178	3,425	1	1
323117	447	2,543	1,214	6	3
511120	5,840	2,080	876	0.4	0.1
32311	24,090	49,557	23,649	2	1
323120	1,598	3,103	1,481	2	1
511140	886	440	185	0.5	0.2
511199	714	126	53	0.2	0.1
511191	100	280	118	3	1
51111	7,165	3,850	1,621	1	0.2
Total	71,648	112,842	53,253	–	–

G.33 Photo Processing Using Formulations Containing Formaldehyde

According to NICNAS, commercial film processing machines operate 4 to 5 hours per day, 5 days per week (NICNAS, 2006).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during photo processing (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site.

EPA identified two sites in NEI that potentially use formulations containing formaldehyde for photo processing; however, EPA does not expect this to cover all uses of formaldehyde for this exposure scenario. Therefore, EPA applied a bounding estimate using the NAICS codes 512199 – Other Motion Picture and Video Industries and 541922 – Commercial Photography to estimate a total of 3,951 sites, 357 workers, and 204 ONUs. Market data was not available on formaldehyde use in these products; therefore, this may overestimate the number of sites and workers that actually use formaldehyde-containing products. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-33.

Table_Apx G-33. Number of Workers for Photo Processing Using Formulations Containing Formaldehyde

NAICS Code	Total Number of Unique Sites	Total Number of Workers	Total Number of ONUs	Number of Workers/Site	Number of ONUs/Site
541922	3,740	328	195	0.1	0.1
512199	211	29	9	0.1	0.04
Total	3,951	357	204	–	–

G.34 General Laboratory Use

In the 2020 CDR, there are four industrial processing and use reports indicating the downstream use of formaldehyde in laboratory chemicals (U.S. EPA, 2020a). Two of the reporters indicated 20 percent of their PV going toward incorporation into the formulation. The other two reporters indicated 80 percent of their PV going toward repackaging. One reporter indicated 2 percent of its use in the commercial/consumer use category for laboratory chemicals with a maximum formaldehyde concentration of 1 to less than 30 percent (U.S. EPA, 2020a).

OSHA estimates approximately 12,000 laboratories use formaldehyde, including chemical, animal, biomedical, and research laboratories (Goris et al., 1998). In TRI, NEI, and DMR, 1,635 laboratories were identified.

The 2020 CDR indicates a PV of 324,000 lb of formaldehyde for laboratory use (U.S. EPA, 2020a). Due to a lack of information, EPA does not present annual or daily formaldehyde site throughputs. The Agency assumes that the daily throughput follows a distribution of 0.5 mL to 4,000 mL of formaldehyde per site day based on the Draft Use of Laboratory Chemicals GS (U.S. EPA, 2023d). The GS indicates that facilities typically operate 260 days/year (U.S. EPA, 2023d). The GS also estimates the number of operating days based on data from BLS' Occupational Employment Statistics and assumed shift durations of 8-, 10-, and 12-hour shifts, yielding several operating days of 260 days/yr, 208 days/yr, and 174 days/yr, respectively (U.S. EPA, 2023d).

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during general laboratory use (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 541 – Professional, Scientific, and Technical Services, 611 – Educational Services, Ambulatory Health Care Services, 621 - Ambulatory Health Care Services, 622 – Hospitals, and 927 – Space Research and Technology for this OES based on the mapping of OSHA data described in C.8. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-34. The estimated number of workers per site for general laboratory use is 11. Based on an estimated number of sites of 1,364 for this OES, the total number of workers expected for this OES is 14,401. The estimated number of ONUs per site for this OES is 8, with a total number of ONUs of 10.939.

Table_Apx G-34. Number of Workers for General Laboratory Use

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
927110	8	4	32	5	38
61131	52	14	748	19	975
541380	46	1	44	9	398
611310	319	14	4,587	19	5,980
54171	19	1	19	9	180
622110	643	13	8,410	4	2,287
541940	27	0.3	9	0.2	5
541715	42	1	47	10	437
541713	8	1	5	6	48
611210	30	11	327	3	88
541720	20	1	10	5	94
61121	1	11	11	3	3
541990	8	0.2	1	0.1	1
541714	55	1	36	6	331
6115	1	1	1	0.1	0.1
621111	25	0.04	1	0.01	0.2
611519	4	1	2	0.1	0.4
621511	10	0.1	1	0.2	2
622310	14	3	40	3	38
6113	1	14	14	19	19
621491	8	0.3	2	0.1	0.4
621112	12	0.01	0.2	0.003	0.03
621210	3	0.1	0.2	0.0004	0.001
621399	2	0.03	0.1	0.0004	0.001
621492	2	0.1	0.2	0.02	0.04
6221	4	13	52	4	14
Total	1,364		14,401		10,939

