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EMISSION SCENARI0 DOCUMENT (ESD) ON THE USE OF ADHESIVES

Series on Emission Scenario Documents
No. 34

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IOMC

INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

A cooperative agreement among FAO, ILO, UNDP, UNEP, UNIDO, UNITAR, WHO, World Bank and OECD

Environment Directorate
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
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EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of chemicals used in adhesive products, specifically during the use of adhesives in various industries. It is also intended to serve as a preliminary screening tool for assessing such chemicals. The document focuses primarily on water-based and organic solvent-based solution, hot-melt, pressure-sensitive, and reactive (excluding radiation curable[1]) adhesives during industrial applications for the purposes of joining substrates. The adhesives may be applied using spray, roll, curtain, or syringe or bead application methods. The document presents standard approaches for estimating the environmental releases of and occupational exposures to additives and components used in adhesive formulations. These approaches are intended to provide conservative, screening-level estimates resulting in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in the real world setting.

This ESD may be periodically updated to reflect changes in the industry and new information available, and extended to cover the industry area in countries other than the lead (the United States). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Exposure Assessment, which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (www.oecd.org/env/riskassessment).

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to non-volatile chemical components contained in an adhesive formulation. This document also can provide screening-level release and exposure estimates for vapors from volatile chemicals; however, it does not provide a method for estimating vapor releases during application (spray, roll, or curtain coating or syringe or bead application) or for estimating vapor exposures during curing or drying. The reader should note that this document is a screening-level tool to serve EPA's new chemicals assessment needs; therefore, the application of this document to chemicals with vapor pressures exceeding 35 torr is not appropriate. The reader should also be aware that the estimation methods provided in this document may result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might

[1] The use of radiation curable adhesives is covered under the *Emission Scenario Document on Radiation Curable Coating, Inks, and Adhesives* (OECD, 2011).

actually occur in real world practice. This is because the ESD makes conservative assumptions about facility operations and workplace practices. For example, the ESD defaults to the most conservative adhesives application method if the end use is unknown. For occupational exposures, the ESD methodology does not account for the use of personal protective equipment.

The users of this ESD should consider how the information contained in the document emulates the specific scenario being assessed. Where specific information is available, it should be used in lieu of the defaults presented in this document, as appropriate. All input values (default or ESD-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

The U.S. Environmental Protection Agency (EPA) developed this ESD using relevant data[2] and information on the use of adhesives to join substrates in various industries, including process descriptions, operating information, chemicals used, wastes generated, waste treatment, worker activities, and exposure information. EPA supplemented the collected data with standard models[3] to develop the environmental release and occupational exposure estimating approaches presented in this ESD.

The information in this document is based on U.S. data. Certain aspects of adhesives application may differ in other countries; therefore, alternate assumptions and parameters may be necessary in some applications of this emission scenario. For example, in response to European regulatory requirements, the Association of the European Adhesive & Sealant Industry (FEICA) has developed exposure estimation methodology documents that address worker, consumer, and environmental safety. These documents are intended for use under the European Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) program. They have provided EPA with a fact sheet summarizing these documents, which we have included as Appendix E.[4]

The primary sources of information cited in this ESD include information published by the U.S. Census Bureau's Economic Census and Current Industrial Reports, and various EPA and other government sources (e.g. CEB, OECD, and regional/state pollution prevention organizations). Additional information on the sources investigated and the references cited in this document are presented in Section 8.

This ESD includes methods for estimating the environmental releases of and associated occupational exposures to non-volatile chemicals used during the use of adhesives. Additionally, this document provides screening-level release and exposure estimates for vapors from volatile chemicals; however, it does not provide a method for estimating vapor releases during application (spray, roll, or curtain coating or syringe or bead application) of adhesive products or for estimating vapor exposures during curing or drying operations. For

[2] Please refer to Section 8 for a list of the specific references used in developing this ESD.

[3] EPA has developed a series of "standard" models for use in performing conservative release and exposure assessments in the absence of chemical- or industry-specific data. Several of these standard models are described in Appendix B to the ESD.

[4] FEICA has recently completed the SPERC (Specific Environmental Release Categories) for Industrial Use of Substances in Adhesives (FEICA, 2013a) and published a fact sheet (FEICA, 2013b) that provides an overview of FEICA Exposure Scenarios (ES).

EPA new chemical assessments, volatile chemicals are considered to be those whose vapor pressures are above 0.001 torr (CEB, 2008a). The volatilization of chemicals with vapor pressures below 0.001 torr, for the purposes of estimating screening-level inhalation exposures and air releases, is considered negligible (CEB, 1994 and 1995). Also, models presented in this document may not be applicable to chemicals with adjusted vapor pressures greater than 35 torr.[5] Therefore, chemicals with adjusted vapor pressures above 35 torr are outside the scope of this ESD.

A review of Premanufacture Notices (PMNs) submitted to EPA under section 5 of the Toxic Substances Control Act (TSCA) for chemicals used as industrial adhesives indicates that vapor pressures are typically below 0.001 torr. Based on a sample of 39 PMNs, 10% had vapor pressures between 0.001 and 35 torr. Only one of the reviewed PMNs was for a chemical with a vapor pressure greater than 35 torr. The remaining PMNs (87% of the sample) were for chemicals with vapor pressures below 0.001 torr.

PMN submissions submitted to EPA generally represent a distinct chemical substance that may be entering commerce in the United States. EPA maintains a database of the function and uses of chemicals reviewed under the PMN program (e.g. EPA's new chemicals review program).

The types of chemicals that may be used in adhesives, and for which this ESD is applicable, include, but are not limited to:

- Fillers;
- Plasticizers;
- Solvents;
- Stabilizers;
- Viscosity control agents;
- Preservatives;
- Surfactants; and
- Antioxidants.

Adhesives may be formulated as liquids or solids; however, the literature reviewed for this ESD indicates that they are typically applied as solutions or polymers. Based on engineering judgment, those adhesives that are formulated as solids are expected to be shaped into rods, blocks, or pellets by formulators. As a result, this ESD does not cover potential environmental releases or occupational exposures from the use of powders.

Adhesives containing these chemicals may be applied to substrates in a variety of methods. Application methods depend on a variety of factors including the type of adhesive, type of substrate, size and geometry of the substrate, and the precision requirement of the

[5] The adjusted vapor pressure is the product of the vapor pressure and vapor pressure correction factor. The correction factor accounts for vapor pressure differences between the chemical of interest in a neat sample versus in a mixture.

bond. Based on a review of PMN data (see Appendix D), the application methods most typically utilized by industry include spray coating, roll coating, curtain coating, and syringe or bead application. Therefore, these application methods are specifically covered in this ESD.

The end use of adhesives is an extremely broad and diverse subject as adhesives are used across virtually all industries; therefore, several limitations are recommended for the ESD. The ESD will present methodologies for estimating potential environmental releases of and occupational exposures to volatile and non-volatile chemicals present in the following types of adhesives during industrial application for the purposes of joining substrates: water-based and organic solvent-based solution, hot-melt, and pressure-sensitive adhesives. The adhesives may be applied using spray, roll, curtain, or syringe or bead application methods, as indicated above.

The ESD will focus on industrial applications of adhesives to join substrates in the following end-use markets: electrical and electronic product manufacturing; vehicle, vehicle parts, and tire manufacturing (except retreading); flexible packaging manufacturing; labels and tapes manufacturing; and general assembly and binding. These end-use markets were selected based on a review of PMN data, which associated these industries with the top five industrial uses of adhesives (see Appendix D). A summary of the applicable application methods for each industry, as determined from PMN data, is provided below in Table 1.

Table 1. Application Methods Utilized by Each of the End-Use Industries Covered in this ESD

End-Use Industry	Potential Application Method[a]
Computer/Electronics Manufacturing	Curtain Coating
	Roll Coating
	Syringe or Bead
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	Spray Coating
	Dip Coating
	Syringe or Bead
Flexible Packaging Manufacturing	Roll Coating
Labels and Tapes Manufacturing	Roll Coating
	Curtain Coating
General Assembly/Binding	Curtain Coating
	Roll Coating
	Dip Coating
	Syringe or Bead

a – See Appendix D

As stated above, the aforementioned industries are associated with the top five industrial uses of adhesives, as determined from a review of PMN data (see Appendix D). The reader should be aware that while the general assembly end-use comprises a wide range of industries, which have been collectively identified as “General Assembly/Binding,” it is not intended to be used as a catchall for assessing adhesive uses that are not applicable to the other end-use industries listed in Table 1. The general assembly end-use industry should only be used if the assessed chemical is an industrial adhesive used in the general assembly or binding of individual components into a final multi-component product.

Commercial (e.g. adhesives used to lay carpet or roofing shingles) and consumer (e.g. rubber cement) applications are outside the scope of the ESD. Industrial applications typically occur at the same site throughout the year, while in commercial applications workers will apply the adhesive at many different sites throughout the year (e.g. carpet layers moving between job sites). Consumer applications typically occur on an as needed basis. The scenario also will not cover adhesives that are mixed together with other materials and extruded or molded into an object (e.g. adhesives mixed with wood shavings and sawdust for particleboard manufacturing) because of significantly different process operations specific to the article being manufactured.

The scope of the ESD will only cover the industrial end use of adhesives. The manufacturing of the adhesive component chemicals, the formulation of adhesive components, the formulation of adhesive products, the use of the product manufactured with the adhesive (e.g. use of packaging, tape, electronics), and end of life considerations are outside the scope of the ESD. Note that for the purposes of the ESD, the end use of adhesive for tapes, labels, tiles, and other self-adhesive products is considered to be the adhesive application to the tape backing or label, not the use of the tape or label. Figure 1 provides an illustration of the scope of the ESD within the lifecycle of a chemical of interest. The formulation of adhesive components into adhesive products is covered under the *ESD on Adhesive Formulation* (OECD, 2009).

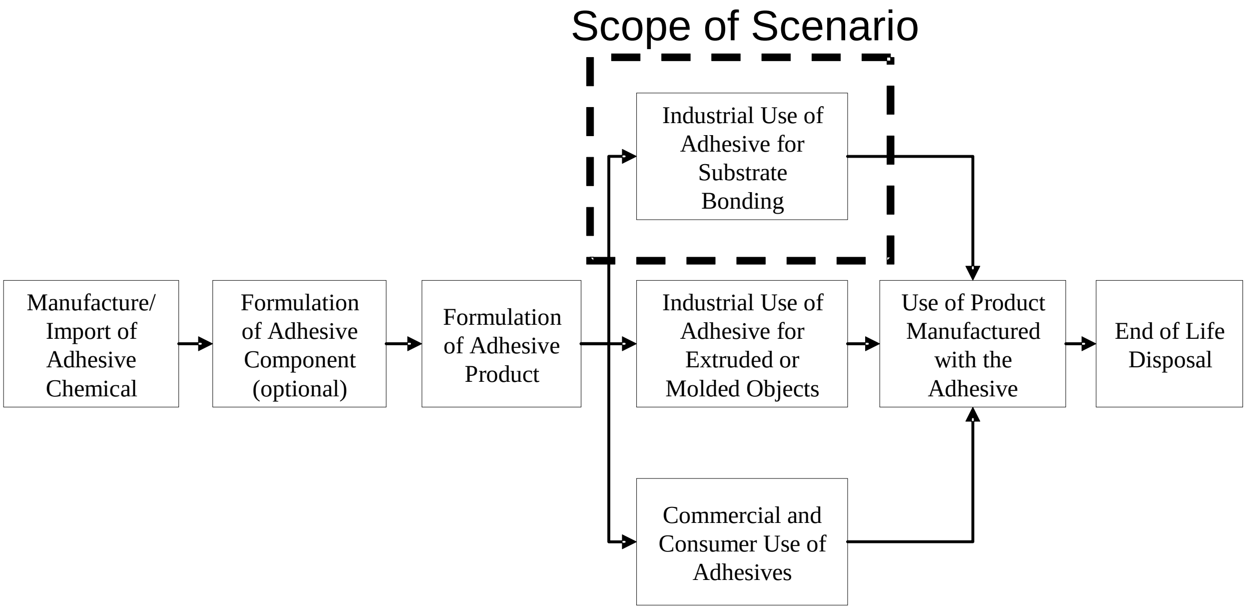


Figure 1. Adhesive Chemical Life-Cycle Diagram

To estimate environmental releases for the application process, this ESD assumes that volatile chemicals may be released to air at certain points in the process and associated inhalation exposures to the chemical vapors may occur as a result of handling those chemicals. Each user will have to define *volatile* based on the specific objectives of the assessment. For example, EPA often assumes that releases and exposures are negligible for chemicals having a vapor pressure less than 0.001 torr. Non-volatile chemicals result in negligible releases to air from volatilization and negligible associated inhalation exposures to vapors (CEB, 1994 and 1995). However, other air releases and associated inhalation exposures (e.g. overspray) from process operations may occur.

While inhalation exposures to chemical vapors during adhesives application or drying may occur, EPA has not developed estimation methods to quantify potential exposures. Quantification of inhalation exposures would require specific information about the application process, such as the chemical evaporation rate and length of time over which evaporation occurs. Also, the proximity and extent of worker activity during application or drying would need to be known. Such an assessment is beyond the scope of this ESD, which is intended to serve as a preliminary screening tool for assessing new chemicals. As a result, inhalation exposures to chemical vapors during adhesives application and drying are presented as a data gap in the ESD.

The methods for estimating the following facility operating parameters and the releases and exposures to chemicals used during the application and curing of adhesive products onto a substrate or an article are discussed in this ESD:

- Number of sites in the United States applying adhesives containing the chemical of interest onto various substrates and the duration of these activities;
- Releases of volatile chemicals during transfer from the container into the process (storage or mixing vessel);
- Releases from transport container residue (via container cleaning or direct disposal of empty containers);
- Releases during the adhesive product application process (from spray or mist generation or the application's transfer inefficiencies);
- Releases from equipment cleaning;
- Number of workers that may come into contact with the adhesive product during the application process;
- Inhalation and dermal exposures during container unloading;
- Inhalation and dermal exposures during container cleaning and disposal;
- Inhalation and dermal exposures during the application process; and
- Inhalation and dermal exposures during equipment cleaning.

The estimation methods in this ESD apply to any volatile or non-volatile adhesive component, regardless of its function within the adhesive formulation.

How this document was developed

The U.S. EPA, with support from Eastern Research Group, Inc. (ERG), has developed this ESD document on the use of adhesives.

This document is published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.

TABLE OF CONTENTS

1 INDUSTRY SUMMARY AND BACKGROUND

Introduction to Adhesives

1. The end use market for adhesives is extremely broad and diverse. Approximately 18 billion pounds (8.2 billion kilograms) of adhesives and sealants with an estimated value of $12.3 billion were used in the United States in 2003 (Impact Marketing, 2005). To characterize this industry, this section is divided into the following sub-sections:

- Section 0 presents an introduction to adhesives and how they function;
- Section 0 presents an overview of the different types of adhesives;
- Section 0 presents an overview of the different types of chemical components that may be incorporated into adhesive formulations; and,
- Section 0 presents an overview of the adhesives market.

2. An adhesive is any substance capable of holding two objects together in a functional manner through non-mechanical means (Kirk-Othmer, 2002). In this context, mechanical means refer to the use of fasteners at the macroscopic level (e.g. bolts, screws, and rivets). Adhesives are generally composed of a binder material formulated with other components. Binders are typically natural or synthetic high molecular weight polymers. Binders may alternatively contain reactive organic compounds (e.g. prepolymers, oligomers, monomers) that form polymers during the bonding process. Some materials commonly used as binders in adhesive formulations are esters, natural and synthetic rubber, polyvinyl compounds, polyurethanes, epoxy resins, and acrylate polymers. Adhesives may also contain components such as non-reactive resins, plasticizers, fillers, thickeners, solvents, hardeners, and setting retarders (Ullmann, 1985).

3. Adhesives are capable of producing a strong, lightweight bond at a relatively low cost when compared to screws, bolts, or welds. These materials form a bond between two substrates by wetting the surfaces and subsequently setting, curing, or adhering to form a strong bond. Figure 1-1 presents a cross section of an adhesive bond.

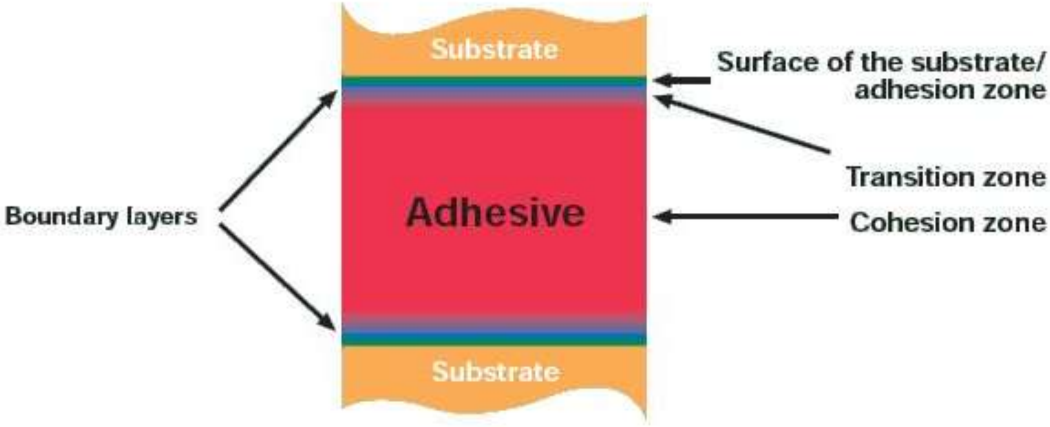


Figure 1-1. Cross Section of an Adhesive Bond

Source: FEICA, 2004.

4. Adhesive bond strength is dependent on both the cohesion and adhesion properties of the adhesive. Cohesion is the inner strength of the adhesive (e.g. how well the adhesive sticks to itself based on chemical bonds, crosslinking, and other intermolecular forces). Adhesion is the strength of the bond between the adhesive and the substrate (FEICA, 2004).

5. Several different theories have been developed to explain the mechanism of adhesion; however, none has been proven to completely explain the adhesion process. The mechanism of adhesion is a complex addition of various effects, not a consistent or isolatable process (Ullmann, 1985). Some theories that may combine to explain the mechanism of adhesion are listed below. These theories may be applicable to all types of adhesives (Ullmann, 1985).

- Mechanical Adhesion Theory – The adhesive polymer mechanically anchors, at the molecular level, to the pores and irregularities in the substrates.
- Electrostatic Theory of Adhesion – Electron transfer potentials (e.g. the tendency of electrons to flow to positive charges or away from negative charges) cause the buildup of electrostatic forces at the boundary layer between the adhesive and the substrate.
- Adsorption Theory – Secondary valance or van der Waal’s forces (e.g. intermolecular attractive forces) between the adhesive and the substrate cause adhesion.
- Diffusion Theory – The adhesive polymer and substrate mutually penetrate then dissolve in each other and cure to form a solid bond.
- Liquid Adhesion – The adhesive polymer creates a thin film of an extremely high viscosity liquid causing surface tension (e.g. the tendency of interior molecules to draw the surface molecules into the bulk of the liquid and minimize the liquid surface area) between the two substances.

Types of Adhesives

6. The variety of existing adhesives and the increasing number of hybrid adhesives (e.g. multiple types of adhesives combined to utilize the strengths of each type) make it difficult to concisely categorize these compounds; however, three general adhesives classifications are solution (water- and solvent-based), solventless/solid (e.g. hot-melts), and reactive adhesives. Pressure sensitive adhesives (PSAs) are unique in that they are initially formulated as solution adhesives but are inherently tacky and often incorporated as a thin film coated on a continuous web before being sold for use (e.g. tapes, labels). PSAs remain the same chemically throughout their useful life and do not undergo a chemical transformation in order to bond to a substrate. Table 1-1 provides a list of typical binders (e.g. polymers) that are used in the solution (water- and solvent-based), hot-melt, and pressure-sensitive, and reactive adhesive types.

Table 1-1. Typical Polymers or Reagents used in Solution, Hot-melt, Pressure-Sensitive, and Reactive Adhesives

Adhesive Type	Typical Polymers or Reagents Used as Binder
Water-Based Solution	Natural polymers, polyurethane dispersions, polyvinyl alcohol (PVA), polyvinyl acetate (PVAC) emulsions, polychloroprene
Organic Solvent-Based Solution	Natural rubber, polychloroprene, polyurethane, styrene-butadiene-styrene block polymers, styrene-butadiene rubber (SBR), butadiene-acrylonitrile rubber, acrylic or vinyl resins
Hot-Melt	Ethylene-vinyl acetate copolymers, styrenic block polymers, synthetic elastomers, ethylene-ethyl acrylate copolymers, amorphous polyolefins, branched polyethylenes, polypropylene, polybutene-1, phenoxy resins, polyamides, polyesters, polyurethanes
Pressure-Sensitive	Natural rubber, polybutadiene, polyorganosiloxanes, SBR, carboxylated styrene-butadiene rubber, halogenated butyl rubber, polyalkyl acrylate homopolymers/ copolymers, polyvinyl ethers, amorphous polyolefins, block polymers based on styrene with isoprene, butadiene, ethylene-propylene, or ethylene-butylene
Reactive Adhesives[6]	Cyanoacrylates, methyl methacrylates, dimethyl acrylates, epoxies, polyurethanes, phenol-formaldehyde resins, silicones, polyimides

Source: Kirk-Othmer Encyclopedia of Chemical Technology, 2002.

1.1.1 Solution Adhesives

7. Solution adhesives contain a synthetic or natural binder material and other components dispersed within an organic solvent or water. In organic solvent-based solution adhesives, the adhesive polymer is typically dissolved within the solvent. Typical solvents include toluene, xylene, and hexane (Ebnesajjad, 2011). Most water-based solution adhesives are aqueous dispersions. In solution adhesives the adhesive polymers do not cure (e.g. undergo a chemical reaction); rather they set via evaporation of the solvent (with or

[6] Note that the listed chemicals are not in and of themselves polymers. Rather, they are reagents that convert to adhesive polymers upon reaction. This is discussed in detail in Section 1.1.4.

without heat) once applied to a substrate. Solution adhesives can be used on a wide range of substrates, such as wood, paper, plastic, metal, rubber, silicate-containing materials, moistenable adhesive tapes, and fiberboard (Ullmann, 1985).

8. Many solution adhesives are used for joining large surface areas. Major end uses of solution adhesives are carpet manufacturing (attaching carpet fibers to backing material), construction (gluing down carpet, tiles, wood flooring, and wall paper), packaging (making envelopes, paper bags, and paper-board cartons and tubes), and furniture manufacturing (woodworking and laminates) (Kusumgar, 2000). Solution adhesives are also used in many consumer products, such as Elmer's® glue (water-based), rubber cement (organic solvent-based), and adhesives to seal envelopes (water-based, but remoistenable). Many PSAs are formulated as solution adhesives, but are subsequently incorporated onto a continuous web without their solvent. PSAs are described in detail in Section 1.1.3.

9. Due to increasing volatile organic compound (VOC) emission and exposure regulations, the industry has shifted away from the use of organic solvents. For example, in 1985 approximately 50 percent of flooring installation adhesives were water-based and 50 percent organic solvent-based. In 2003, water-based adhesives comprised over 90 percent of the same market (FEICA, 2004).

1.1.2 Hot-Melt Adhesives

10. Hot-melt adhesives comprise polymeric compounds that are solids at room temperature. When applied, they are heated to form a molten liquid and adhere firmly to surfaces when cooled. They do not set via a chemical reaction. Hot-melt adhesives are most often used in packaging, bookbinding, disposable paper products, shoe making, and textile binding. Consumers may use hot-melt adhesives in hot-glue guns (e.g. in arts and crafts activities). Since hot-melt adhesives are solvent free, they are considered to be environmentally friendly, though evaporative emissions can result from their use. The market share of hot-melt adhesives is expected to increase in the early 21st century (Kirk-Othmer, 2002).

1.1.3 Pressure-Sensitive Adhesives

11. Pressure-sensitive adhesives (PSAs) contain binders that are permanently soft, tacky substances that adhere spontaneously to surfaces with very little pressure. Most PSAs are initially formulated as a water- or organic solvent-based solution and then applied to a continuous web substrate where the solvent is removed by evaporation before being sold as a component of various industrial and consumer products. PSAs may also be formulated as solventless (e.g. hot-melts) or reactive adhesives, but most are solution-based (Petrie, 2005). Typical PSA products include duct, masking, or packaging tapes, and self-adhesive labels and stamps. PSA tapes may also be used for industrial applications (e.g. construction and automobile manufacturing).

12. PSAs differ from other adhesive types because they remain soft, tacky, and ready for use after solvent evaporation. Many PSAs can also be easily removed from one substrate and placed on another (e.g. moving a self-stick note). In contrast, once other adhesives are applied and set, they have hardened and bonded to the substrate (Kirk-Othmer, 2002).

1.1.4 Reactive Adhesives

13. In reactive adhesives, the adhesive polymer is formed by one of the following mechanisms after the formulation has been applied to the substrate.

- Polymerization (radical or ionic) – A chemical reaction in which two or more molecules combine to form larger molecules that contain repeating structural units. Polymerization adhesives harden through radical or ionic polymerization of the monomers, often concurrent with graft polymerization or crosslinking of unsaturated polymers (Ullmann, 1985).

- Polyaddition – A polymerization reaction in which monomers containing multiple-bonds (e.g. C=C) combine through an addition reaction, forming chains of singly bonded atoms (e.g. -C-C-C…) (Silberberg, 2000).

- Polycondensation – A polymerization reaction in which monomers with two functional groups are linked together via a dehydration-condensation reaction (e.g. H- and OH- groups on separate molecules react to form water as a product) (Silberberg, 2000).

14. These reactive formulations are significantly different from the other categories of adhesives (e.g. solution and hot-melt adhesives) because they do not contain an adhesive polymer. Rather, they contain unreacted prepolymers, oligomers, or monomers that react to form a crosslinked polymer at the point of application. The resulting polymer serves as the adhesive, binding the surfaces together. Reactive adhesive products are typically marketed as one of the following (Ullmann, 1985):

- 2-Part System – Reactive components are kept separate until they are used, at which point they must be mixed together to initiate the curing/crosslinking reaction.

- 1-Part System – Reaction is initiated by exposure to air, moisture, or heat.

- No-Mix System – Components of the reaction are pre-applied to each surface to be adhered, and the bond forms instantly when the two surfaces are brought together.

15. Reactive adhesives are used to bond metals, plastics, silicate-containing materials, rubber, and wood (high-strength spot or small-area bonds) (Ullmann, 1985). Table 1-2 presents the general classification of reactive adhesives and examples of each category.

Table 1-2. General Classification of Reactive Adhesives

Curing Mechanism	Examples
Polymerization (radical or ionic)	• Cyanoacrylates: cure initiated by moisture; type of adhesive in industrial and consumer superglue. • Methyl Methacrylates (MMA): 2-part system; used in automobile and rail vehicle manufacturing. • Anaerobic adhesives (e.g. dimethyl acrylates): cure upon contact with copper or iron in the absence of oxygen. • Radiation-curable adhesives[a]: cure upon exposure to ultra-violet or electron beam radiation; can only be used if one substrate allows light to penetrate to the adhesive.
Polyaddition	• Epoxies: 1-Part heat cured (including reactive hot-melts) or cold curing 2-Part systems; used in many industries, including automotive, aerospace, construction, electronics (with conductive additives), and plastics. • Polyurethanes: cold curing 2-Part, heat curing 1-Part, or moisture-curing 1-Part systems; used across most industries.
Polycondensation	• Phenol-formaldehyde resins: heat cured; good for high temperature applications (e.g. automotive brake pads, aerospace); also used extensively in furniture manufacturing. • Silicones: cold curing 2-Part or moisture-curing 1-Part systems; excellent resistance to UV light, moisture, and weathering; low adhesive strength; mainly used as sealants. • Polyimides: typically require an autoclave to cure; used in high-quality, high-temperature metal bonds in aerospace applications.

Source: FEICA, 2004.
a - Radiation-curable adhesives are covered under a separate ESD being developed by EPA.

16. Two commonly used reactive adhesives are epoxy adhesives and moisture-curable adhesives.

17. Epoxy adhesives are commonly formulated into 2-part systems. One mixture will primarily contain the epoxy resin; the other will contain the hardener (catalysts and crosslinkers). Typical hardeners are aliphatic and cycloaliphatic amines, adducts of polyamines, phenol-amine combinations, and polyaminoamides (Ullmann, 1985). Epoxies may also be formulated into a one-part, heat-activated mixture that usually requires temperatures above 100°C to cure. Typical hardeners for heat-activated epoxies are dicarboxylic acid anhydrides, dicyanodiamide, and aromatic amines (Ullmann, 1985).

18. Moisture-curable adhesives (e.g. silicone- and urethane-based sealants used to line bathroom fixtures) cure when exposed to atmospheric moisture (Ullmann, 1985). The atmospheric moisture neutralizes the acidic stabilizer in the adhesives causing rapid polymerization. Optimal curing conditions for moisture-curable adhesives are room temperature with a relative humidity between 40 percent and 60 percent (Petrie, 2004). Lower humidity slows curing; however, higher humidity may lower the bond strength. The

most popular moisture-curable adhesive resins are cyanoacrylates, silicones, and polyurethanes (Petrie, 2004).

Components of Adhesive Formulations

19. The main components of water-based, organic solvent-based, and hot-melt adhesives are polymers/elastomers and tackifiers; however, other components may include fillers, pigments, plasticizers, stabilizers, viscosity control agents, preservatives, surfactants, antioxidants, and solvents. Note that some components are not used in every adhesive type. Table 1-3 presents a summary of available formulation data that has been found to date for solution and hot-melt adhesives.

20. As discussed in Section 1.1.3, PSAs may be formulated as hot-melts, reactive adhesives, or solution-based adhesives; therefore, the main components of the formulation will depend on the type of adhesive used to produce the PSA. In lieu of specific formulation data, EPA assumes PSA formulations are similar to solution-based adhesives, since most PSAs are solution-based (Petrie, 2005). Available data for either organic solvent-based or water-based solution adhesives may be used to estimate PSA formulations.

21. Typical components of reactive adhesives are polymers, prepolymers/oligomers, viscosity control agents, plasticizers, tougheners, adhesion promoters, colorants, fillers, and solvents. Table 1-4 and Table 1-5 present available formulation data for two common reactive adhesives: moisture-cure reduced temperature vulcanizing (RTV) silicone and urethane adhesives, respectively. Adhesives also may be formulated as solids; however, based on the literature reviewed for this ESD, they are typically applied as solutions or polymers. Based on engineering judgment, those adhesives that are formulated as solids are expected to be shaped into rods, blocks, or pellets by formulators. As a result, this ESD does not cover environmental releases and occupational exposures to powdered adhesives.

Table 1-3. Summary of Available Information on the Formulation of Solution and Hot-Melt Adhesives

Component	Weight Fraction of Adhesive Components by Type	Function	Compounds
Elastomer or Adhesive Polymer[a]	Organic Solvent: 0.11-0.16 Water: 0.55-0.61 Hot-Melt: 0.30	Elasticity	Styrene-butadiene-styrene block copolymer; nitrile rubber; latex; polychloroprene (Neoprene); ethylene vinyl acetate
Tackifier[a]	Organic Solvent: 0.13-0.25 Water: 0.02 Hot-Melt: 0.35	Increase the tack of the adhesive	Rosin-based resin
Filler	Organic Solvent: 0.33[b] Water: 0.33[b] Hot-Melt: 0.35[a]	Increase cohesive strength; reduce tack; modify elasticity; modify thermal expansion properties; lower cost	Microcrystalline wax; paraffin wax
Plasticizer[b]	All: Assume 0.01	Improve flexibility and plastic flow properties	Chlorinated biphenyl; formamide; phthalates; polyacrylates
Solvent[b]	Organic Solvent: 0.60-0.75 Water: 0.29 Hot-Melt: --	Carrier	Acetone; methylene chloride; heptane; n-propyl bromide; water
Stabilizer	Organic Solvent: 0.03[b] Water: 0.01[c] Hot-Melt: 0.01[c]	Prevent unwanted alteration of physical state	1,2-butylene oxide; 1,3-dioxolane
Viscosity Control	Organic Solvent: 0.005[b] Water: 0.002-0.4[c] Hot-Melt: 0.005[b]	Regulate viscosity	Acrylic copolymer; polyurethane
Preservative	Organic Solvent: 0.001[b] Water: 0.001-0.01[c] Hot-Melt: 0.001[b]	Protect adhesive from microorganism growth and spoilage	Aldehydes; benzoate; esters; phenolics
Surfactant[c]	Organic Solvent: NA Water: 0.001-0.005 Hot-Melt: NA	Reduce surface tension of the liquid; increase spreading and wetting properties	Polycarboxylic acid salt; polyglycolesters; mineral oil; polysiloxane copolymer
Antioxidant[a]	Organic Solvent: 0.01 Water: 0.005 Hot-Melt: 0.001	Retard oxidation	Aromatic amines; substituted phenolic compounds
Other Components[c]	All: Assume 0.01		

NA – Not available. Concentration data for surfactants used in these adhesive types have not been identified to date.
a - Source: Swanson et al. developed "typical" adhesive formulations for various organic solvent- and water-based adhesives used in foam furniture and bedding manufacture (Swanson et al., 2002).

b - Source: *CEB Cheat Sheets: Adhesive Manufacturing* (CEB, no date). These data are based on engineering judgment. No other data for typical concentrations of these component types have been identified to date.
c - Source: Specific component product specification sheets from Ciba Specialty Chemicals and Munzing, available at the *SpecialChem Adhesives & Sealants* web site (SpecialChem, 2006).

Table 1-4. Formulation of Moisture-Curable RTV Silicone Adhesives

Component	Weight Fraction	Function
Silicone Polymers	0.45-0.85	Adhesive polymer
Calcium Carbonate	0.20-0.30	Regulate viscosity and strengthen the bond from shear stress
Plasticizer	0.05-0.20	Improve flexibility and plastic flow properties
Silanes	0.05-0.07	Adhesion promoter
Fumed Silica	0.02-0.15	Regulate viscosity
Other	0.03-0.05	

Source: Petrie, 2004.

Table 1-5. Formulation of Moisture-Curable Urethane Adhesives

Component	Weight Fraction	Function
NCO Prepolymers	0.50-0.55	Adhesive prepolymer
Calcium Carbonate	0.33	Regulate viscosity and strengthen the bond from shear stress
Carbon Black	0.04-0.36	Pigment; adds conductivity
Silica	0.03-0.06	Regulate viscosity
Titanium Dioxide	0.02	Pigment
Toluene	0.01-0.02	Solvent

Source: Petrie, 2004.

Market Profile

22. Approximately 18 billion pounds (8.2 billion kilograms) of adhesives and sealants with an estimated value of $11 billion were used in the United States in 2003 (Impact Marketing, 2005). From 2003 to 2008 the market was estimated to grow by 12 percent, in terms of market value, and by 6 percent in terms of physical volume. Adhesives comprise more than 80 percent of the adhesives and sealants industry (Kirk-Othmer, 2002). Table 1-6 and Table 1-7 provide a summary of the U.S. consumption of adhesives by end use and by product type. Table 1-8 provides a matrix linking the end use markets covered in this ESD to the types of adhesives utilized in the industry.

Table 1-6. U.S. Consumption of Adhesives and Sealants by End-Use Market

End Use Market	Volume (million kg)[a]		Value ($ million)		Examples
	2003 (actual)	2008 (estimated)	2003 (actual)	2008 (estimated)	
Construction	567	608	1,850	2,050	Ceramic tile, carpet, piping, roofing, caulk
Consumer	88	95	460	510	Art and hobby, do-it-yourself, cosmetic
Dental and Medical	0.91	1.4	57	70	Orthodontic, joint replacement
Electrical and Electronic	34	39	180	220	Batteries, cables, motors, circuit boards
Industrial Assembly	231	249	680	820	Appliances, book binding, carpet, footwear, textiles
Miscellaneous	209	222	490	516	Jewelry, education
Packaging	3,221	3,562	4,130	4,650	Bags, container sealing, cardboard boxes, labels, tapes
Transportation	172	186	865	960	Aircraft, automobiles, marine, professional automotive repair
Wood and Related Products	3,665	3,711	2,290	2,520	Drywall, furniture, particleboard, plywood
Total	**8,188**	**8,674**	**11,002**	**12,316**	

Source: Impact Marketing, 2005.
a – Original data presented in pounds. Converted to kilograms by dividing by 2.2046 lb/kg.

Table 1-7. U.S. Consumption of Adhesives and Sealants by Product Type

Product Type	Volume (million kg)[a]		Value ($ million)	
	2003 (actual)	2008 (estimated)	2003 (actual)	2008 (estimated)
Adhesive Films	88	102	800	940
Aerosols	5.0	5.4	200	220
Binders	3,436	3,679	1,570	1,666
Conductive	0.45	0.45	40	50
Dental and Medical	0.45	0.91	45	65
General Purpose	3,726	3,843	5,972	6,630
Hot Melts	612	692	1,550	1,810
Pressure Sensitive	318	349	750	850
Radiation Curable	1.8	2.3	75	85
Total	**8,188**	**8,674**	**11,002**	**12,316**

Source: Impact Marketing, 2005.
a – Original data presented in pounds. Converted to kilograms by dividing by 2.2046 lb/kg.

Table 1-8. Matrix Relating Adhesive Types to End Use Markets

End Use Market	Market Application	Covered by the ESD	Natural-Binder Solution	Water-Based Solution / Dispersions (includes PSAs)	Solvent-Based Solution (includes PSAs)	Hot Melt (includes reactive hot-melts)	Reactive (includes UV Curable)
Construction	Carpet Layment			X	X	X	X
	Ceramic Tile			X			X
	Civil Engineering (e.g. bridge, highway)						X
	Concrete					X	X
	Countertop Lamination			X	X	X	
	Flooring Underlayment			X	X		X
	Glass/Window Glazing			X	X		X
	Heating, Ventilation, Air Conditioning			X	X		
	Joint Cements				X		X
	Manufactured Housing			X	X	X	X
	Resilient Flooring			X	X		X
	Roofing			X	X		X
	Wall Covering		X	X			
Consumer	Consumer Tapes	Partial[a,b]		X	X	X	
	Decorative Films	Partial[a,b]		X	X		
	Do-It-Yourself Products		X	X	X	X	X
	Model & Hobby Supplies			X		X	X
	School & Stationery Products		X	X		X	
Dental and Medical	Dental Fillings						X
	Surgical/Medical/First Aid Tape			X	X	X	
Electrical and Electronic	Electrical/Electronic Tape	Partial[a,b]		X	X	X	
	Electronics (e.g. circuit boards)	X			X	X	X
Industrial Assembly	Air & Liquid Filters	X		X	X	X	X
	Apparel Laminates	X		X		X	X
	Appliances	X		X		X	X

End Use Market	Market Application	Covered by the ESD	Natural-Binder Solution	Water-Based Solution / Dispersions (includes PSAs)	Solvent-Based Solution (includes PSAs)	Hot Melt (includes reactive hot-melts)	Reactive (includes UV Curable)
	Bookbinding/Graphic Arts	X	X	X		X	
	Fabric Combining	X		X		X	X
	Flocking Cements	X		X	X		X
	Footwear & Leather	X		X	X	X	X
	General Industrial Tape	X		X	X	X	
	Housewares	X		X	X	X	X
Industrial Assembly	Lamination	X		X	X	X	X
	Machinery	X		X	X	X	X
	Rug Backing	X		X		X	X
	Sandwich Panels	X		X	X	X	X
	Sports Equipment	X		X	X	X	X
Packaging	Bags		X	X		X	
	Carton Side Seam & Closure		X	X		X	
	Cigarettes/Filters		X	X			
	Composite Containers & Tubes		X	X		X	
	Corrugated Board		X	X		X	
	Cups		X	X			
	Disposables (Nonwovens)			X		X	
	Envelopes	X[b]		X	X	X	
	Flexible Packaging	X		X	X		X
	Labels/Signs/Decals	Partial[a,b]	X	X	X	X	
	Masking/Protective Tape	Partial[a,b]		X	X	X	
	Packaging Tape	Partial[a,b]		X	X	X	
	Remoistenable Products	X[b]	X	X	X	X	
	Specialty Packaging	X	X	X	X	X	X
Transportation	Aftermarket (Repair & Maintenance)			X		X	X
	Aircraft & Aerospace			X	X	X	X
	Exterior Vehicle Trim[c]	X		X	X	X	X
	Interior Vehicle Trim[c]	X		X		X	
	Marine/Shipbuilding			X	X	X	X
	Tire Manufacturing[c]	X		X			

End Use Market	Market Application	Covered by the ESD	Natural-Binder Solution	Water-Based Solution / Dispersions (includes PSAs)	Solvent-Based Solution (includes PSAs)	Hot Melt (includes reactive hot-melts)	Reactive (includes UV Curable)
	Rail				X		X
	Vehicle Assembly[c]	X			X	X	X
Wood and Related Products	Drywall Lamination			X	X		
	Furniture/Upholstery		X	X	X	X	X
	Plywood and Particleboard			X	X		X
	Woodworking/Windows, Doors, Cabinetry			X	X	X	X

Source: ASC, 2004; Kirk-Othmer, 2000.

a – The ESD covers the application of the adhesive to the tape, label, or other backing materials, but will not cover the use of the tape.

b – This market application is covered under labels and tapes manufacturing.

c – This market application is covered under motor and non-motor vehicle, vehicle parts, and tire manufacturing (except retreading).