G.35 Worker Handling of Wastes

As per 2018 TRI reports, 715 facilities managed, in total, over 132 million lb of formaldehyde as waste (U.S. EPA, 2017b). Of this total, approximately 70 million lb were treated, nearly 35 million lb were recycled, over 20 million lb were released or otherwise disposed of, and over 7 million lb were burned for energy recovery. Of the 70 million lb of formaldehyde that were treated, about 65 million lb were treated on-site, and 5 million lb were treated off-site. Similarly, 99 percent of the formaldehyde waste that was recycled was recycled on-site, and 93 percent of the formaldehyde waste that was used for energy recovery was combusted on-site.

Nearly three-quarters of the formaldehyde that was disposed of or released occurred to land, the majority of which (14.2 million lb) was disposed of on-site to Class I underground injection wells, and about 240,000 lb was disposed of off-site to Class I underground injection wells. Over 4.6 million lb of formaldehyde were released to air; 93 percent of which was in the form of point source air (stack) emissions. Releases to water and other releases not mentioned above accounted for small amounts of the total releases at just 1 and 2 percent, respectively (U.S. EPA, 2017b).

Using TRI, NEI, and DMR data, EPA identified 1,123 sites specifically in the waste collection and waste management industries.

EPA used BLS and SUSB data specific to the OES to estimate the number of workers and ONUs per site potentially exposed to formaldehyde during worker handling of wastes (U.S. BLS, 2016; U.S. Census Bureau, 2015). This approach involved the identification of relevant Standard Occupational Classification (SOC) codes within the BLS data for the identified NAICS codes. Section 2.4 includes further details regarding methodology for estimating the number of workers and ONUs per site. EPA assigned the NAICS code subsectors 221 – Utilities, 325 – Chemical Manufacturing, 562 - Waste Management and Remediation Services. The full list of NAICS codes assessed for this OES is listed in Table_Apx G-35. The estimated number of workers per site for worker handling of wastes is 4. Based on an estimated 1,003 number of sites for this OES outlined in Section 4.36.2, the total number of workers expected for this OES is 3,519. The estimated number of ONUs per site for this OES is 2, with a total number of ONUs of 1,768.

Table_Apx G-35. Number of Workers for Worker Handling of Waste

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
562211	49	9	441	5	253
562212	219	3	756	2	434
562219	51	3	142	2	81
562111	16	1	20	0.1	2
221320	361	2	786	1	318
22132	237	2	516	1	209
562213	47	13	623	8	357
2213	2	2	4	1	2
562910	8	2	18	2	14
562119	1	1	1	0.1	0.1
56211	2	1	2	0.1	0.3
562998	3	1	4	1	3
325180	1	25	25	12	12
325110	1	64	64	30	30
325120	2	14	28	7	13
325998	1	14	14	5	5
325194	1	34	34	16	16

NAICS Code	Total Number of Unique Sites	Number of Workers/Site	Total Number of Workers	Number of ONUs/Site	Total Number of ONUs
325199	1	39	39	18	18
Total	1,003		3,519		1,768

Appendix H EXAMPLE OF ESTIMATING NUMBER OF WORKERS AND OCCUPATIONAL NON-USERS

This appendix summarizes the methods that EPA/OPPT used to estimate the number of workers who are potentially exposed to formaldehyde in each of its conditions of use. The method consists of the following steps:

1. Check relevant emission scenario documents (ESDs) and Generic Scenarios (GSs) for estimates on the number of workers potentially exposed.
2. Identify the NAICS codes for the industry sectors associated with each condition of use.
3. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics data (BLS, 2016).
4. Refine the Occupational Employment Statistics estimates where they are not sufficiently granular by using the U.S. Census' (U.S. Census Bureau, 2015) Statistics of U.S. Businesses (SUSB) data on total employment by 6-digit NAICS.
5. Estimate the percentage of employees likely to be using formaldehyde instead of other chemicals (*i.e.*, the market penetration of formaldehyde in the condition of use).
6. Estimate the number of sites and number of potentially exposed employees per site.
7. Estimate the number of potentially exposed employees within the COU.