2 PROCESS DESCRIPTION

23. The following subsections discuss in detail the formulation and industrial application of adhesive products:

- Section 2.1 presents information on the formulation process;
- Section 2.2 presents an overview on the application process; and,
- Section 2.3 presents typical formulations of adhesives.

Formulation

24. Adhesives are formulated by mixing together volatile and non-volatile chemical components, such as binders, plasticizers, and solvents in sealed, unsealed, or heated processes. The specific formulation process, which is outside the scope of this ESD, depends on the type of adhesive being produced. This ESD assumes that the formulation step occurs at a separate site from the application step. Additional information on the formulation of adhesives, including methodologies to estimate environmental releases and occupational exposures, can be found in the *Emission Scenario Document on Adhesive Formulation* (OECD, 2009).

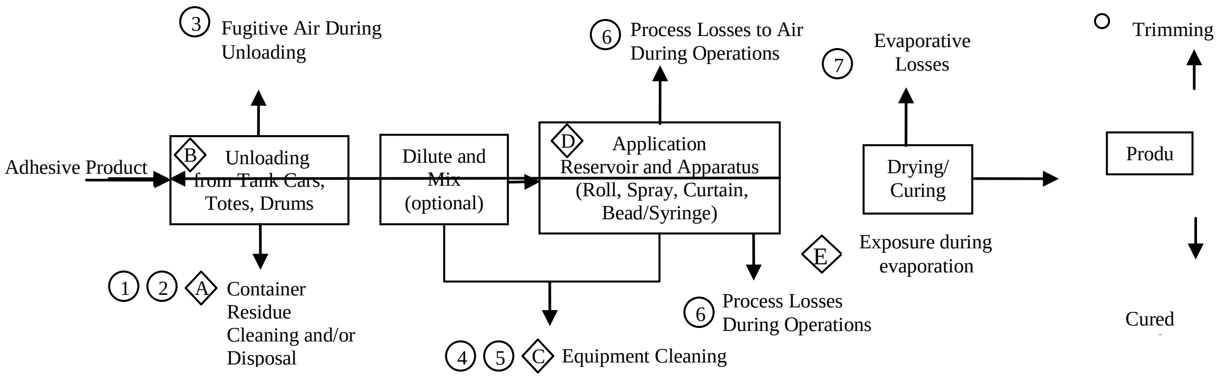
25. The main components of adhesive products typically include elastomers or adhesive polymers, tackifiers, fillers, and solvents; however, other components may include plasticizers, stabilizers, viscosity control agents, preservatives, surfactants, and antioxidants.

26. Table 1-3, Table 1-4, and Table 1-5 present general formulation information for adhesives. If only the general component type or function of the chemical of interest is known, these data may be used.

Adhesive Application

27. The adhesive application method will depend on a variety of factors including the type of adhesive, type of substrate, size and geometry of the substrate, and the precision requirement of the bond. Four application methods commonly used for adhesives are spray, roll, curtain, and syringe or bead application.[7] Figure 2-1 illustrates the general application process for adhesives and the associated release sources and worker exposure activities. Releases and exposures specific to each application method are discussed in greater detail in the following subsections.

[7] Note the *ESD on Radiation Curable Coating, Inks, and Adhesives (OECD, 2011)* discusses the application of radiation curable adhesives via spray, roll, or curtain coating. This ESD assumes the same application methods are applicable for the adhesive types covered in the scope of this ESD.



=Environmental Releases:

1. Container residues from adhesive transport container (release to water, incineration or land)
2. Open surface losses of volatile chemicals to air during container cleaning (release to air)
3. Transfer operation losses to air of volatile chemicals (release to air)
4. Equipment cleaning releases (release to water, incineration or land)
5. Open surface losses of volatile chemicals to air during equipment cleaning (release to air)
6. Application losses (overspray, application excess, or other application losses). Release to water, air, incineration, or land, depending on the application method utilized (e.g., spray coating or roll coating; see Section 4.7)
7. Evaporative losses during drying/curing (release to air or incineration)
8. Trimming wastes (release to incineration or land)

= Occupational Exposures:

A. Inhalation (volatile chemicals only) and dermal exposure to adhesives during container cleaning
B. Inhalation (volatile chemicals only) and dermal exposure during equipment loading/container unloading
C. Inhalation (volatile chemicals only) and dermal exposure during equipment cleaning
D. Inhalation (volatile and non-volatile chemicals) and dermal exposure during application
E. Inhalation (volatile chemicals only) exposure during drying/curing

Figure 2-1. General Adhesive Application Process

28. Liquid formulations are typically unloaded from transport containers (e.g. tank trucks, totes, drums) directly into the coating reservoir. Although adhesive products may be supplied using feed lines, this ESD assumes they are poured manually (Release 3, Exposure B). Solid formulations (e.g. hot melts) are typically received in solid shapes that are loaded directly into dispensing equipment. Transport containers may be cleaned off site by a third party. This ESD assumes container residues are disposed directly by the receiving facility, either by rinsing empty containers or discarding them directly to off-site landfills or incineration (Release 1, Release 2, Exposure A).

29. The application process involves applying the adhesive to a flat or three-dimensional substrate, joining the substrate, and curing. Once curing takes place, the chemical of interest is incorporated onto the substrate or article and is no longer a concern for release or exposure. Many methods are used to apply coatings. Each method has a working viscosity range that will produce a quality cure. Four coating applications represent the majority of adhesive application technologies and are discussed in this ESD: spray coating, roll coating, curtain coating, and syringe or bead application.

30. As stated above, application methods will vary according to the type of adhesive used to bond substrates; therefore, no end-use industry will employ an application method exclusively. To identify which application methods are most typically associated with industrial adhesives use, EPA conducted a review of all Premanufacturing Notices (PMNs)

submitted to EPA between January 2007 and June 2010 (see Appendix D).[8] EPA maintains a database of the functions and uses of chemicals reviewed under the PMN program (e.g. EPA's new chemicals review program). EPA conducted a query of this database to identify PMNs related to the industrial use of adhesives. The application methods identified by the PMN data query are summarized below in Table 2-1. The application methods summarized below are based directly on process descriptions provided within the PMN submissions. Overall, the table shows that most of these industries may utilize more than one application method.

Table 2-1. Application Methods Utilized by the End-Use Industries Covered in this ESD According to the PMN Data Query

End-Use Industry	Potential Application Method[a]
Computer/Electronics Manufacturing	Curtain Coating
	Roll Coating
	Syringe or Bead
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	Spray Coating
	Dip Coating
	Syringe or Bead
Flexible Packaging Manufacturing	Roll Coating
Labels and Tapes Manufacturing	Roll Coating
	Curtain Coating
General Assembly/Binding	Curtain Coating
	Roll Coating
	Dip Coating
	Syringe or Bead

a – Based on a sample of 77 PMNs submitted between 2007 and 2010 (see Appendix D).

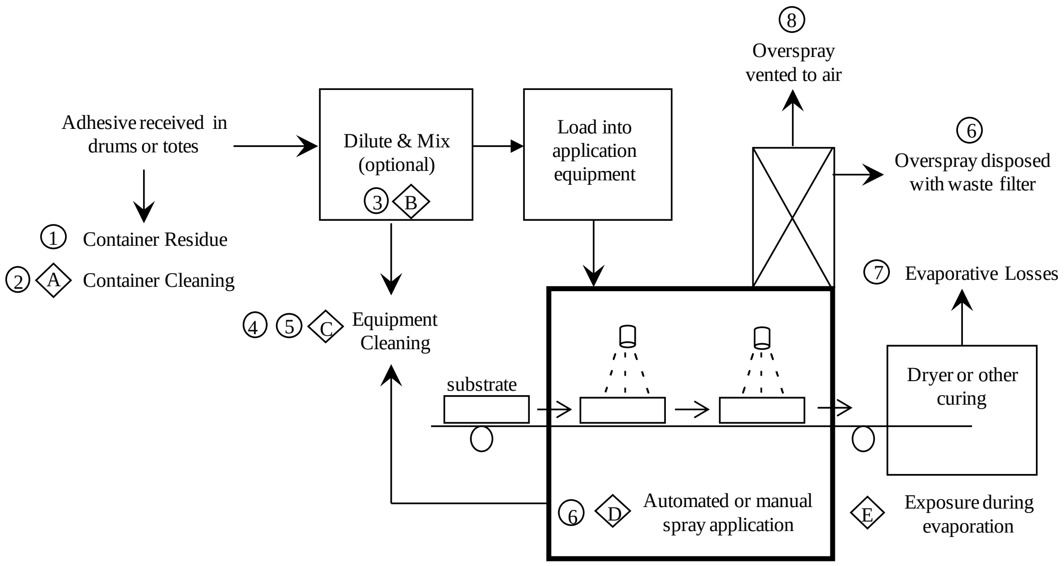
31. The vapor pressures associated with adhesive chemicals are typically expected to be below 0.001 torr, as based on the PMN data review. Based on a sample of 39 PMNs, a subset of the sample of 77 PMNs, 10% had vapor pressures between 0.001 and 35 torr. Only one of the reviewed PMNs was for a chemical with a vapor pressure greater than 35 torr. The remaining PMNs (87% of the sample) were for chemicals with vapor pressures below 0.001 torr. EPA assumes the volatilization of chemicals with a vapor pressure below 0.001 torr is negligible. Such chemicals result in negligible releases to air from volatilization and negligible associated inhalation exposures (CEB, 1994 and 1995); however, other air releases and associated inhalation exposure (e.g. overspray) from process operations may occur. Chemicals exceeding 35 torr are outside the scope of this ESD.

2.1.1 Spray Coating

32. In spray application compressed air is used to generate droplets or a mist of adhesive. Spray application is optimal for covering large surface areas. Whereas roll and curtain coating are typically limited to coating two-dimensional substrates (e.g. panels,

[8] PMNs are submitted to EPA under section 5 of the Toxic Substances Control Act (TSCA). In general, each PMN submission represents a distinct chemical substance that may enter commerce in the United States (e.g. two submissions would typically not be received for the same substance).

plywood, tape), spray application can be used for three-dimensional objects (e.g. automobile and aircraft parts). Figure 2-2 presents a preliminary process flow diagram for the spray application process.



=Environmental Releases:

1. Container residues from adhesive transport container (release to water, incineration, or land)
2. Open surface losses of volatile chemicals during container cleaning (release to air)
3. Transfer operation losses of volatile chemicals (release to air)
4. Equipment cleaning wastes (release to water, incineration, or land)
5. Open surface losses of volatile chemicals during equipment cleaning (release to air)
6. Overspray particulates/mists captured within spray area (release to water, air, incineration or land, depending on the control technology utilized; see Section 0)
7. Evaporative losses during drying or curing (release to air or incineration)
8. Overspray not captured by emission controls and vented to outside air (release to air)

= Occupational Exposures:

A. Inhalation (volatile chemicals only) and dermal exposure to adhesives during container cleaning
B. Inhalation (volatile chemicals only) and dermal exposure during equipment loading/container unloading
C. Inhalation (volatile chemicals only) and dermal exposure during equipment cleaning
D. Inhalation (volatile and non-volatile chemicals) and dermal exposure during spray application
E. Inhalation (volatile chemicals only) exposure during drying/curing

Figure 2-2. Spray Application Preliminary Process Flow Diagram

33. Spray application of adhesives is commonly used in furniture, automobile, and airplane manufacturing (EPA, 1995a; EPA, 1998). In furniture manufacturing, water-based solution adhesives (solvent-based have been mostly phased out) are spray applied in either an open top workbench spray area with side panels that may have some local ventilation, or in an open room with no mist containment and general room ventilation. After the adhesive is sprayed, the pieces are pressed together and allowed to bond (Swanson, 2002). This technique is commonly used to bond foam pads to seat backings or other furniture surfaces.

34. As shown in Figure 2-2, occupational exposure may occur during container unloading, handling, and transfers. Additionally, mist will be generated during the spray application process. If the spray application equipment is automated and enclosed, occupational exposure may be minimized; however, exposure may occur during manual application. Overspray will be the major release source for spray application; however,

releases of both volatile and non-volatile components may also occur from container residue and equipment cleaning.

35. The quantity of release and media of release will vary significantly between volatile and non-volatile components. Volatile components are expected to evaporate from open surfaces during container cleaning, transfers, and equipment cleaning. Additionally, as the adhesive is sprayed and dried the majority of volatile components are expected to evaporate and be released to air (e.g. 100 percent of the applied solvent will evaporate). In contrast, non-volatile components are expected to adhere to the desired substrate, fall to the shop floor, or be captured by control technologies. Inhalation exposure to volatile components will also be significantly greater.

2.1.2 Roll Coating

36. In roll coating, a continually spinning roller brush applies the adhesive to the substrate as it moves past. The adhesive is carried from the reservoir to the substrate by the roller. A blade, air-knife, or metering roller may be used to control the thickness of the adhesive. Figure 2-3 presents a preliminary process flow diagram for the roll coating process.

37. There are many variants of roll coating; however, they all are based on a similar principle. Some variants include (NEWMOA, 1999):

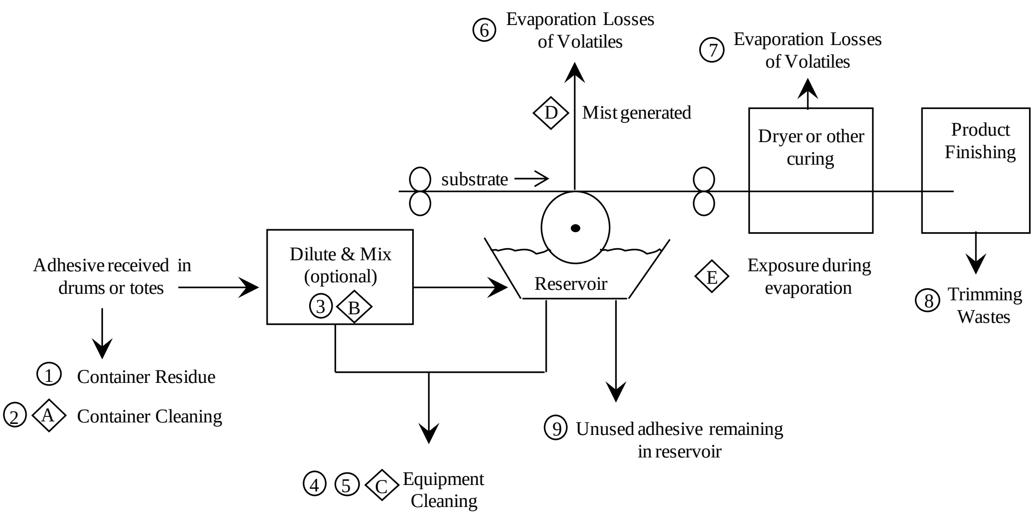
- Direct roll coating – one roller transfers the adhesive from the reservoir to the substrate. In direct roll coating, the roller and the substrate move in the same direction.

- Reverse roll coating – similar to direct roll coating in that one roller transfers the adhesive from the reservoir to the roller; however, the roller is moving in the opposite direction of the substrate. Reverse roll coating can produce smoother and more uniform coatings than direct roll coating.

- Off-set roll coating – two rollers are used in off-set coating. One roller is in contact with the reservoir and transfers the coating to another roller spinning in the opposite direction in contact with the substrate. Off-set coating is more precise than direct or reverse coating.

- Gravure coating – the rollers are engraved with designs and patterns; therefore, the adhesive is applied in a desired pattern. This is more common for coatings, but may be used for certain adhesive applications.

38. Roll coating is common for items that can be wound (e.g. tapes, laminates). The primary limitation of roll coating is that it can only be used for two-dimensional surfaces.



=Environmental Releases:

1. Container residues from adhesive transport container (release to water, incineration or land)
2. Open surface losses of volatile chemicals to during container cleaning (release to air)
3. Transfer operation losses of volatile chemicals (release to air)
4. Equipment cleaning wastes (release to water, incineration or land)
5. Open surface losses of volatile chemicals during equipment cleaning (release to air)
6. Evaporation losses of volatiles during adhesives application (release to air)
7. Evaporation losses of volatiles during drying or curing (release to air or incineration)
8. Trimming wastes from product finishing (release to incineration or land)
9. Unused adhesive remaining in reservoir (release to water, incineration or land)

= Occupational Exposures:

A. Inhalation (volatile chemicals only) and dermal exposure to adhesives during container cleaning
B. Inhalation (volatile chemicals only) and dermal exposure during reservoir loading/container unloading
C. Inhalation (volatile chemicals only) and dermal exposure during equipment cleaning
D. Inhalation (volatile and non-volatile chemicals) exposure during adhesive roll coating application
E. Inhalation (volatile chemicals only) during drying/curing

Figure 2-3. Roll Coating Preliminary Process Flow Diagram

39. A common application of roll coating is tape manufacturing. Tape manufacturing begins with a large roll of backing or web. One side of the backing is generally pre-coated with a release coating to which the adhesive does not stick. Using a roll coating process the other side of the tape is coated with a PSA. The tape then passes through a drier or curing unit and is finally wound and cut into the desired size (NEWMOA, 1999). Other industrial applications of roll coating may include lamination, cardboard manufacturing, and resilient flooring manufacturing.

40. As shown in Figure 2-3, occupational exposure may occur from roll coating during container unloading, handling, and transfers. Additionally, mist may be generated by the roll coating process depending on the speed of the rollers. However, the roll coating process may be contained, limiting the potential inhalation exposure. Releases may occur from container residue, equipment cleaning, and from unused adhesives remaining in the reservoir.

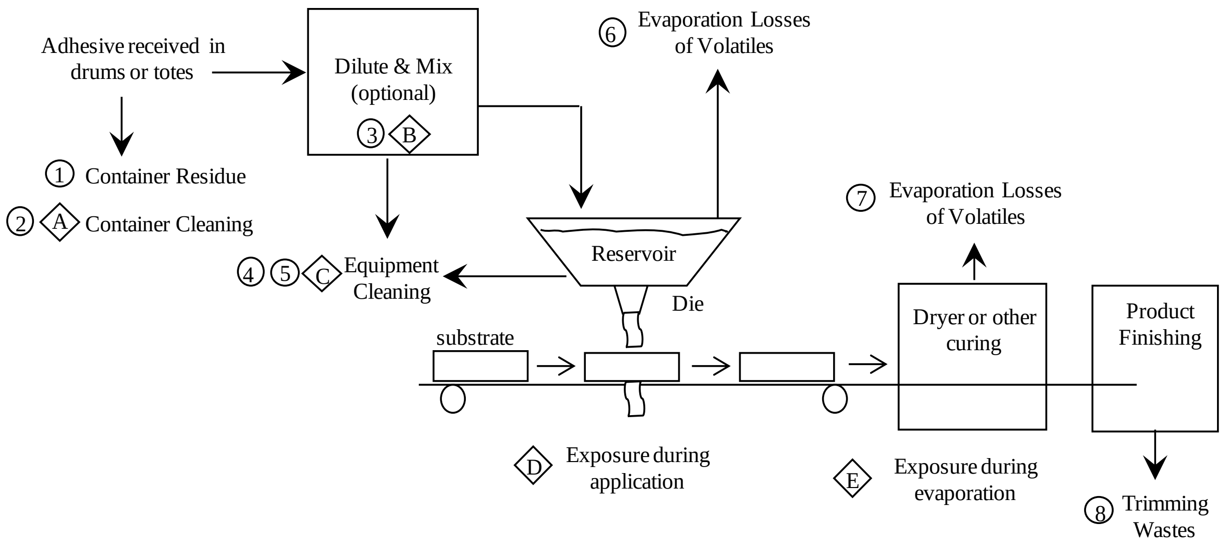
41. The quantity of release and media of release will vary significantly between volatile and non-volatile components. Volatile components are expected to evaporate from open surfaces during container cleaning, transfers, and equipment cleaning. Additionally, as the adhesive is dried or cured the majority of volatile components are expected to evaporate and

be released to air (e.g. 100 percent of the applied solvent will evaporate). In contrast, non-volatile components are expected to adhere and remain on the substrate. Inhalation exposure to volatile components will also be significantly different.

2.1.3 Curtain Coating

42. Curtain coating is similar to roll coating; however, instead of the adhesive being applied by the roller, the adhesive is applied as the substrate passes through a liquid curtain. The adhesive falls from a bath with an aperture or die onto the substrate. A blade, air-knife, or metering roller may be used to control the thickness of the adhesive. Figure 2-4 presents a preliminary process flow diagram for the curtain coating process.

43. Curtain coating derives its name from the fact that a sheet of liquid is formed at a die and allowed to fall freely to a substrate passing underneath (Converting Magazine, 2002). Figure 2-4 illustrates a typical curtain coating system.



=Environmental Releases:

1. Container residues from adhesive transport container (release to water, incineration or land)
2. Open surface losses of volatile chemicals during container cleaning (release to air)
3. Transfer operation losses of volatile chemicals (release to air)
4. Equipment cleaning wastes (release to water, incineration or land)
5. Open surface losses of volatile chemicals during equipment cleaning (release to air)
6. Evaporation losses of volatiles during adhesives application (release to air)
7. Evaporation losses of volatiles during drying or curing (release to air or incineration)
8. Trimming wastes from product finishing (release to incineration or land)

= Occupational Exposures:

A. Inhalation (volatile chemicals only) and dermal exposure to adhesives during container cleaning
B. Inhalation (volatile chemicals only) and dermal exposure during reservoir loading/container unloading
C. Inhalation (volatile chemicals only) and dermal exposure during equipment cleaning
D. Inhalation (volatile chemicals only) exposure during adhesive application
E. Inhalation (volatile chemicals only) exposure during drying/curing

Figure 2-4. Curtain Coating Preliminary Process Flow Diagram

44. Curtain coating requires low viscosity formulations that are clear or have low filler concentrations (RadTech, 1995). The curtain is formed by the coating fluid issued from a precision die, typically from a height of 10-30 cm above the substrate. The edges of the curtain are pinned to prevent "necking" or narrowing of the curtain near the substrate. The coating solution wets and spreads on the substrate through a combination of surface energy and the momentum of the falling liquid (Converting Magazine, 2002). The portion of the coating that is not transferred onto the substrate will drip into collection tunnels and may be recycled to the feed reservoir or disposed (CEB, 2008b). In adhesive application processes, the curtain must flow smoothly over the substrate so that the adhesive is applied evenly and efficiently, which negates the potential for mist or splashing; therefore, no mists and corresponding occupational exposures are expected from this coating operation. Figure 2-5 shows the general flow of the liquid as it exits the precision die and contacts the substrate.

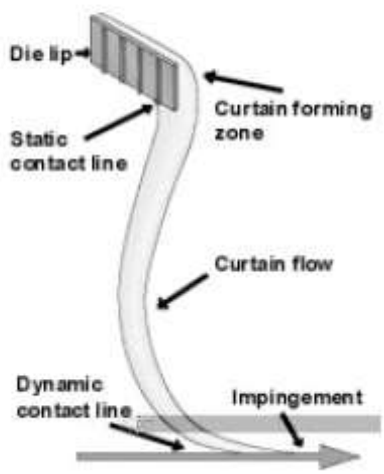


Figure 2-5. Curtain Flow during Coating Process

Source: Converting Magazine, 2002.

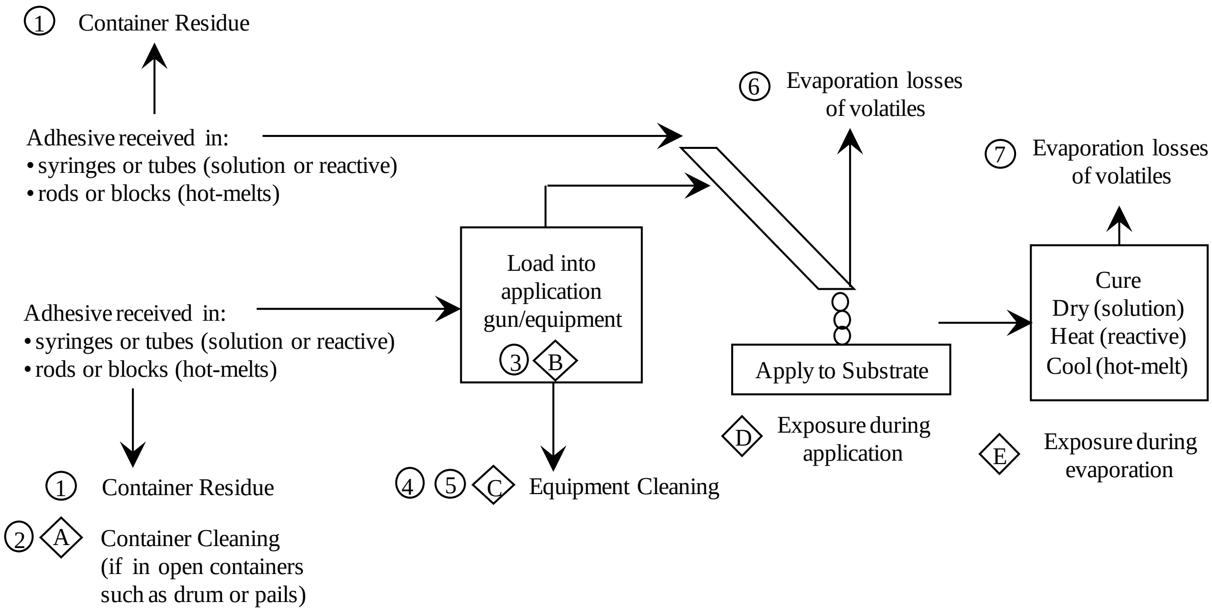
45. The transfer efficiency of coating to substrate also ranges from 90 to 98 percent for curtain coating methods and fits well with higher film builds and finishing flat stock (P2Pays, 1997). Excess coating material that did not adhere to the substrate may be collected and recycled to the feed reservoir. Limited information was found on the disposal of spent coating material. EPA assumes disposal to incineration or landfill (Release 6) as these are the most likely environmental release media. This ESD assumes that the feed trough is disposed and recharged with new coating material daily as a conservative estimate.

2.1.4 Syringe or Bead Application

46. In syringe or bead application the adhesive is squeezed out of a tube or syringe as a liquid (e.g. two-part epoxies) or extruded from a glue gun in beads or lines (e.g. hot glue gun) onto the substrate. The adhesive may be applied in long lines or beads or applied in small quantities to an exact location (e.g. an adhesive to bond a chip to a circuit board). Figure 2-6 presents a preliminary process flow diagram for syringe or bead application.

47. Syringe or bead application is generally chosen over other application techniques when the adhesive only needs to be applied to specific locations. Spray applied adhesives will cover the entire surface; syringe or bead applied adhesives can be localized.

Additionally, expensive spray or roll application equipment is not required for syringe applied adhesives; however, most electronic adhesives are precisely applied using automated equipment. The localization of the application of syringe or bead adhesives is also their principle disadvantage. Whereas spray, roll, or curtain applied adhesives will distribute the adhesive load over the entire surface of the bonded substrates, syringe and bead applied adhesives can only support loads where they are applied.



=Environmental Releases:

1. Container residues from adhesive transport container (release to incineration or land)
2. Open surface losses of volatile chemicals during container cleaning (release to air)
3. Transfer operation losses of volatile chemicals (release to air)
4. Equipment cleaning wastes (release to water, incineration or land)
5. Open surface losses of volatile chemicals during equipment cleaning (release to air)
6. Evaporation losses of volatiles during adhesive application (release to air)
7. Evaporation losses during drying or curing (release to air or incineration)

= Occupational Exposures:

A. Inhalation (volatile chemicals only) and dermal exposure to adhesives during container cleaning
B. Inhalation (volatile chemicals only) and dermal exposure during equipment loading/container unloading
C. Inhalation (volatile chemicals only) and dermal exposure during equipment cleaning
D. Inhalation (volatile chemicals only) exposure during adhesive application
E. Inhalation (volatile chemicals only) exposure during drying/curing

Figure 2-6. Syringe or Bead Application Preliminary Process Flow Diagram

48. Some common end use markets for bead or syringe applied adhesives include:

- Electronic circuit board manufacturing – epoxies and polyimides with conductive additives are commonly used in semiconductor manufacturing in the die attach process to attach silicon wafers to their support structures (SiliconFarEast, 2006).

- Book binding – After the collection of pages is set, the edge to be bound is ground off to provide a rough surface for the adhesive to bind to. Hot-melt adhesives are commonly applied to the surface and the cover attached (Kirk Othmer, 2002).

- Furniture manufacturing – lines of hot-melt or polyvinyl acetate (water-based solution) adhesives are applied to seams to bind wood pieces together (EPA, 1995).

49. Of the application methods presented in this ESD, syringe or bead application has the lowest potential for environmental release and occupational exposure during application.

50. Container residuals may serve as an environmental point of release for this application type if the adhesive is received in drums or pails (e.g. two-part epoxies). However, direct disposal of syringes, tubes, rods, blocks, or pellets containing the chemical of interest is most likely based on engineering judgment. Equipment cleaning may also contribute to environmental releases, depending on the type of adhesive used. Equipment cleaning releases are expected for liquid adhesives but not hot melts. All releases are expected to be to incineration or landfill, as direct release to water or air is not probable. Environmental releases from overspray and adhesive remaining in the reservoir are not expected.

51. During application, mist generation is not expected; however, inhalation exposure may occur to volatile components.

52. Based on engineering judgment, dermal exposures are not expected. This is because the adhesive is most likely enclosed in small containers (solution or reactive adhesives) or entrained in solid rods or blocks (hot melts), which negates the potential for dermal exposures during container unloading or cleaning. Furthermore, this application type utilizes automated equipment or mechanical tools (e.g. glue guns) to apply adhesives in a controlled and highly localized manner. In such instances, these adhesives are extruded directly onto substrates from syringes/glue guns and then dried/cured; therefore, the potential for direct dermal contact during application is negligible.

53. For hot-melt adhesives, the potential for dermal exposure is further mitigated by the fact that it must be heated during application. Application temperatures may range from 150 to 190°C (Ullman, 1985). Per EPA qualitative assessments, dermal exposures to chemicals handled at temperatures exceeding 140°F (60°C) are assessed as negligible (CEB, 1991a).

Equipment Cleaning

54. Limited information was found regarding standard equipment cleaning practices within the various industries that use adhesive products. A flexible packaging manufacturing site visited by EPA (ERG, 2009) during the development of this ESD cleaned cylinders and pans from the roll coating equipment by wiping them with brushes and rags. Cylinders, pans, and sumps are also cleaned using solvent rinsing, and the rinsate is collected in drums and handled as waste. If needed, cylinders could undergo additional cleaning to remove cured adhesive in a water bath using ultra-sonic cleaning. The spent wash water is pretreated on site and sent to the local publicly-owned treatment works (POTW). Pans could also undergo additional cleaning using a solvent wash machine. Spent solvent from the wash machine is collected and sent for off-site incineration. This particular facility cleaned equipment at the end of each campaign (job run) (ERG, 2009). While some facilities may clean process

equipment after a campaign, this ESD assumes that the residues are removed daily as a conservative estimate.

3 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES FOR THE USE OF ADHESIVE PRODUCTS

55. This ESD presents EPA's standard approach for estimating environmental releases of and worker exposures to components in adhesive products during the application and curing of the product onto an article or substrate.

56. The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible; however, EPA acknowledges several areas in which additional adhesive products industry data are needed. These data needs are summarized in Section 7. It should be noted that the default values cited throughout this ESD are intended to be used only when appropriate site-specific or industry-specific information is not available. Because this ESD presents several alternative default assumptions or values for some estimation parameters, one must consider carefully how the selection of these defaults will affect the final assessment results.

57. This section of the ESD presents general facility calculations for application sites, which estimate daily use rates of adhesive products, the number of application sites using the chemical of interest, and the number of days the chemical is expected to be used in the application process.

58. Section 4 of the ESD presents the environmental release assessments for several application methods, which use the general facility estimates to estimate the quantity of chemical released from various points in the application process and the most likely media of release for each release source.

59. Section 5 of the ESD presents the occupational exposure assessments of several application methods, which use both the general facility estimates and release estimates to estimate the number of workers potentially exposed while performing various process activities and the corresponding potential level (quantity) and routes of those exposures.

Introduction to the General Facility Estimates

60. Throughout the remainder of this section, a method utilizing available adhesive products industry data is described to determine daily use rate of the chemical of interest for an application site. The daily use rate can be estimated using several facility parameters, including the annual facility production use rate ($Q_{app\_site\_yr}$); the number of application sites that may use a particular product containing the chemical of interest (N_{app_sites}); and the days of operation ($TIME_{app\_working\_days}$). Industry data for adhesives production is provided in Table 1-6. Additional information on the number of application sites was obtained from the 2002 Economic Census (USCB, 2005a-f).

61. Combined with available formulation data presented in Table 1-3, market production data and census data can be used to calculate the annual facility production use rate and daily

use rate of the chemical of interest. The number of shipping containers that are transferred into the operation annually can also be determined.

62. The general facility estimates described in this section are summarized with their associated inputs/bases and corresponding ESD section number in Table 3-1. In addition, Table A-2 in Appendix A presents a detailed summary of the default values used as inputs to each of the general facility estimates, accompanied by their references.

Table 3-1. Summary of General Facility Parameters for Application Sites

Parameter	Description	ESD Section
$F_{app\_adhesive}$	Fraction of the total adhesive product type used that contains the chemical of interest (Default: 1 kg product containing the chemical/kg total product used).	3.1
$Q_{app\_site\_yr}$	Annual facility adhesive product use rate containing the chemical of interest (kg product containing the chemical/site-yr).	
$Q_{app\_site\_use\_rate}$	Total annual facility adhesive product use rate (kg/site-yr) (See Section 0 for default production use rates).	0
$TIME_{app\_working\_days}$	Annual number of days the formulation product is applied at each facility (days/yr).	
F_{chem_comp}	Mass fraction of the chemical of interest in the adhesive component (kg chemical/kg component).	0
F_{comp_form}	Mass fraction of the component used in the formulated adhesive product (kg component/kg product).	0
F_{chem_form}	Mass fraction of the chemical of interest in the formulated adhesive product (kg chemical/kg product).	0
$N_{bt\_site\_year}$	Annual number of batches of adhesive used, per site (batches/site-year).	0
Q_{app_bt}	Mass of adhesive product used per batch (kg product/batch).	
$N_{bt\_site\_day}$	Daily number of batches of adhesive used at each site (batch/site-day).	
$Q_{app\_chem\_site\_day}$	Daily use rate for the chemical of interest at each facility (kg of chemical/site-day).	0
Q_{chem_yr}	Annual production volume of the chemical of interest for the end use being assessed (kg chemical/yr).	0
N_{app_sites}	Number of facilities using the chemical of interest in application processes (sites).	
$N_{form\_cont\_empty\_site\_yr}$	Annual number of chemical-containing adhesive product containers emptied per facility (container/site-yr).	0
Q_{cont_empty}	Mass of the adhesive product in the container (kg product/container).	
V_{cont_empty}	Volume of adhesive product per container (Default: 208 L product/container (55-gallon drum); See Table B-1 in Appendix B for alternative default container volumes).	
$RHO_{formulation}$	Density of the adhesive product (Default: 1 kg product/L product).	

63. The method described in the remaining sections incorporates certain assumptions in cases where industry-specific data were not found. These key assumptions are presented throughout this section and are accompanied by a discussion of their uncertainties and potential effects on the estimates.

64. In lieu of site-specific information, it is assumed that the chemical of interest is in all adhesive products used at an application site ($F_{app\_adhesive}$ = 1 kg product incorporating

chemical/kg total product applied). The following calculation may be used to determine the annual facility use rate for the adhesive product containing the chemical of interest ($Q_{app\_site\_yr}$):

$$Q_{app\_site\_yr} = Q_{app\_site\_use\_rate} \times F_{app\_adhesive} \quad \text{(Eqn. 3-1)}$$

Where:

$Q_{app\_site\_yr}$	=	Annual facility adhesive product use rate containing the chemical of interest (kg product containing the chemical/site-yr)
$Q_{app\_site\_use\_rate}$	=	Total annual facility adhesive product use rate (kg/site-yr) (See Section 0 for default production use rates.)
$F_{app\_adhesive}$	=	Fraction of the total adhesive product type used that contains the chemical of interest (Default: 1 kg product containing the chemical/kg total product used)

Annual Facility Adhesive Product Use Rate and Number of Operating Days

65. This section summarizes the annual facility adhesive product use rate ($Q_{app\_site\_use\_rate}$) for the end-use markets covered in the scope of this ESD as well as the number of operating days ($TIME_{app\_working\_days}$) associated with each end use. Some $Q_{app\_site\_use\_rate}$ parameters are estimated using available 2003 consumption rates for adhesive products by various end-use industries and assumed associated number of application sites, which are determined by end-use markets. Some $Q_{app\_site\_use\_rate}$ parameters are estimated from industry-supplied data. Appendix C presents two of the three methods used for estimating $Q_{app\_site\_use\_rate}$. The first is a general methodology used to derive $Q_{app\_site\_use\_rate}$ for three end-use markets based on a “top-down” approach (e.g. national use rate data divided by the number of sites). A second method for one end-use market estimates $Q_{app\_site\_use\_rate}$ using site-specific data. For this method, site-specific use rates obtained from industry were used as what-if use rates across the given end-use market. The third method for the generic “general assembly” end-use market is shown in 3.1.5 and estimates $Q_{app\_site\_use\_rate}$ using PMN data and assumptions. Each approach references available data sources for production and facility information and identifies general assumptions and limitations in the derived facility use rates. The recommended default value for $Q_{app\_site\_use\_rate}$ depends on the type of adhesive product (e.g. water-based, organic solvent-based, hot-melt) and the end-use market.

66. Figure 3-1 presents a logic diagram that can be used to determine the appropriate defaults for $Q_{app\_site\_use\_rate}$. Specific discussion of the defaults, including the sources and methodology used to estimate them, are presented in subsections 3.1.1 through 3.1.5. A summary of the defaults recommended by this ESD are also provided in Table 3-2.