Step 1: Identifying Affected NAICS Codes

As a first step, EPA/OPPT identified NAICS industry codes associated with each condition of use. EPA/OPPT generally identified NAICS industry codes for a COU by:

- Querying the U.S. Census Bureau's *NAICS Search* tool using keywords associated with each condition of use to identify NAICS codes with descriptions that match the condition of use.
- Referencing EPA/OPPT Generic Scenarios (GS's) and Organisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESDs) for a COU to identify NAICS codes cited by the GS or ESD.
- Reviewing CDR data for the chemical, identifying the industrial sector codes reported for downstream industrial uses, and matching those industrial sector codes to NAICS codes using Table_Apx F-2 provided in the CDR reporting instructions (U.S. EPA, 2020).

Each condition of use section in the main body of this report identifies the NAICS codes EPA/OPPT identified for the respective condition of use.

Step 2: Estimating Total Employment by Industry and Occupation

BLS's (BLS, 2016) OES data provide employment data for workers in specific industries and occupations. The industries are classified by NAICS codes (identified previously), and occupations are classified by Standard Occupational Classification (SOC) codes.

Among the relevant NAICS codes (identified previously), EPA/OPPT reviewed the occupation description and identified those occupations (SOC codes) where workers are potentially exposed to formaldehyde. Table_Apx H-1 shows the SOC codes EPA/OPPT classified as occupations potentially exposed to formaldehyde. These occupations are classified as workers (W) and occupational non-users (O). All other SOC codes are assumed to represent occupations where exposure is unlikely.

Table_Apx H-1. SOCs with Worker and ONU Designations for All Conditions of Use Except Dry Cleaning

SOC	Occupation	Designation
11-9020	Construction Managers	O
17-2000	Engineers	O
17-3000	Drafters, Engineering Technicians, and Mapping Technicians	O
19-2031	Chemists	O
19-4000	Life, Physical, and Social Science Technicians	O
47-1000	Supervisors of Construction and Extraction Workers	O
47-2000	Construction Trades Workers	W
49-1000	Supervisors of Installation, Maintenance, and Repair Workers	O
49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	W
49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	W
49-9010	Control and Valve Installers and Repairers	W
49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	W
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9060	Precision Instrument and Equipment Repairers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-1000	Supervisors of Production Workers	O
51-2000	Assemblers and Fabricators	W
51-4020	Forming Machine Setters, Operators, and Tenders, Metal and Plastic	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W
51-6030	Sewing Machine Operators	O
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O
51-8020	Stationary Engineers and Boiler Operators	W
51-8090	Miscellaneous Plant and System Operators	W
51-9000	Other Production Occupations	W
W = worker designation; O = ONU designation		

For dry cleaning facilities, due to the unique nature of work expected at these facilities and that different workers may be expected to share among activities with higher exposure potential (*e.g.*, unloading the dry-cleaning machine, pressing/finishing a dry-cleaned load), EPA/OPPT made different SOC code worker and ONU assignments for this condition of use. Table_Apx H-2 summarizes the SOC codes with worker and ONU designations used for dry cleaning facilities.

Table_Apx H-2. SOCs with Worker and ONU Designations for Dry Cleaning Facilities

SOC	Occupation	Designation
41-2000	Retail Sales Workers	O
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W

SOC	Occupation	Designation
51-6030	Sewing Machine Operators	O
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O
W = worker designation; O = ONU designation		

After identifying relevant NAICS and SOC codes, EPA/OPPT used BLS data to determine total employment by industry and by occupation based on the NAICS and SOC combinations. For example, there are 110,640 employees associated with 4-digit NAICS 8123 (Drycleaning and Laundry Services) and SOC 51-6010 (Laundry and Dry-Cleaning Workers).

Using a combination of NAICS and SOC codes to estimate total employment provides more accurate estimates for the number of workers than using NAICS codes alone. Using only NAICS codes to estimate number of workers typically result in an overestimate, because not all workers employed in that industry sector will be exposed. However, in some cases, BLS only provide employment data at the 4-digit or 5-digit NAICS level; therefore, further refinement of this approach may be needed (see next step).

Step 3: Refining Employment Estimates to Account for lack of NAICS Granularity

The third step in EPA/OPPT's methodology was to further refine the employment estimates by using total employment data in the U.S. Census Bureau's (U.S. Census Bureau, 2015) SUSB. In some cases, BLS OES's occupation-specific data are only available at the 4- or 5-digit NAICS level, whereas the SUSB data are available at the 6-digit level (but are not occupation-specific). Identifying specific 6-digit NAICS will ensure that only industries with potential formaldehyde exposure are included. As an example, OES data are available for the 4-digit NAICS 8123 Drycleaning and Laundry Services, which includes the following 6-digit NAICS:

- NAICS 812310 Coin-Operated Laundries and Drycleaners;
- NAICS 812320 Drycleaning and Laundry Services (except Coin-Operated);
- NAICS 812331 Linen Supply; and
- NAICS 812332 Industrial Launderers.