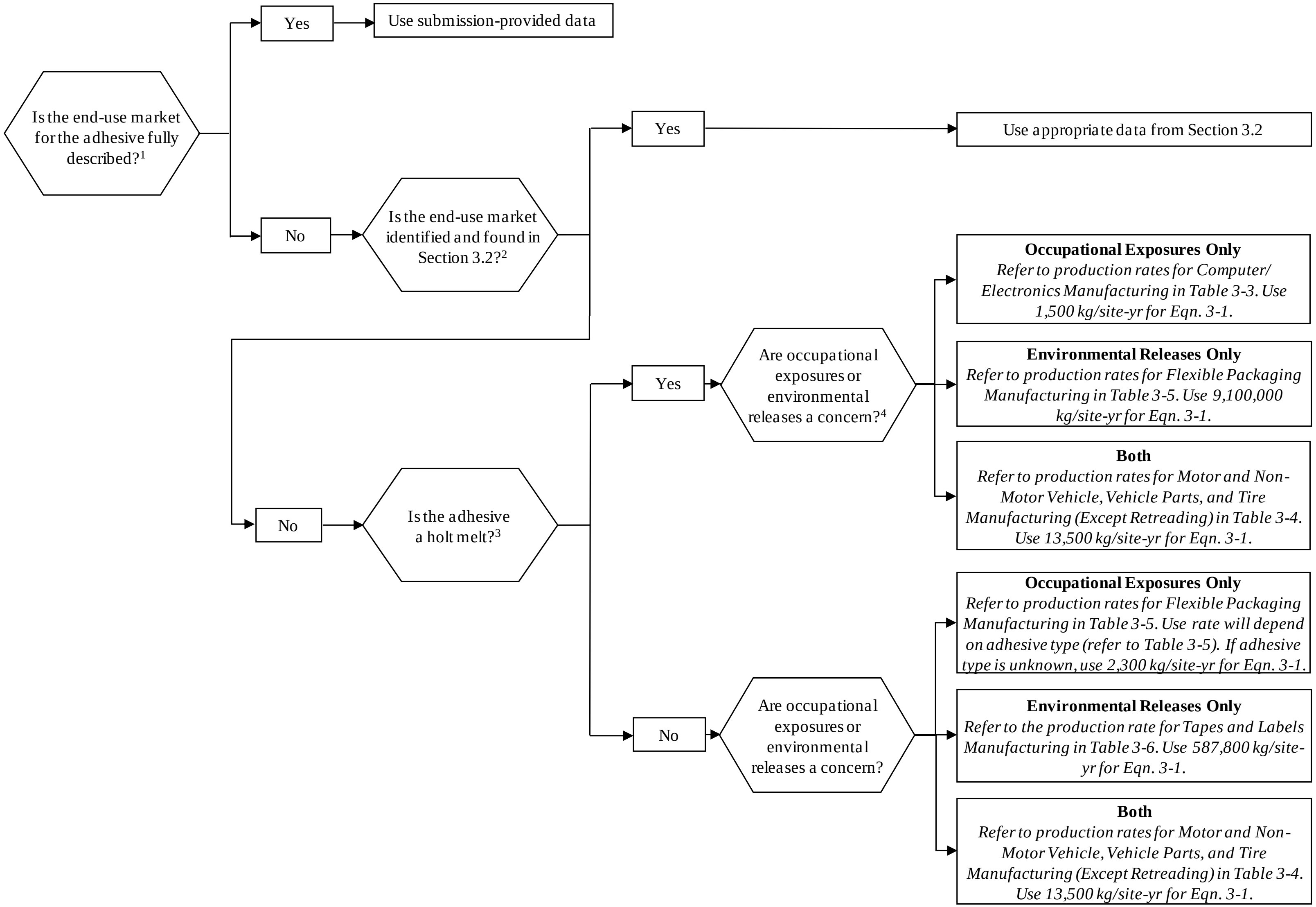
67. The industries covered in this ESD were selected based on the results of the PMN data review (see Appendix D) and represent the top five industries associated with industrial adhesive use. The reader should note that the general assembly end-use comprises a wide range of industries, which have been collectively identified as “General Assembly/Binding.” While this end-use industry spans a wide range of industrial adhesive uses, it is not intended to be utilized as a catchall category for assessing adhesives that are not relevant to the other industries presented in this ESD. The general assembly end-use industry should only be used

if the assessed chemical is an industrial adhesive used in the general assembly or binding of individual components into a final multi-component product.

Table 3-2. Summary of Recommended Default Values for Annual Adhesive Use Rates by Industry Category

General End-Use Category	Default $Q_{app\_site\_use\_rate}$ (kg/site-yr)	Estimation Methodology
Computer/Electronic and Electrical Product Manufacturing	1,500[a]	Average use rate derived from adhesive consumption rates using a “top-down” approach.
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	13,500[b]	Average use rate derived from adhesive consumption rates using a “top-down” approach.
Flexible Packaging Manufacturing	2,300 to 9,100,000 (value will depend on the adhesive type used; see Table 3-5)[c]	What-if use rate derived from site-specific data using the “bottom-up” approach.
Labels and Tapes Manufacturing	587,800[d]	Average use rate derived from adhesive consumption rates using a “top-down” approach.
General Assembly	141,498[e]	What-if use rate estimated from PMN data submitted to EPA between 2007 and 2010.

[a] See Section 3.1.1 for discussion of data sources and limitations.
[b] See Section 3.1.2 for discussion of data sources and limitations.
[c] See Section 3.1.3 for discussion of data sources and limitations.
[d] See Section 3.1.4 for discussion of data sources and limitations.
[e] See Section 3.1.5 for discussion of data sources and limitations.



Is the end-use market for the adhesive fully described?[1]
Yes
Use submission-provided data
No
Is the end-use market identified and found in Section 3.2?[2]
Yes
Use appropriate data from Section 3.2
No
Is the adhesive a holt melt?[3]
Yes
Are occupational exposures or environmental releases a concern?[4]
Occupational Exposures Only
Refer to production rates for Computer/ Electronics Manufacturing in Table 3-3. Use 1,500 kg/site-yr for Eqn. 3-1.
Environmental Releases Only
Refer to production rates for Flexible Packaging Manufacturing in Table 3-5. Use 9,100,000 kg/site-yr for Eqn. 3-1.
Both
Refer to production rates for Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading) in Table 3-4. Use 13,500 kg/site-yr for Eqn. 3-1.
No
Are occupational exposures or environmental releases a concern?
Occupational Exposures Only
Refer to production rates for Flexible Packaging Manufacturing in Table 3-5. Use rate will depend on adhesive type (refer to Table 3-5). If adhesive type is unknown, use 2,300 kg/site-yr for Eqn. 3-1.
Environmental Releases Only
Refer to the production rate for Tapes and Labels Manufacturing in Table 3-6. Use 587,800 kg/site-yr for Eqn. 3-1.
Both
Refer to production rates for Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading) in Table 3-4. Use 13,500 kg/site-yr for Eqn. 3-1.

Figure 3-1. Logic Diagram to Determine Appropriate Defaults for $Q_{app\_site\_use\_rate}$ and $TIME_{app\_working\ days}$[9]

Footnotes:

1) If the specific end-use market (e.g. computer/electronics, tapes and labels, etc.) for the adhesive product is fully described in the PMN submission (e.g. number of sites, days of operation per year, application method) then submission-specific data should be used.

2) If the end-use of the adhesive product is known but is not fully described in the PMN submission, then data from Section 0 (e.g.$Q_{app\_site\_use\_rate}$ or $TIME_{app\_working\ days}$) should be used for the appropriate end-use market.

3) If the end-use is unknown then $Q_{app\_site\_use\_rate}$ must be assumed based on adhesive type. If the adhesive type is unknown, EPA recommends assuming that the adhesive is not a hot melt, as this will result in more a conservative release/exposure assessment. This is because syringe or bead application has the lowest potential for environmental release and occupational exposure relative to the other application methods presented in this ESD (see Section 2.1.4). When selecting $Q_{app\_site\_use\_rate}$ based on potential concerns, EPA typically uses the following methodology to make conservative assessments. For conservative occupational exposure estimates, facilities with the lowest $Q_{app\_site\_use\_rate}$ are typically selected. This maximizes the number of use sites and therefore maximizes the number of workers. In this instance, an industry is chosen that provides both a low $Q_{app\_site\_use\_rate}$ and an application method that results in occupational exposures to workers. For conservative environmental release assessments, facilities with the highest $Q_{app\_site\_use\_rate}$ are typically selected. This maximizes $Q_{app\_site\_use\_rate}$ and therefore results in the highest daily release. If both releases and exposures are a concern, median values are typically utilized.

4) If the adhesive is known to be a hot melt, then a facility use rate must be assumed based on potential concerns. For conservative occupational exposure estimates, refer to the $Q_{app\_site\_use\_rate}$ for Computer/Electronics Manufacturing. This selection maximizes the number of use sites and therefore maximizes the number of workers. For conservative environmental release assessments, refer to the $Q_{app\_site\_use\_rate}$ for Flexible Packaging Manufacturing. This selection maximizes the daily use rate and therefore results in the highest daily release. If both releases and exposures are a concern, refer to the $Q_{app\_site\_use\_rate}$ for Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading). This selection provides median values for assessing both exposures and releases.

[9] Logic diagram footnotes are provided on the following page.

3.1.1 Computer/Electronic and Electrical Product Manufacturing

68. This end-use market includes manufacturers of computer and electronic products (NAICS code 334) and electrical equipment, appliances, and components (NAICS code 335). Average facility use rate data is derived from industry-provided adhesive annual production volume data consumed by this market in 2003 (Impact Marketing, 2005) and number of facilities provided in the 2002 Economic Census (USCB, 2005a and 2005b). Although Impact Marketing also provided 2008 projected adhesive production volumes, these data are not used for the following reasons: 1) it is preferable to use actual data over projected data, and 2) it is preferable to use annual production volumes and number of facilities compiled from the same year. As following the second reason is not possible given the available sources, the annual production volume data are used from the year that most nearly coincides with the year in which the U.S. Census Bureau compiled the number of facilities.

69. The average annual facility use rate, as derived from industry and NAICS data, is provided below in Table 3-3. To determine the average facility use rate on a daily basis, as provided in the final column, the annual use rate is divided by the number of operating days typical of end-use sites. $TIME_{app\_working\_days}$ is based on a review of PMN data submitted to EPA between 2007 and 2010 for adhesives (see Appendix D), which indicates there may be up to 365 exposure days per year at non-submitter-controlled sites. EPA assumes that the number of operating days per year is equal to the number of exposure days per year reported in the PMN submissions. If the number of days of operation is not known, $TIME_{app\_working\_days}$ should be assumed to be equal to 365 operating days per Table 3-3.

Table 3-3. Input Data and Facility Use Rate Estimate for Adhesives Use in Computer/ Electronic and Electrical Product Manufacturing

End-Use Market Volume of Adhesives (kg/year)[a]	Number of Sites[b]	$Q_{app\_site\_use\_rate}$ (kg/site-year)	$TIME_{app\_working\_days}$[c]
34,000,000	22,294	1,500	365

a – Impact Marketing Consultants, Inc., 2005 (data reproduced and presented in Table 1-6)
b – U.S. Census Bureau, 2005a and 2005b
c – Based on PMN data (see Appendix D). EPA conservatively assumes the number of operating days per year is equal to the largest value identified for this end-use category during the PMN data review.

70. EPA received information from a trade association regarding the use of adhesives in computer/electronic and electrical product manufacturing. The information was provided based on industry experience and is not based on specific data or industry surveys. In lieu of more specific data, and given the trade associations' experience with computer/electronics manufacturing, EPA assumes this information is representative of industry.

71. Conversations with the Information Technology Industry Council (ITIC) (ERG, 2011) indicate that the bulk of the adhesives used by this industry group is for manufacturing individual computer/electronics components, which are assembled downstream by original equipment manufacturers (OEMs). To a limited extent, adhesives may also be used

upstream, where multi-component computer/electronics products are assembled using syringe or bead application methods.

72. The Institute for Printed Circuits (IPC), which represents the design, printed circuit board manufacturing, and electronics assembly industries, has stated that this industry applies adhesives through syringes or applicators when manufacturing individual computer/electronics components (IPC, 2011). The proportion of syringes to applicators was stated to be 50/50. The applicators were described as being small tubes or cans of varying shapes.

3.1.2 Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)

73. This section discusses the use of adhesives during the manufacture or assembly of automobiles, non-automotive vehicles (e.g. trailers), and vehicle components (e.g. interiors, exteriors, vehicle parts, or tires). The number of end-use sites is estimated from U.S. Census data for industry group-level NAICS codes 3361, 3362, and 3363 (Motor Vehicle Manufacturing, Motor Vehicle Body and Trailer Manufacturing, and Motor Vehicle Parts Manufacturing, respectively). The specific NAICS code 326211 (Tire Manufacturing (Except Retreading)) is also included, based on literature identifying tire manufacturing as pertaining to automotive applications for water-based adhesives (Kusumgar, 2000).

74. Average facility use rates are derived from adhesives consumption data for 2003 (Impact Marketing, 2005) and number of facilities provided in the 2002 Economic Census (USCB, 2005c and 2005d). Although Impact Marketing also provided 2008 projected adhesive production volumes, this data is not used for the following reasons: 1) it is preferable to use actual data over projected data, and 2) it is preferable to use annual production volumes and number of facilities compiled from the same year. As following the second reason is not possible given the available sources, the annual production volume data is used from the year that most nearly coincides with the year in which the U.S. Census Bureau compiled the number of facilities.

75. The average annual facility use rate, as derived from industry and NAICS data, is provided below in Table 3-4 and represents various end-use markets of the motor and non-motor vehicle manufacturing industry, including tire manufacturing. To determine the average facility use rate on a daily basis, the annual rate is divided by the number of operating days typical for this end use. $TIME_{app\_working\_days}$ is based on a review of PMN data submitted to EPA between 2007 and 2010 for adhesives (see Appendix D), which indicates there may be up to 260 exposure days per year at non-submitter-controlled sites. EPA assumes that the number of operating days per year is equal to the number of exposure days per year reported in the PMN submissions. If the number of days of operation is not known, $TIME_{app\_working\_days}$ should be assumed to be equal to 250 days per year per Table 3-4.

Table 3-4. Input Data and Facility Use Rate Estimate for Adhesive Use in Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)

End-Use Market Volume of Adhesives (kg/year)[a]	Number of Sites[b,c]	$Q_{app\_site\_use\_rate}$ (kg/site-year)	$TIME_{app\_working\_days}$[d]
112,974,169	8,366	13,500	260

a – Impact Marketing Consultants, Inc., 2005 (see Tables C-4 and C-5 for derivation of estimate)
b – Vehicle (motor and non-motor) and tire manufacturing sites are 8,208 and 158, respectively
c – U.S. Census Bureau, 2005c and 2005d
d – Based on PMN data (see Appendix D). EPA conservatively assumes the number of operating days per year is equal to the largest value identified for this end-use category during the PMN data review.

3.1.3 Flexible Packaging Manufacturing

76. Flexible packaging refers to any packaging material whose shape can be readily changed. Some examples include bags, liners, and wrapping films. It is not immediately clear exactly which specific NAICS codes cover all flexible packaging operations, although flexible packaging operations are included in NAICS codes 322221 for Coated and Laminated Packaging Paper Manufacturing, NAICS code 322225 for Laminated Aluminum Foil Manufacturing for Flexible Packaging Uses, and NAICS code 326112 for Plastics Packaging Film and Sheet (including Laminated) Manufacturing.

77. Annual facility use rates and days of operation per year for the packaging and label manufacturing industries are provided below in Table 3-5. To determine the average facility use rate on a daily basis, the annual rate is divided by the number of operating days typical for this end use. $Q_{app\_site\_use\_rate}$ and $TIME_{app\_working\_days}$ are based on data obtained from industry questionnaires conducted by the Flexible Packaging Association (FPA) (FPA, 2009). $TIME_{app\_working\_days}$ should be set equal to the number of days/year in Table 3-5 that corresponds to the assessed adhesive type.

Table 3-5. Input Data and Facility Use Rate Estimates for Flexible Packaging Sites

Adhesive Type	Application Method[a]	$Q_{app\_site\_use\_rate}$ (kg/site-year)[b]	$TIME_{app\_working\_days}$ [a]
Hot melts	Syringe/Bead Application[c]	9,100,000	300
Solventless	Roll Coating	110,000	365
Organic-based	Roll Coating	2,300	200
Water-based	Roll Coating	240,000	260

Source: FPA, 2009.
a – Based on FPA questionnaire data (FPA, 2009).
b – Original data presented in pounds. Converted to kilograms by dividing by 2.2046 lb/kg.
c – Original source stated “extrusion lamination,” which is treated as syringe/bead application in this ESD.

78. The annual facility use rate selected from Table 3-5 should be based on the type of adhesive for which the chemical is used. If the adhesive type is unknown EPA recommends basing the selection on its potential environmental/exposure concerns as follows:[10]

- Occupational exposure concerns – assume use of an organic-based adhesives;
- Environmental release concerns – assume use of water-based adhesives; or
- Both – assume use of solventless adhesives.

79. Note that although hot melt adhesives have the greatest daily throughput of the four adhesive types presented in Table 3-5, it is not recommended for addressing environmental release concerns. As discussed in Section 2.1.4, hot melt adhesives have the lowest potential for environmental release of all the adhesive types presented in this ESD and therefore would not result in a conservative release assessment.

80. The questionnaires provide site-specific data from four facilities, each using different types of adhesives (e.g. hot melts, solventless, and water and organic solvent-based). In lieu of more specific data, this ESD uses the questionnaire data as bases for “what-if” facility use rates. What-if estimates are used when data representative of real industry use rates cannot be found. As stated above, the $Q_{app\_site\_use\_rate}$ should be based on the adhesive type being used. Although PMN data could also be used as a basis for estimating $Q_{app\_site\_use\_rate}$, it would not be able to account for the adhesive type because it was not specified in PMN submissions. For this reason, the ESD uses FPA instead of PMN data.

81. A flexible packaging manufacturing site visited by EPA (ERG, 2009) during the development of this ESD employed extrusion lamination and rotogravure roll coating

[10] When selecting default application methods based on potential concerns, EPA typically uses the following methodology to make conservative assessments. For conservative occupational exposure estimates, facilities with the lowest annual use rates are typically selected. This maximizes the number of use sites and therefore maximizes the number of workers. In this instance, an industry is chosen that provides both a low annual use rate and an application method that results in occupational exposures to workers. For conservative environmental release assessments, facilities with the highest annual use rates are typically selected. This maximizes the daily use rate and therefore results in the highest daily release. If both releases and exposures are a concern, median values are typically utilized.

methods to produce flexible packaging such as juice containers, peelable yogurt lids, and chewing gum packaging. This facility utilized extrusion lamination and rotogravure processes to apply adhesives products onto substrates.

82. The extrusion lamination process observed at the site involves the lamination of extruded polymer blends onto substrates. The facility purchases polymer pellets and blends them according to product needs. The blended polymer is extruded in its melt phase onto a substrate. Adhesive is not required to bind the extruded polymer to the substrate as the polymer blend is applied while in a melt phase. It then cools upon application to the substrate. The extruded polymer blends form a liner that may be used as a self-sealing liner to adhere substrates to an article upon heating. Substrates with extruded polymer-blend liners may be further coated or printed as required using rotogravure lamination.

83. During rotogravure lamination, the application cylinder is coated with adhesive from a pan. A doctor blade removes excess formulation from the cylinder. Substrates are then brought into contact with the coated cylinder via a rubber roller, where the formulation is transferred from the original cylinder to the substrate. The adhesive-coated substrate is transferred through a heated dryer to remove the solvent, leaving behind the adhesive solids and achieving a desired tack. The dried adhesive-coated substrate is then brought to a nip point, where rollers bring the adhesive-coated substrate into contact with another substrate for the purpose of bonding them together. The adhesive cures via reaction during product setting.

3.1.4 Labels and Tapes Manufacturing

84. This end-use market encompasses substrate coating operations used to manufacture labels and tapes. Average facility use rate data are derived from industry-provided adhesive annual production volume data consumed by this market in 2003 (Impact Marketing, 2005) and number of facilities provided in the 2002 Economic Census (USCB, 2005e and 2005f). General NAICS codes for this industry may include 322 (Paper Manufacturing) (EPA, 2002).

85. The average annual facility use rate, as derived from industry and NAICS data, is provided below in Table 3-6. To determine the average facility use rate on a daily basis, as provided in the final column, the annual rate is divided by the number of operating days typical of end-use sites. $TIME_{app\_working\_days}$ is based on a review of PMN data submitted to EPA between 2007 and 2010 for adhesives (see Appendix D), which indicates there may be up to 250 exposure days per year at non-submitter-controlled sites. EPA assumes that the number of operating days per year is equal to the number of exposure days per year reported in the PMN submissions. If the number of days of operation is not known, $TIME_{app\_working\_days}$ should be assumed to be equal to 250 days per year per Table 3-6.

Table 3-6. Input Data and Facility Use Rate Estimate for Adhesives in End-Use Markets for Labels and Tapes Manufacturing

End-Use Market Volume of Adhesives (kg/year)[a]	Number of Sites[b]	$Q_{app\_site\_use\_rate}$ (kg/site-year)	$TIME_{app\_working\_days}$[c]
318,000,000	541	587,800	250

a – Impact Marketing Consultants, Inc., 2005

b – U.S. Census Bureau, 2005e and 2005f
c – Based on PMN data (see Appendix D). EPA conservatively assumes the number of operating days per year is equal to the largest value identified for this end-use category during the PMN data review.

3.1.5 General Assembly/Binding

86. This end-use constitutes a wide variety of industry categories in which adhesives are used during the general assembly or binding of individual components into a final multi-component product. The terms "general assembly" and "binding" are broad catchall terms that this ESD uses to describe this end-use category. While there are many diverse industries whose operations fit the description "General Assembly/Binding," no specific industries are associated with the term outright, making the identification and utilization of representative, industry-specific data difficult. For this reason, PMN data submitted to EPA between 2007 and 2010 under section 5 of TSCA (see Appendix D) was used to develop "what-if" facility use rate estimates, which are provided below in Table 3-7.

87. In lieu of more specific data, the average values presented in Table 3-7 are used as bases for "what-if" $Q_{app\_site\_use\_rate}$ estimates. What-if estimates are used when data representative of real industry use rates cannot be found. The facility use rate estimates provided in Table 3-7were derived by dividing the annual adhesive use volume by the number of sites and operating days specified in the PMN submissions. If the number of days of operation is not known, EPA recommends assuming $TIME_{app\_working\_days}$ to be equal to 250 days per year, which is the uppermost value presented in Table 3-7, rather than the average value.

88. As stated above, the general assembly/binding end-use comprises a wide range of industries that have been collectively identified as "General Assembly/Binding." While this end-use industry spans a wide range of industrial adhesives uses (e.g. building products, wind turbines), it is not intended to be utilized as a catchall category for assessing adhesives that are not relevant to the other industries presented in this ESD. The general assembly end-use industry should only be used if the assessed chemical is an industrial adhesive used in the general assembly or binding of individual components into a final multi-component product.

Table 3-7. Input Data and Facility Use Rate Estimates for Adhesives Use in General Assembly End-Use Markets[a]

No.[b]	Adhesive Use Volume (kg/yr)	No. of Use Sites	$TIME_{app\_working\_days}$[c]	$Q_{app\_site\_use\_rate}$ (kg/site-year)
1	500,000	3	240	166,667
2	200,000	5	200	40,000
3	45,400	1	250	45,400
4	2,621,232	20	50	131,062
5	2,621,232	20	50	131,062
6	2,000,000	2	200	1,000,000
7	277,778	20	100	13,889
8	60,607	20	250	3,030
9	45,400	2	250	22,700
10	20,000	20	240	1,000
11	1,667	1	50	1,667
Average	**763,029**	**10**	**171**	**141,498**

a – The complete data set and a description of the methodology for collecting the data is provided in Appendix D.
b – Although 20 past submissions related to general assembly were identified, only 11 of these submissions provided all data necessary to allow the calculation of the adhesive daily use rate.
c – The number of operating days per year is assumed to be equal to the number of exposure days per year, which was collected from the PMN data.

89. EPA gathered the PMN data presented above by querying a PMN database maintained by EPA that contains the functions and uses of chemicals reviewed under the PMN program (e.g. EPA's new chemicals review program). This query retrieved all past chemical assessments containing the term "adhesive" in the use description. This query, which was conducted in 2010, returned all EPA assessments conducted in the previous three calendar years (e.g. 2007 to June 2010). Submissions reviewed before 2007 were excluded from the scope of the PMN data review in order to ensure that the review captured current industrial practices and trends. In this manner, EPA identified 77 past submissions containing applicable and relevant information about industrial adhesive uses covered in this ESD. EPA then reviewed each assessment and gathered the relevant information presented in Table 3-7. Of the 77 submissions identified, 20 were related to general assembly. A detailed description of EPA's PMN review and data-gathering methodology is provided in Appendix D.

Mass Fraction of the Chemical of Interest in the Adhesive Component (F_{chem_comp})

90. The chemical of interest may only be a fraction of the adhesive product component (e.g. elastomers, tackifiers, fillers, solvents). If specific information about the chemical-containing component is not known, EPA recommends assuming 100 percent chemical of interest when performing the calculations in this assessment[5]:

F_{chem_comp}	=	Mass fraction of the chemical of interest in the adhesive component (Default: 1 kg chemical/kg component)

Mass Fraction of the Component in the Adhesive Product (F_{comp_form})

91. Available data for the general composition of an adhesive formulation are presented in Table 1-3, Table 1-4, and Table 1-5. If the component type containing the chemical of interest is known, the mass fraction of the component in the formulated product may be estimated using the data presented in these tables. If the component type is not known, it is recommended that the type having the highest concentration (e.g. elastomer for water borne) be assumed from Table 1-3, as a default. If a range of component concentration is presented in either the PMN submission or Table 1-3, Table 1-4, and Table 1-5, then the average of the range can be used for mass balance calculations. The upper bound of the range can be used for assessing exposures.[11]

[11] Using the upper bound concentration will provide a conservative (worst case) assessment for releases, as well as worst case exposure doses; however, it will not provide a conservative result in the total number of workers potentially exposed to the chemical of interest (e.g. the total number of sites, and thus the number of workers will be minimized).

F_{comp_form}	=	Mass fraction of the component used in the formulated adhesive product (Default: 0.61 kg component/kg product for an elastomer or adhesive polymer for water-borne adhesives. See Table 1-3, Table 1-4, and Table 1-5 for alternative fractions, as appropriate.)

Mass Fraction of the Chemical of Interest in the Adhesive Product (F_{chem_form})

92. The fraction of the chemical of interest contained in the adhesive product can be determined using the following equation:

$$F_{chem\_form} = F_{chem\_comp} \times F_{comp\_form} \qquad \text{(Eqn. 3-2)}$$

Where:

F_{chem_form}	=	Mass fraction of the chemical of interest in the formulated adhesive product (kg chemical/kg product)
F_{chem_comp}	=	Mass fraction of the chemical of interest in the adhesive component (Default: 1 kg chemical/kg component) (See Section 0)
F_{comp_form}	=	Mass fraction of the component used in the formulated adhesive product (Default: 0.61 kg component/kg product for an elastomer for water-borne adhesives. See Table 1-3, Table 1-4, and Table 1-5 for alternative fractions, as appropriate.) (See Section 0)

Annual Number of Batches ($N_{bt\_site\_yr}$)

93. To estimate the annual number of batches, a batch size must be calculated. The batch size can be estimated using the following equation, assuming the number of batches used per site per day is one:

$$Q_{app\_bt} = \frac{Q_{app\_site\_yr}}{TIME_{app\_working\_days} \times N_{bt\_site\_day}} \qquad \text{(Eqn. 3-3)}$$

Where:

Q_{app_bt}	=	Mass of adhesive product used per batch (kg product/batch)
$Q_{app\_site\_yr}$	=	Annual facility adhesive product use rate containing the chemical of interest (kg product/site-yr) (See Section 0)
$TIME_{app\_working\_days}$	=	Annual number of days the adhesive product is used (Default: see Section 0 for the most appropriate value for the end use being assessed)
$N_{bt\_site\_day}$	=	Daily number of batches of adhesive used at each site (Default: 1 batch/site-day)

94. The following calculation estimates the annual number of batches for each use site based on the annual facility production rate and the batch size:

$$N_{bt\_site\_yr} = \frac{Q_{app\_site\_yr}}{Q_{app\_bt}} \qquad \text{(Eqn. 3-4)}$$

Where:

$N_{bt\_site\_yr}$	=	Annual number of batches of adhesive used, per site (batches/site-yr)
$Q_{app\_site\_yr}$	=	Annual facility adhesive product use rate containing the chemical of interest (kg product/site-yr) (See Section 0)
Q_{app_bt}	=	Mass of adhesive product used per batch (kg product/batch) (see Equation 3-3)

Daily Use Rate of the Chemical of Interest ($Q_{app\_chem\_site\_day}$)

95. The daily use rate of the chemical of interest during application of adhesive products onto various substrates is estimated using the following equation, based on the annual product use volume, the concentration of the chemical of interest, and the number of operating days.

$$Q_{app\_chem\_site\_day} = \frac{Q_{app\_site\_yr} \times F_{chem\_form}}{TIME_{app\_working\_days}} \qquad \text{(Eqn. 3-5)}$$

Where:

$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest contained in adhesive products applied to substrates (kg chemical used/site-day)
$Q_{app\_site\_yr}$	=	Annual facility adhesive product use rate containing the chemical of interest (kg product used/site-yr) (See Section 0)
F_{chem_form}	=	Mass fraction of the chemical of interest in the formulated adhesive product (kg chemical/kg product) (See Section 0)
$TIME_{app\_working\_days}$	=	Annual number of days the adhesive product is applied (days/yr) (Default: see Section 0 for most appropriate value for the end use being assessed)

Number of Application Sites (N_{app_sites})

96. The following calculation combines the annual use volume of adhesive formulations for applicators ($Q_{app\_site\_yr}$) and the fraction of the chemical of interest in the adhesive product (F_{chem_form}) to estimate the number of applicator sites for the end-use industry being assessed that are expected to utilize the amount of chemical of interest:

$$N_{app\_sites} = \frac{Q_{chem\_yr}}{Q_{app\_site\_yr} \times F_{chem\_form}} \qquad \text{(Eqn. 3-6)}$$

Where:

N_{app_sites}[12]	=	Number of applicators using the adhesive product containing the chemical of interest (sites)
Q_{chem_yr}	=	Annual production volume of the chemical of interest for the end use being assessed (kg chemical/yr)
$Q_{app\_site\_yr}$	=	Annual facility adhesive product use rate containing the chemical of interest (kg product/site-yr) (See Section 0)
F_{chem_form}	=	Mass fraction of the chemical of interest in the formulated adhesive product (kg chemical/kg product) (See Section 0)

97. The number of sites that apply the formulation onto substrates is estimated based on the total amount of the chemical-containing component produced (kg/yr) and the annual facility use rate of the adhesive product (kg/site-yr). The maximum number of sites should not exceed the total number of sites listed in Section 0 for each end-use market.

98. Note, if the number of sites is known, Equation 3-6 may be used to solve for $Q_{app\_site\_yr}$. Sections 0 and 0 may then be followed to calculate the annual number of batches and the daily use rate of the chemical of interest, respectively.

Annual Number of Adhesive Product Containers Emptied per Facility

99. The number of adhesive product containers unloaded annually per site can be estimated based on the daily use rate, container size, and concentration of the chemical of interest in the formulation (F_{chem_form}). EPA suggests that a default transportation container size of a 55-gallon drum could be used in the absence of site-specific information. Engineering judgment should be used to determine if another container type or size is more appropriate. If the density of a liquid formulation is not known, the density for water can be used as a default (1 kg/L).

$$N_{form\_cont\_empty\_site\_yr} = \frac{Q_{app\_chem\_site\_day} \times TIME_{app\_working\_days}}{F_{chem\_form} \times Q_{cont\_empty}} \quad \text{(Eqn. 3-7)}$$

Where:

$N_{form\_cont\_empty\_site\_yr}$	=	Annual number of containers emptied containing the chemical of interest per site (containers/site-yr)

[12] The value for N_{app_sites}, calculated using Equation 3-8, should be rounded to the nearest non-zero integer value. $Q_{app\_site\_yr}$ and $TIME_{app\_working\_days}$ should then be adjusted for the N_{app_sites} integer value (to avoid errors due to rounding) while maintaining the same value of $Q_{app\_chem\_site\_day}$ calculated in Section 0. First, $TIME_{app\_working\_days}$ is recalculated using $Q_{chem\_site\_day}$ and the rounded number of sites:

$$TIME_{app\_working\_days} = \frac{Q_{chem\_yr}}{N_{app\_sites} \times Q_{app\_chem\_site\_day}}$$

Next, $TIME_{app\_working\_days}$ is rounded to the nearest non-zero integer. Then, $Q_{app\_site\_yr}$ is recalculated using the rounded number of application days:

$$Q_{app\_site\_yr} = \frac{Q_{app\_chem\_site\_day} \times TIME_{app\_working\_days}}{F_{chem\_form}}$$

$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest contained in adhesive products applied to substrates (kg chemical/site-day) (See Equation 3-6)
$TIME_{app\_working\_days}$	=	Annual number of days the adhesive product is applied (Default: see Section 0 for the most appropriate value for the end use being assessed)
F_{chem_form}	=	Mass fraction of the chemical of interest in the formulated adhesive product (kg chemical/kg product) (See Section 0)
Q_{cont_empty}[13]	=	Mass of the adhesive product in a full container (kg product/container)

[13]If the mass of the adhesive product in each container is not known, it can be calculated using the volume of the container and the density of the formulation:

$$Q_{cont\_empty} = V_{cont\_empty} \times RHO_{formulation}$$

Where:

V_{cont_empty}	=	Volume of adhesive product per container (Default: 208 L adhesive product/container (55-gallon drum); See Table B-1 in Appendix B for alternative default container volumes)
$RHO_{formulation}$	=	Density of the adhesive product (Default: 1 kg product/L product)

4 ENVIRONMENTAL RELEASE ASSESSMENTS FOR THE APPLICATION OF ADHESIVE PRODUCTS

100. This section presents approaches for estimating the amount of the adhesive chemical of interest released during the application process. The release sources are presented in the order discussed in Section 0 (see Figure 2-1) and include the most likely receiving media (e.g. air, water, landfill, or incineration). The primary sources of release include container residue, process equipment cleaning, and process releases during the application process. Key default values used for the release estimates, accompanied by their respective references, are provided in Table A-1 of Appendix A.

101. It is generally assumed that during the application of adhesive products, losses of the chemical of interest are minimized in actual practice; however, some pre-process or other upstream releases will occur. Because losses are assumed to be minimized, the methodology presented in this section for estimating releases of the chemical of interest from the application process does not include adjustments to account for pre-process or other upstream releases of the chemical. For example, while some material may remain in the transport container, the entire volume received in the container is assumed to be emptied into the equipment, in order to generate conservative equipment cleaning release estimates. These omissions of mass balance adjustments should not result in a negative throughput of the chemical of interest in these calculations (e.g. the total amount of chemical released from the process should not exceed the amount that enters the process).

102. All release equations estimate daily rates for a given site. To estimate annual releases for all sites for a given source, the release rates must be multiplied by the number of days of release and by the total number of sites using the chemical of interest (N_{app_sites}) (See Equation 3-3).

103. Some of the process releases are expected to be released to the same receiving medium on the same days. Therefore, daily and annual releases to a given medium may be summed to yield total amounts.

104. Many of the environmental release estimates presented in this document are based on standard EPA release models, with the exception of the methodology described in Section 4.8 for estimating the amount of the chemical of interest released from the application process. This release estimate is based on a transfer efficiency of the application method used. Additionally, industry specific information is consistent with several of EPA's standard release models. Table 4-1 summarizes the release estimation methods used in this ESD.

105. Note that the standard model default values cited are current as of the date of this ESD; however, EPA may update these models as additional data become available. It is recommended that the most current version of the models be used in these calculations.

106. EPA has developed the Chemical Screening Tool for Exposures and Environmental Releases (ChemSTEER), a software package containing these models as well as all current

EPA defaults. Appendix B provides additional information on ChemSTEER, including instructions for obtaining the program, as well as background information, model equations, and default values for several parameters for all standard EPA models.

Table 4-1. Summary of Adhesive Application Scenario Release Models

Release Source #	Description	Model Name or Description[a]	Standard EPA Model (✓)
1	Container residue losses to water, incineration or land	Specific model used is based on the type and size of the containers, and on the physical state of the formulation: • EPA/OPPT Bulk Transport Residual Model • EPA/OPPT Drum Residual Model • EPA/OPPT Small Container Residual Model	✓
2	Open surface losses of volatile chemical to air during container cleaning	EPA/OPPT Penetration Model	✓
3	Transfer operation losses of volatile chemical to air during unloading	EPA/OAQPS AP-42 Loading Model	✓
4	Equipment cleaning losses to water, incineration, or land	EPA/OPPT Single Process Vessel Residual Model	✓
5	Open surface losses of volatile chemical to air during equipment cleaning	EPA/OPPT Penetration Model	✓
6	Overspray releases to air and incineration or land during spray coating application	EPA/OPPT Automobile Refinish Spray Overspray Loss Model	✓
	Application losses to water, incineration, or land during roll coating or curtain coating application	EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations	✓
	Evaporation losses of volatile chemical to air during application	Evaporation losses are assumed to occur to completion during curing/drying (see Release 7)	
7	Evaporative losses to air or air and incineration during curing/drying	Loss rate is based on mass balance	
8	Trimming wastes released to incineration or land after roll coating or curtain coating application	Loss rate is based on available surrogate industry-specific data	

a – Additional detailed descriptions for each of the models presented in this section are provided in Appendix B to this ESD.

Control Technologies

107. The National Emission Standards for Hazardous Air Pollutants (NESHAP) for Paper and Other Web Coating states that control technologies are utilized to control air releases. Based on the NESHAP, the capture systems utilized by both the flexible packaging and tapes and labels manufacturing industries collect fugitive emissions from solvents evaporating during coating application and solvent drying. The NESHAP identifies thermal oxidizers

(catalytic and thermal) and, to a lesser extent, carbon adsorbers and solvent recovery condensers as the most common control devices, accounting for 92 percent of the devices or recovery methods employed by these industries. The NESHAP suggests that other control devices, such as wet scrubbers and cyclones, may also be used; however, they are primarily for controlling airborne particulate matter.

108. Air emissions at the flexible packaging manufacturing facility visited by EPA are abated by the use of either regenerative thermal oxidation or regenerative catalytic oxidation. Permanent total enclosures around the adhesive application sections of the various machines are also utilized. Emission control devices are permitted to provide 95% efficiency or better (ERG, 2009).

109. The estimated air release capture efficiencies for these industries may range from zero to 100 percent, with the average capture efficiency being greater than 90 percent (EPA, 2000). If little or no information about air release controls is known, EPA suggests that as a default, assume a capture efficiency of 90 percent for the flexible packaging and tapes and labels manufacturing industries. For all other industries, EPA suggests assuming that air release controls are not employed.

110. Wastewater generated by facilities that use adhesives may be treated prior to discharge; however, data were not found on typical pollution prevention control technologies used in these industries. EPA recommends that as a default, it should be assumed all aqueous wastes are discharged directly to a publicly owned treatment works (POTW) for pretreatment prior to discharge to surface waters.

111. Information for other media (e.g. landfill or incineration) indicates that control technologies can vary widely across industries and across facilities within a single industry. Facilities may collect and dispose of liquid and solid process wastes by incineration or in landfills; however data were not found on the types of incinerators or landfills typically utilized (e.g. municipal, hazardous).

Container Residue Losses to Water, Incineration, or Landfill of Adhesive Formulation (Release 1)

112. The amount of chemical of interest remaining in transportation containers will likely depend on the size of the transport container and the physical form of the component product. Adhesive products may be received as liquid solutions, viscous liquid polymers, or as solid blocks, rods, or pellets. However, as discussed later in this section, container residue from solid blocks, rods, or pellets are not expected. Therefore, the following standard EPA models may be used to estimate container residue releases of liquids:

- *EPA/OPPT Bulk Transport Residual Model* may be used for large containers (e.g. totes, tank trucks, rail cars) containing greater than or equal to 100 gallons of liquid;
- *EPA/OPPT Drum Residual Model* may be used for drums containing between 20 and 100 gallons of liquid; and
- *EPA/OPPT Small Container Residual Model* may be used for liquid containers containing less than 20 gallons.

113. Note that these models estimate between 0.2 percent (bulk containers) and 3 percent (drums) of the received material may be released to the environment. The rationale, defaults, and limitations of these models are further explained in Appendix B. The release estimates are based on the current version of the models. Standard EPA/OPPT models are subject to change; therefore, the current version of the standard EPA/OPPT model should be used.