In this example, only NAICS 812320 is of interest. The Census data allow EPA/OPPT to calculate employment in the specific 6-digit NAICS of interest as a percentage of employment in the BLS 4-digit NAICS.

The 6-digit NAICS 812320 comprises 46 percent of total employment under the 4-digit NAICS 8123. This percentage can be multiplied by the occupation-specific employment estimates given in the BLS OES data to further refine our estimates of the number of employees with potential exposure. Table_Apx H-3 illustrates this granularity adjustment for NAICS 812320.

Table_Apx H-3. Estimated Number of Potentially Exposed Workers and ONUs under NAICS 812320

NAICS	SOC Code	SOC Description	Occupation Designation	Employment by SOC at 4-Digit NAICS Level	% of Total Employment	Estim. Employment by SOC at 6-digit NAICS Level
8123	41-2000	Retail Sales Workers	O	44,500	46.0	20,459
8123	49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W	1,790	46.0	823
8123	49-9070	Maintenance and Repair Workers, General	W	3,260	46.0	1,499
8123	49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W	1,080	46.0	497
8123	51-6010	Laundry and Dry-Cleaning Workers	W	110,640	46.0	50,867
8123	51-6020	Pressers, Textile, Garment, and Related Materials	W	40,250	46.0	18,505
8123	51-6030	Sewing Machine Operators	O	1,660	46.0	763
8123	51-6040	Shoe and Leather Workers	O	Not reported for this NAICS code		
8123	51-6050	Tailors, Dressmakers, and Sewers	O	2,890	46.0	1,329
8123	51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O	0	46.0	0
Total Potentially Exposed Employees				**206,070**		**94,740**
Total Workers						**72,190**
Total Occupational Non-users						**22,551**
Source: US Census, 2015 (U.S. Census Bureau, 2015); BLS, 2016 (BLS, 2016) Note: numbers may not sum exactly due to rounding. W = worker; O = occupational non-user						

Step 4: Estimating the Percentage of Workers Using Formaldehyde Instead of Other Chemicals

In the final step, EPA/OPPT accounted for the market share by applying a factor to the number of workers determined in Step 3. This accounts for the fact that formaldehyde may be only one of multiple chemicals used for the applications of interest. EPA/OPPT did not identify market penetration data for any conditions of use. In the absence of market penetration data for a given condition of use, EPA/OPPT assumed formaldehyde may be used at up to all sites and by up to all workers calculated in this method as a bounding estimate. This assumes a market penetration of 100 percent.

Step 5: Estimating the Number of Workers per Site

EPA/OPPT calculated the number of workers and ONUs in each industry/occupation combination using the formula below (granularity adjustment is only applicable where SOC data are not available at the 6-digit NAICS level):

Number of Workers or ONUs in NAICS/SOC (Step 2) ´ Granularity Adjustment Percentage (Step 3) = Number of Workers or ONUs in the Industry/Occupation Combination

EPA/OPPT then estimated the total number of establishments by obtaining the number of establishments reported in the U.S. Census Bureau's SUSB (U.S. Census Bureau, 2015) data at the 6-digit NAICS level.
Next, EPA/OPPT summed the number of workers and ONUs over all occupations within a NAICS code and divided these sums by the number of establishments in the NAICS code to calculate the average number of workers and ONUs per site.

Step 6: Estimating the Number of Workers and Sites for a Condition of Use
EPA/OPPT estimated the number of workers and occupational non-users potentially exposed to formaldehyde and the number of sites that use formaldehyde in a given condition of use through the following steps:

6.A. Obtaining the total number of establishments by:
   i. Obtaining the number of establishments from SUSB (U.S. Census Bureau, 2015) at the 6-digit NAICS level (Step 5) for each NAICS code in the condition of use and summing these values; or
   ii. Obtaining the number of establishments from the TRI, DMR, NEI, or literature for the condition of use.

6.B. Estimating the number of establishments that use formaldehyde by taking the total number of establishments from Step 6.A and multiplying it by the market penetration factor from Step 4.

6.C. Estimating the number of workers and occupational non-users potentially exposed to formaldehyde by taking the number of establishments calculated in Step 6.B and multiplying it by the average number of workers and ONUs per site from Step 5.

6.D.

6.E.