114. Information specific to the flexible packaging industry on the types of containers used for storing and transporting adhesives indicate that drums may be used for liquid-based adhesives while drums, tote boxes, or silos may be used for solid-based adhesives (FPA, 2009). Drums containing adhesives wastes will be emptied to maximize the residuals recovery and minimize residual wastes. Drum residuals are estimated to have a loss fraction of less than one percent (ERG, 2009; FPA; 2009). Water-based wastes are typically collected in 55-gal drums for disposal. Empty drums are shipped offsite to a contractor, for disposal at a state or federal regulated disposal site. The disposal process may be either incineration or solidification followed by land disposal. Solvent-based wastes are collected and sent offsite to a Resource Conservation and Recovery Act Subpart B-permitted treatment, storage, and disposal (TSD) facility. Empty solvent-based adhesive-containing drums are either sent to incineration or sent to a drum reconditioner, who utilizes an emission controlled burn chamber to remove any residual adhesive prior to drum reshaping, painting and testing for resale.

115. Adhesives utilized for syringe or bead applications will generate residual releases from disposal of spent syringes or tubes and may also generate residual releases from drums or pails (e.g. from the use of two-part epoxies); however, based on engineering judgment, use and direct disposal of any syringes, tubes, rods, or blocks is most likely. All releases are expected to be to incineration or landfill, as direct disposal to water or air is not probable. Releases from syringes, tubes, or pails should be assessed using the EPA/OPPT Small Container Residual Model while drum releases should be assessed using the EPA/OPPT Drum Residual Model. Hot-melt adhesives likely will not result in water releases since engineering judgment indicates it will most likely be released to landfill or incineration.

116. EPA suggests that a default transportation container size of a 55-gallon drum should be used. Engineering judgment should be used to determine if another container type or size is more appropriate.

117. Container cleaning may involve an organic and water wash, which could be released to water, incineration, or landfill.

118. The annual number of containers emptied ($N_{form\_cont\_empty\_site\_yr}$) is estimated based on the daily use rate of the component and the container size (see Section 0). EPA recommends assuming 55-gallon (208 L) drums and density of 1 kg/L (density of water) as defaults. If the fraction of the chemical in the adhesive component is unknown, assume 100 percent concentration (see Section 0).

119. If the $N_{form\_cont\_empty\_site\_yr}$ value is fewer than the days of operation ($TIME_{app\_working\_days}$), the days of release equal $N_{form\_cont\_empty\_site\_yr}$ (as calculated in Equation 3-7) and the daily release is calculated based on the following equation:

$$Elocal_{form\_cont\_residue\_disp} = Q_{cont\_empty} \times F_{chem\_form} \times F_{container\_residue} \times N_{form\_cont\_empty\_site\_day} \quad \text{(Eqn. 4-1a)}$$

120. This release will occur over [$N_{form\_cont\_empty\_site\_yr}$] days/year from [$N_{app\_sites}$] sites

Where:

$Elocal_{form\_cont\_residue\_disp}$	=	Daily release of chemical of interest from container residue (kg chemical/site-day)
Q_{cont_empty}	=	Mass of the adhesive product in a full container (kg product/container) (Default: use the same value used to estimate $N_{form\_cont\_empty\_site\_yr}$ in Section 0)
F_{chem_form}	=	Mass fraction of the chemical of interest in the formulated adhesive product (kg chemical/kg product) (See Section 0)
$F_{container\_residue}$	=	Fraction of adhesive component remaining in the container as residue (Default: 0.03 kg component remaining/kg component in full container (CEB, 2002a); see Appendix B for defaults used for other container types)
$N_{form\_cont\_empty\_site\_day}$[14]	=	Number of containers unloaded per site, per day (Default: 1 container/site-day)

121. If $N_{form\_cont\_empty\_site\_yr}$ is greater than $TIME_{app\_working\_days}$ (see Section 0 for the most appropriate value for the end use being assessed), more than one container is unloaded per day (e.g. $N_{form\_cont\_empty\_site\_day} > 1$). The days of release should equal the days of operation, and the average daily release can be estimated based on the following equation:

$$Elocal_{form\_cont\_residue\_disp} = Q_{app\_chem\_site\_day} \times F_{container\_residue} \qquad \text{(Eqn. 4-1b)}$$

122. This release will occur over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites

Where:

$Elocal_{form\_cont\_residue\_dis}$	=	Daily release of chemical of interest from container residue (kg chemical/site-day)
$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest in the adhesive product (kg chemical/site-day) (See Section 0)
$F_{container\_residue}$	=	Fraction of adhesive component remaining in the container as residue (Default: 0.03 kg component remaining/kg shipped for drums (CEB, 2002a); see Appendix B for defaults used for other container types)

Note: This equation may also be used if a container size is not assumed in Equations 3-7 and 4-1a, and $N_{comp\_cont\_empty\_site\_yr}$ is unknown.

[14] The daily number of containers unloaded per site may be estimated as (consistent with Section 0):

$$N_{form\_cont\_empty\_site\_day} = \frac{N_{form\_cont\_empty\_site\_yr}}{TIME_{app\_working\_days}}$$

($N_{form\_cont\_empty\_site\_day}$ should be rounded up to the nearest integer.)

Where:

$N_{form\_cont\_empty\_site\_yr}$	=	Annual number of containers emptied containing chemical of interest per site (containers/site-yr) (See Section 0)
$TIME_{app\_working\_days}$	=	Annual number of days the adhesive product is formulated (days/yr) (see Section 0 for the most appropriate value for the end use being assessed)

Open Surfaces Losses to Air During Container Cleaning (Release 2)

123. For non-volatile chemicals (e.g. the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

124. If the chemical is volatile (e.g. the vapor pressure is > 0.001 torr), it may volatilize and be emitted from the process while empty containers are being rinsed and cleaned ($Elocal_{air\_cleaning}$). To estimate this release, the EPA standard model for estimating releases to air from containers cleaned indoors may be used (*EPA/OPPT Penetration Model*). However, the *EPA/OPPT Penetration Model* is only applicable for chemicals whose adjusted vapor pressure does not exceed 35 torr. See Appendix B and the articles cited therein for additional discussion of the model and its limitations.

125. Table 4-2 lists the model inputs and default values. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-2. *EPA/OPPT Penetration Model* Parameter Default Values for Container Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA default 2 in. (5.08 cm) for all containers less than 5,000 gallons (CEB, 2002b) (See Appendix B for alternative default diameters)
Frequency of Release	Equal to the lesser of $TIME_{app\_working\_days}$ or $N_{form\_cont\_empty\_site\_yr}$ (See Sections 3.2 and 0)
Molecular Weight	Chemical-specific parameter.
Number of Sites	Calculated in Section 0
Operating Hours for the Activity	Number of containers per site, per day ($N_{form\_cont\_empty\_site\_ day}$, consistent with Release 1) divided by the unload rate (CEB, 2002b) (Default: 20 containers/hr for volumes between 20 and 1,000 gallons (CEB, 1991a); Alternative default unload rates are found in Appendix B)
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991a)
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model is not applicable for adjusted vapor pressures greater than 35 torr.

Transfer Operations Losses to Air from Unloading the Adhesive Formulation (Release 3)

126. For non-volatile chemicals (e.g. the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

127. If the chemical is volatile (e.g. the vapor pressure is > 0.001 torr), releases to air may occur from the displacement of saturated air when the chemical is transferred ($Elocal_{air\_transfers}$). The standard EPA estimation model for transfer operations may be used to

estimate the release to air (*EPA/OAQPS AP-42 Loading Model*). The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations (e.g. transferring liquids from transport containers into storage tanks or mixers). The reader should note that there is no vapor pressure restriction for using this particular model with vapor pressures greater than 35 torr.

128. Table 4-3 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-3. *EPA/OAQPS AP-42 Loading Model* Parameter Default Values for Air Releases During Unloading

Input Parameter	Default Values
Saturation Factor	EPA defaults 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (CEB, 2002b) (See Appendix B for alternative default saturation factors)
Frequency of Release	Equal to the lesser of $TIME_{app\_working\_days}$ or $N_{form\_cont\_empty\_site\_yr}$ (See Sections 3.2 and 0).
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 0
Operating Hours for the Activity	Number of containers per site, per day (See Section 0) divided by the unload rate (CEB, 2002b) (default unload rates are found in Appendix B)
Unloading Rate	EPA default 20 containers/hr for volumes between 20 and 1,000 gallons (CEB, 1991a) (Alternative default unload rates are found in Appendix B)
Container Volume	Default: 55-gallon drum (208 L) (See Section 0)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Equipment Cleaning Releases to Water, Incineration, or Landfill (Release 4)

129. The amount of residual adhesive chemical remaining in the process equipment may be estimated using the *EPA/OPPT Single Process Vessel Residual Model*. The model assumes that no more than one percent of the batch size or capacity of the process remains in the equipment as residue that is released as equipment cleaning waste. This is consistent with industry specific information that estimates less than one percent of the throughput is lost during daily equipment cleaning (ERG, 2009 and FPA, 2009). However, if the process being evaluated is known to utilize multiple vessels, then the *EPA/OPPT Multiple Process Vessel Residual Model* should be used. Equipment cleaning releases should be assessed for all

application processes that utilize liquids. Equipment cleaning releases from hot melts are not expected, based on engineering judgment.

130. Equipment cleaning may occur at the end of each campaign or as needed to maintain proper application. During this activity residual adhesives will be cleaned from cylinders, pans, and sumps. Cylinders and pans are wiped with brushes and rags while cylinders, pans, and sumps may be rinsed with the same solvent vehicle used in the adhesive (e.g. ethyl acetate or water). The rinsate is collected in drums and handled as solvent waste (see Section 0). Equipment cleaning residuals are estimated to have a loss fraction of less than one percent (ERG, 2009 and FPA, 2009). Cylinders may undergo additional cleaning to remove adhesives which may have cured. In such cases, cylinders would be placed inside a water bath, where they would undergo an ultra-sonic cleaning to remove cured residual adhesives. The spent wash water is pretreated on site and is expected to be sent to an EPA-regulated local publicly owned treatment works via the plant's sewer line. Pans may also undergo additional cleaning in a solvent wash machine. The spent solvent from the wash machine is collected and sent offsite for treatment.

131. If $N_{bt\_site\_yr}$ or known number of cleanings is fewer than the days of operation ($TIME_{app\_working\_days}$), the days of release equal $N_{bt\_site\_yr}$ (as calculated in Section 0) and the daily release of chemical residue in the process equipment is calculated using the following equation:

$$Elocal_{equipment\_cleaning} = Q_{app\_bt} \times F_{chem\_form} \times N_{bt\_site\_day} \times F_{equipment\_cleaning} \qquad \text{(Eqn. 4-2a)}$$

132. This release will occur over $N_{bt\_site\_yr}$ days/year from N_{app_sites} sites.

133. If $N_{bt\_site\_yr}$ is greater than $TIME_{app\_working\_days}$, the days of release equal the days of operation, and the daily release of chemical residue in the process equipment is calculated using the following equation:

$$Elocal_{equipment\_cleaning} = Q_{app\_chem\_site\_day} \times F_{equipment\_cleaning} \qquad \text{(Eqn. 4-2b)}$$

134. This release will occur over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites

Where:

$Elocal_{equipment\_cleaning}$	=	Daily release of chemical of interest from equipment cleaning (kg chemical/site-day)
Q_{app_bt}	=	Mass of adhesive product used per batch (kg material/batch) (See Section 0)
F_{chem_form}	=	Mass fraction of the chemical of interest in the adhesive product (kg chemical/kg product) (See Section 0)
$N_{bt\_site\_day}$	=	Daily number of batches formulated at each site (batches/site-day) (See Section 0)
$F_{equipment\_cleaning}$	=	Fraction of adhesive product released as residual in process equipment (Default: 0.01 kg product released/kg batch holding capacity (CEB, 1992))
$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest in the adhesive product (kg chemical/site-day) (See Section 0)

Open Surface Losses to Air During Equipment Cleaning (Release 5)

135. For non-volatile chemicals (e.g. the vapor pressure is < 0.001 torr) and solid rods, blocks, or pellets, releases to air are expected to be negligible.

136. If the chemical is volatile (e.g. the vapor pressure is > 0.001 torr) it may evaporate and be released to the air during equipment cleaning ($Elocal_{air\_eqpt\_cleaning}$). This operation is likely to occur indoors; therefore, the *EPA/OPPT Penetration Model* (EPA default for indoor operations) may be used to estimate the release of volatile chemicals during equipment cleaning. Model inputs and default values are listed in Table 4-4. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during equipment cleaning. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

137. The reader should note that the *EPA/OPPT Penetration Model* is only applicable for chemicals whose adjusted vapor pressure does not exceed 35 torr. See Appendix B and the articles cited therein for additional discussion of the model and its limitations.

Table 4-4. *EPA/OPPT Penetration Model* Parameter Default Values During Equipment Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA default 3-ft manhole (92 cm) (CEB, 2002b)
Frequency of Release	$TIME_{app\_working\_days}$ or $N_{bt\_site\_yr}$ (whichever is greater).
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 0
Operating Hours for the Activity	EPA default 1 hr/batch × $N_{bt\_site\_day}$ (See Section 0), consistent with calculations described in Appendix B.
Temperature	For non-heated processes, use the standard EPA default of 298 K (CEB, 1991a). For heated processes (default), assume temperature of 355 K (82°C).
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991a)
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model is not applicable for adjusted vapor pressures greater than 35 torr.

138. The default assumption for the diameter of the opening and the operating hours for this activity are based on the EPA defaults of 3 feet diameter and one hour for cleaning a single, large vessel (CEB 2002b).

Process Releases During Application of the Adhesive (Release 6)

139. The releases generated during the application process are dependent on the type of application method used. Different default values are used to determine the amount of

release from spray, roll, and curtain coating. The reader should note that the release models presented in this section are valid only for adhesive product losses due to transfer inefficiencies. These release models do not account for the evaporation of volatile chemicals during application. If assessing a volatile chemical, refer to the text presented after Table 4-5.

140. If the end-use industry is unknown, then an industry must be assumed based on its potential environmental/exposure concerns.[15] In such instances, refer to the logic diagram provided in Figure 3-1 for the most appropriate end-use industry. Also, Table 4-5 presents a logic table to help determine the most appropriate application method to assume for a given end-use industry. The listed application methods are based on PMN data. As discussed in Figure 3-1, if the end-use industry is known but the adhesive type is not, EPA recommends assuming that the adhesive is not used as a hot melt since the application methods associated with hot melts (e.g. syringe or bead coating) have the lowest potential, relative to the other application methods presented herein, for environmental releases and occupational exposures. For a specific discussion of why hot melts have a low potential for releases/exposures, see Section 2.1.4.

Table 4-5. Logic Table for the Determining Adhesive Application Method[a]

End-Use Industry	Type of Adhesive	Application Method
Computer/Electronics Manufacturing	Hot Melt	Syringe or Bead
	All Other	Roll Coating
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	Hot Melt	Syringe or Bead
	All Other	Spray Coating
Flexible Packaging Manufacturing	Hot melts	Syringe or Bead
	All Other	Roll Coating
Labels and Tapes Manufacturing	All Adhesives	Roll Coating
General Assembly/Binding	Hot Melt	Syringe or Bead
	All Other	Roll Coating
Unknown	Hot Melt	Syringe or Bead
	All Other	Roll Coating

a – This table is based on information obtained from the PMN data review. See Appendix D for the complete data set and a description of the data gathering methodology.

141. Volatile chemicals may evaporate during application of adhesives. The likelihood will depend on the specific function of the chemical of interest. For example, chemicals used as solvents are likely to result in significant releases from volatilization; however, the majority of this release will most likely occur once the adhesive has been applied to the substrate. Chemicals that need to be incorporated or reacted as part of the final cured

[15] When selecting default application methods based on potential concerns, EPA typically uses the following methodology to make conservative assessments. For conservative occupational exposure estimates, facilities with the lowest annual use rates are typically selected. This maximizes the number of use sites and therefore maximizes the number of workers. In this instance, an industry is chosen that provides both a low annual use rate and an application method that results in occupational exposures to workers. For conservative environmental release assessments, facilities with the highest annual use rates are typically selected. This maximizes the daily use rate and therefore results in the highest daily release. If both releases and exposures are a concern, median values are typically utilized.

adhesive are likely to result in smaller volatile releases. Volatile releases to air are assumed to occur to completion during curing/drying and are addressed in Section 0.

142. For EPA new chemical assessments, volatile chemicals are considered to be those whose vapor pressures are above 0.001 torr (CEB, 2008a). The estimation methods presented in this ESD are applicable only to chemicals whose vapor pressures are between 0.001 torr and 35 torr. Chemicals with vapor pressures below 0.001 torr are included in the scope of this document; however, they are expected to result in negligible volatile releases (CEB, 1995). Also, as stated previously within this document, chemicals with vapor pressures above 35 torr are outside the scope of this ESD. Use of the estimation methods presented herein are not appropriate for these chemicals.

143. The reader also should note that, while releases of vapors from volatile chemicals during application to substrates may occur, EPA has not developed estimation methods to quantify these potential releases from this particular activity. Of the reviewed PMNs submitted to EPA under section 5 of TSCA, 10 percent had vapor pressures between 0.001 and 35 torr. While most of the submitted chemicals were non-volatile, use of volatile chemicals is expected. The use of this ESD for assessing such volatile chemicals can result in significant underestimates of process releases during curing/drying of adhesives containing the volatile chemical. Quantification of these releases would require specific information about the application process, such as the chemical evaporation rate and length of time over which evaporation occurs. Such an assessment is beyond the scope of this ESD, which is intended to serve as a preliminary screening tool for assessing new chemicals. As a result, chemical vapor releases during the application of adhesives are presented as a data gap in this ESD.

4.1.1 Spray Coating (Releases to Air and Incineration or Landfill)

144. Spray coating applications are typically used for coating oddly shaped substrates. In spray applications, the formulation is loaded into a pressurized vessel and pumped through the spray gun using compressed air. The formulation is applied to the substrate as a mist generating overspray. Spray coating operations typically occur in spray booths or totally enclosed systems, as adhesives are of high value and minimal product wastes are desired. While control technologies are anticipated, industry-specific information on the type and efficiencies of these technologies was not available. A case study at a radiation curable product application site indicates use of spray booths with dry filters (P2Pays, no date (b)), which may be similar to adhesive application sites. As a conservative estimate, a dry filter with 90 percent capture efficiency ($F_{capture\_eff} = 0.90$) may be assumed (CEB, 1996).[16]

145. Table 4-6 presents efficiencies from various sources that can be used to estimate losses of spent coating. These values are based on:

[16] Although spray application typically involves original equipment, the EPA standard model for OEM applications (*EPA/OPPT Automobile OEM Spray Overspray Loss Model*) is not the recommended default model to estimate releases during spray applications. This EPA model assumes the use of water curtains during spray application. However, a case study at a radiation curable product application site indicates use of spray booths with dry filters (P2Pays, no date (b)), which may be similar to adhesive application sites. If a facility's use of a spray booth with a water curtain is known, the *EPA/OPPT Automobile OEM Spray Overspray Loss Model* may be more appropriate to estimate environmental releases from overspray (CEB, 1996).

- A laboratory-scale experiment investigating transfer efficiencies, overspray, and inhalation exposures from a variety of spray guns (CEB, 1996);
- A pollution prevention bulletin providing heuristic transfer efficiency information for typical application methods for the paint and coatings industry (P2Pays, 1997); and
- Information provided by RadTech in support of the development of the *ESD on Radiation Curable Coating, Inks, and Adhesives* (OECD, 2011) document providing heuristic transfer efficiency information for the radiation curable products industry (RadTech, 2007).

146. If the type of spray application process is unknown assume a conventional air-atomized spray coating process and a transfer efficiency of 25% as the conservative default.

Table 4-6. Transfer Efficiencies of Spray Coating Application Processes

Spray Coating Process	Transfer Efficiency in CEB, 1996 (%)	Transfer Efficiency in P2Pays, 1997 (%)	Transfer Efficiency in RadTech, 2007 (%)	Default Value (%)
High Volume, Low Pressure (HVLP)	>65	67-70	NA	65
Low Volume, Low Pressure (LVLP)	>65	NA	NA	65
Air-atomized (Conventional) (Default)	20-40 (25, default)	30-60	<50	25
Airless/Air-assisted	NA	NA	65	65
Electrostatic Airless/ Rotary Bell	60-90	NA	80	60

NA – Not available.
Source: CEB, 1996; P2Pays, 1997; RadTech, 2007.

147. The EPA standard model for estimating releases from spray coating may be used (*EPA/OPPT Automobile Refinish Spray Overspray Loss Model*)[16]. This operation will assume the use of a conventional spray gun within a spray booth having dry filters to capture overspray.

148. Based on the daily use rate and transfer efficiency of the technology used, the daily releases from spray coating operations are calculated using the following equation:

$$Elocal_{application\_losses} = Q_{app\_chem\_site\_day} \times (1 - F_{transfer\_eff}) \qquad \text{(Eqn. 4-3)}$$

149. This release will occur over [TIMEapp_working_days] days/year from [Napp_sites] sites.

Where:

$Elocal_{application\_losses}$	=	Daily release of chemical of interest from application (kg chemical/site-day)
$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest contained in the adhesive product (kg chemical/site-day)

$F_{transfer\_eff}$	=	Fraction of adhesive product adhered (Based on transfer efficiency of application methods; Default = 0.25 kg product adhered/kg applied, see Table 4-6 for alternative values)

150. For spray applications, spray booths are typically implemented to provide makeup air, capture overspray, and exhaust emissions. As previously discussed, a spray booth capture efficiency of 90 percent ($F_{capture\_eff}$ = 0.9) may be assumed (CEB, 1996). The portion captured in the dry filters may be sent to incineration or landfill. The following equations can be used to partition the individual releases to air and to incineration or landfill from the spray application process.

Air Releases: $\%_{air} = (1 - F_{capture\_ef}) \times 100$ (Eqn. 4-4a)

Incineration or Landfill Releases: $\%_{land\_inc} = F_{capture\_ef} \times 100$ (Eqn. 4-4b)

Where:

$\%_{air}$	=	Percentage of releases to air from spray coating (%)
$\%_{land\_inc}$	=	Percentage of releases to land or incineration from spray coating (%)
$F_{capture\_eff}$	=	Fraction of mist captured in spray booth technology (Default: 0.9 kg mist captured/kg released for dry filter)

4.1.2 Roll Coating (Releases to Water, Incineration, or Landfill)

151. Roll coating applications are typically used to apply coatings to various flat substrates. Roll coating may apply clear and pigmented coatings. Roll coating processes may involve high line speeds that have a potential for splatter and mist generation during application that is disposed to water, incineration, or land. Disposal of the coating in the reservoir may also be sent to incineration or land.

152. The EPA standard model for estimating releases from roll coating and curtain coating may be used (*EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations)*. The model estimates a transfer efficiency range of 90 to 98 percent during application. This is based on a pollution prevention bulletin providing heuristic transfer efficiency information for typical application methods for the paint and coatings industry (P2Pays, 1997). If the transfer efficiency of roll coating or curtain coating is not known, a 90 percent transfer efficiency ($F_{tranfer\_eff}$ = 0.90) can be used as a conservative default to estimate an overall application loss (CEB, 2008b).

153. Releases for these application methods can be estimated using the following equations, based on the daily use rate and transfer efficiency of the technology used:

$$Elocal_{application\_losses} = Q_{app\_chem\_site\_day} \times (1 - F_{transfer\_eff}) \qquad \text{(Eqn. 4-5)}$$

154. This release will occur over [TIMEapp_working_days] days/year from [Napp_sites] sites.

Where:

$Elocal_{application\_losses}$	=	Daily release of chemical of interest from application (kg chemical/site-day)
$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest contained in the adhesive product (kg chemical/site-day)

$F_{transfer\_eff}$ = Loss fraction of adhesive product released (Based on transfer efficiency of application methods; Default = 0.90 kg product adhered/kg applied for roll coating or curtain coating)

4.1.3 Curtain Coating (See Roll Coating for Releases)

155. Similar to roll coating, curtain coating applications are typically used to apply clear coatings to flat stock, including metal, wood, paper, and plastic substrates. In curtain coating, a stream of coating flows at a controlled rate as the substrate is conveyed across the stream. The amount of coating that is not transferred to the substrate drips down collection tunnels and may be recycled to the feed reservoir or disposed to water, incineration, or landfill. No additional industry-specific information is provided to determine the amounts released to air, water, incineration or land. The *EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations* may also be applied to estimate releases during curtaining coating to account for losses of spent coating.

4.1.4 Syringe or Bead Application (No Releases Expected)

156. As discussed in Section 2.1.4, syringe or bead application generally has the lowest potential for environmental release or occupational exposure of the application methods presented in this document; therefore, environmental releases during application are expected to be negligible.

Evaporative Losses to Air or Air and Incineration during Curing/Drying (Release 7)

157. This section is applicable only to non-reactive volatile chemicals that must be driven off after application of the adhesive (for example, a solvent). In these cases, it should be assumed that 100 percent of the volatile chemical is released during curing/drying, less any upstream losses from container cleaning, equipment cleaning, and application losses. Upstream losses may be calculated per the models presented in Table 4-1. It may then be assumed that the remainder of the volatile chemical is released during the drying or curing step. Evaporation losses may be calculated per Equation 4-6. Note that upstream volatile releases may occur before the drying step (e.g. during container cleaning, container unloading, equipment cleaning, or application to substrates); however, they are not included in Equation 4-6 since these releases are less significant than container and equipment residual and application losses.

158. Reactive volatiles also may result in volatile releases during curing; however, EPA has not developed estimation methods to quantify these potential releases. As a simplifying assumption, reactive volatiles can be assessed as a non-reactive chemical, but note that the resulting release estimate will present a conservative, upper bound value since it will not account for the depletion of the volatile chemical as it reacts over time. More precise estimation methods for quantifying volatile releases during curing/drying would require specific information about the drying process, such as the curing rate, the chemical evaporation rate, and the length of time over which evaporation occurs. Such an assessment is beyond the scope of this ESD, which is intended to serve as a preliminary screening tool for assessing new chemicals. As a result, volatile releases of reactive volatiles during adhesive curing are presented as a data gap in this ESD.

159. The reader should note that this evaporative losses model is not limited to a particular vapor pressure range. This is because an adhesive application process will

completely evaporate the volatile chemical if such an evaporation step is necessary for the final drying or curing of the adhesive, even if the volatile chemical has a low vapor pressure. The drying steps typically feature a drying oven (EPA, 2000), which yield a higher temperature and greater mass convection to induce total evaporation. The reader should use this model if it is known or appropriate to assume that the assessed adhesive application process and end-use industry would completely evaporate a solvent or any other non-reactive volatile chemicals during the drying or curing step.

$$Elocal_{evaporation\_losses} = Q_{app\_chem\_site\_day} \times \left(1 - F_{container\_residue} - (1 - F_{transfer\_eff}) - F_{equipment\_cleaning}\right)$$ (Eqn. 4-6)

This release will occur over [TIMEapp_working_days] days/year from [Napp_sites] sites.

Where:

$Elocal_{evaporation\_losses}$	=	Daily release of chemical of interest during curing/drying (kg chemical/site-day)
$Q_{app\_chem\_site\_day}$	=	Daily use rate of the chemical of interest contained in the adhesive product (kg chemical/site-day)
$F_{container\_residue}$	=	Fraction of adhesive formulation remaining in the container as residue (Default: 0.03 kg formulation/kg shipped for drums (CEB, 2002a); See Appendix B for defaults used for other container types)
$F_{transfer\_eff}$	=	Fraction of adhesive formulation adhered (Based on transfer efficiency of application methods; Default = 0.25 kg product adhered/kg applied for spray coating, see Table 4-6 for alternative values; Default = 0.90 kg product adhered/kg applied for roll coating or curtain coating; Default = 1.0 kg product adhered/kg applied for syringe or bead application)
$F_{equipment\_cleaning}$	=	Fraction of adhesive formulation released as residual in process equipment (Default: 0.01 kg product released/kg batch holding capacity (CEB, 1992))

160. As discussed in Section 0, the estimated air release capture efficiency for the flexible packaging and tapes and labels tapes manufacturing industries may range from zero to 100 percent, with the average capture efficiency being greater than 90 percent (EPA, 2000). For curing/drying operations, EPA recommends using a capture efficiency of 90 percent when assessing adhesives use in either of these industries. The most likely release media for these two industries are air and incineration, and can be partitioned using the following equations. The media of release for the remaining industries should assume a complete release to air.

Air Releases: $\%_{air} = (1 - F_{capture\_ef}) \times 100$ (Eqn. 4-7a)

Incineration Releases: $\%_{inc} = F_{capture\_ef} \times 100$ (Eqn. 4-7b)

Where:

$\%_{air}$	=	Percentage of releases to air from curing/drying (%)
$\%_{inc}$	=	Percentage of releases to incineration from curing/drying (%)
$F_{capture\_eff}$	=	Fraction of volatile chemical captured by control system (Default: 0.9 kg volatile chemical captured/kg volatile chemical released)

Trimming Wastes Released to Incineration or Landfill (Release 8)

161. Trimming wastes represent a potential release point that may be applicable during adhesives application. Though this release is not expected in every case, it is applicable when the products must be cut per specific size requirements. If the adhesive is cured or dried such that the chemical of interest is reacted or encapsulated within the adhesive, estimating trimming wastes containing the chemical of interest may not be necessary. If an estimated trimming waste is desired, site-specific data, if available, should be used to estimate this release. Where site specific data are not available, surrogate data from the carbonless copy paper industry may be used. For carbonless copy paper manufacturing, approximately 4 percent of the throughput may be lost during product finishing (CEB, 1991b). It is assumed trimming wastes from adhesive use will be similar. The wastes will most likely be sent to incineration or landfilled.

162. This release should only be assessed if trimming losses are expected for the end-use being assessed. This release is not associated with all end-use industries. For example, the use of adhesives in the computer/electronics industry will most likely consist of syringe or bead application, which, as discussed in Section 2.1.4, is typically applied in small quantities to a precise location. Therefore, the potential for trimming waste releases would be negligible. Furthermore, trimming losses are substrate-specific. For example, three-dimensional substrates are not likely to be trimmed after the adhesive has been applied, whereas it would be more likely for flat, two-dimensional substrates. The assessor should use their best judgment in determining the applicability of this release point. Releases from trimming can be estimated using the following equation, based on the daily use rate as:

$$Elocal_{trimming\_release} = Q_{app\_chem\_site\_day} \times F_{trimming\_generation} \qquad \text{(Eqn. 4-8)}$$

Where:

$Elocal_{trimming\_release}$	=	Daily release of chemical of interest from trimmings (kg chem./site-day)
$Q_{app\_chem\_site\_day}$	=	Daily use rate of chemical of interest (kg chemical/site-day)
$F_{trimming\_generation}$	=	Fraction of chemical lost from trimming (Default: 0.04 kg chem. in trimmings/kg chem. applied)

5 OCCUPATIONAL EXPOSURE ASSESSMENTS FOR THE APPLICATION OF ADHESIVE PRODUCTS

163. The following section presents estimation methods for worker exposures to the chemical of interest during the application process. Figure 2-1 illustrates the occupational activities performed within the application process that have the greatest potential for worker exposure to the chemical.

164. Some industry-specific occupational exposure information was found in the references reviewed for this ESD (refer to Section 8 for a description of the sources reviewed and full citations for those specifically used in these calculations). Industry-specific occupational exposure information includes monitoring studies of specific chemicals, observed PPE usage, and the total number of workers employed by the various industries that use adhesives available from the U.S. Census Bureau. The occupational exposure estimates presented in this document are based on standard EPA exposure models. Table 5-1 summarizes the exposure estimation methods used in this ESD.

165. Swanson et al. (Swanson et al., 2002) and several NIOSH Health Hazard Evaluation Reports (NIOSH, 1991; NIOSH, 1995; NIOSH, 2006) provide monitoring studies in different industries of specific chemicals. The provided air concentrations in these studies account for the volatilities of each specific chemical and do not strictly represent exposures inherent to the application method (e.g. typical mist concentrations from spray applications).

166. This ESD applies special consideration to hot-melt adhesives when using the assessment approaches presented in the following subsections. Since hot melts are applied at temperatures ranging from 150 to 190°C (Ullmann, 1985), the potential for dermal exposures during application is minimal. Per EPA qualitative assessments, dermal exposures to chemicals handled at temperatures exceeding 140°F (60°C) are assessed as negligible (CEB, 1991a); therefore, dermal exposures assessed in the following subsections are not applicable to hot melts.

167. Note that the standard model default values cited are current as of the date of this ESD; however, EPA may update these models as additional data become available. It is recommended that the most current version of the models be used in these calculations.

168. EPA has developed a software package (ChemSTEER) containing these models as well as all current EPA defaults. Because of the complexity of the inhalation exposure to vapor models, ChemSTEER is recommended for estimating these exposures. Appendix B provides additional information on ChemSTEER, including information on obtaining the program, as well as background information, model equations, and default values for several parameters for all standard EPA models.

Table 5-1. Summary of Adhesive Application Scenario Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description[a]	Standard EPA Model (✓)
A	Exposure to adhesive product during container cleaning	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
B	Exposure to liquid or solid adhesive formulation during unloading or transferring	Inhalation of volatile liquid chemical vapors	Specific model is based on the volume of total material handled and the physical form of the material: • EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical or solid chemical	Specific model is based on the physical form of the material: • EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
C	Exposure to liquid adhesive product during equipment cleaning	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
D	Exposure to adhesive product during application	Inhalation of mist from spray coating	EPA/OPPT Automobile OEM Spray Coating Inhalation Model	✓
		Inhalation of mist from roll coating	EPA/OPPT UV/EB Roll Coating Inhalation Model	✓
		Inhalation of volatile liquid chemical vapors	No current EPA model for quantifying exposure	
		Dermal exposure to liquid chemical	Specific model is based on the application method: • EPA/OPPT 2-Hand Dermal Contact with Liquid Model • EPA/OPPT 2-Hand Dermal Immersion in Liquid Model	✓
E	Exposure to volatile chemicals during curing/drying	Inhalation of volatile liquid chemical vapors	No current EPA model for quantifying exposure	

a – Additional detailed descriptions for each of the models presented in this section are provided in Appendix B to this ESD.

Personal Protective Equipment

169. EPA does not assess the effectiveness of personal protective equipment (PPE) at mitigating occupational exposures in this ESD. The exposure mitigation by PPE is affected

by many factors including availability, cost, worker compliance, impact on job performance, chemical and physical properties of the substance and protective clothing, and the use, decontamination, maintenance, storage, and disposal practices applicable to the industrial operation (CEB, 1997b). Therefore, the conservative, screening-level occupational exposure estimates presented in this ESD do not account for PPE. Actual occupational exposure may be significantly less than the estimates presented in this ESD.

170. Data from the FPA questionnaire indicates that the flexible packaging manufacturing industry utilizes the following PPE: chemical-resistant gloves and safety glasses. Heat-resistant gloves are used when applying hot-melt adhesives. Of the four sites that replied to the questionnaire, only one reported the use of respirators. This site applied solventless adhesives to substrates. In lieu of industry-wide survey data, this ESD assumes that the PPE reported by the questionnaires sites is representative of industry practices (FPA, 2009).

171. Information on typical PPE for the application and use of adhesive formulations focuses on minimizing exposure due to spray application or VOC emissions. General assumptions can be made based on the known hazards of certain adhesive formulation processes: hot-melt adhesives are processed at temperatures over 150°C and solution adhesives generally have VOC concerns. Chemical PMN submissions recently submitted to EPA by adhesive chemical manufacturers show that, at a minimum, all manufacturers recommended the use of gloves and safety glasses with side shields or goggles. Approximately half of the submissions also recommended the use of some kind of ventilation and respirators if necessary. One submission for a hot-melt adhesive chemical also specifically recommended the use of thermal gloves.

Number of Workers Exposed Per Site

172. Limited industry-specific data on the number of workers potentially exposed while performing each of the application activities were found in the references reviewed for this ESD (refer to Section 8). Table 5-2 summarizes data collected from the 2007 Economic Census for the various industries that may use adhesive products. In the absence of site-specific data, the default number of workers should be based on the industry selected from Figure 3-1. The following subsections provide the default number of workers for these industries.

173. The 2007 Economic Census also provides estimates for production workers (USCB, 2007), which are defined by the U.S. Census Bureau to include…

> *…workers (up through the line-supervisor level) engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, shipping (but not delivering), maintenance, repair, janitorial and guard services, product development, auxiliary production for plant's own use (e.g. power plant), record keeping, and other services closely associated with these production operations at the establishment (USCB, 2007).*

> All other "non-production" employees include…

> *…those engaged in supervision above the line-supervisor level, sales (including driver-salespersons), sales delivery (highway truck drivers and their helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office functions, executive, purchasing, financing, legal, personnel (including cafeteria, medical, etc.), professional, technical employees, and employees on the payroll of the manufacturing*

establishment engaged in the construction of major additions or alterations utilized as a separate work force (USCB, 2007).

174. The 2007 Economic Census does not provide information that could provide bases for estimating the specific numbers of production workers that perform each of the exposure activities discussed in this section. In the absence of data, the number of workers potentially exposed to the chemical of interest during each activity should be conservatively estimated to be the number of workers per site for the end-use market being assessed (see Table 5-2).

Table 5-2. Number of Production Workers Potentially Exposed During Application Processes

End-Use Market	Number of Workers per Facility	Notes
Computer/Electronic and Electrical Product Manufacturing	38[a]	See Section 5.1.1 for discussion.
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	90[a]	See Section 5.1.2 for discussion.
Flexible Packaging Manufacturing	36[b]	See Section 5.1.3 for discussion.
Labels and Tapes Manufacturing	48[a]	See Section 5.1.4 for discussion.
General Assembly/Binding	26[c]	See Section 5.1.5 for discussion.

a – Number of workers per facility is based on U.S. Census data. See Appendix C for derivation.
b – Number of workers per facility is based on data provided by FPA.
c – Number of workers per facility is based on PMN data. See Appendix D for derivation.

5.1.1 Computer/Electronic and Electrical Product Manufacturing

175. The number of production workers and number of facilities is based on data from the U.S. Census Bureau. These data may be used to calculate the average number of workers per facility. Table 5-3 presents the average number of workers per facility for the computer/electronic product manufacturing industries.

Table 5-3. Number of Production Workers Potentially Exposed to Adhesives during Computer/Electronic Product Manufacturing

Industry	NAICS Subsector	Average Number of Workers per Facility[a]
Computer and Electronic Product Manufacturing	334	35
Electrical Equipment, Appliance, and Component Manufacturing	335	48
Aggregated Average	**–**	**38**

a – Average number of workers per facility is based on U.S. Census data. See Appendix C for derivation.

5.1.2 Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)

176. The 2007 Economic Census data may be used to calculate the average number of workers per facility for the motor and non-motor vehicle, vehicle parts, and tire manufacturing (except retreading) industries. Table 5-4 presents the average number of workers per facility for the motor and non-motor vehicle, vehicle parts, and tire manufacturing (except retreading) industries.

Table 5-4. Number of Production Workers Potentially Exposed to Adhesives during Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)

Industry	Average Number of Workers per Facility[a]
Motor and Non-Motor Vehicle Manufacturing	106
Vehicle Parts Manufacturing	77
Tire Manufacturing (except retreading)	92
Aggregated Average	**90**

a – Average number of workers per facility is based on U.S. Census data. See Appendix C for derivation.

177. A NIOSH Health Hazard Evaluation Report (NIOSH, 2006) included a study of a single automobile manufacturing facility. The study notes, at the investigated site, that approximately 120 workers per shift work in the body shop, approximately 120 workers per shift work in the paint shop, approximately 700 workers per shift work in the assembly area, and approximately 130 workers per shift work in skilled trades, such as maintenance workers and electricians. An additional 85 skilled-trade workers work during the midnight shift. It is not clear how many of these workers would be exposed to adhesives during manufacturing.

178. NIOSH Health Hazard Evaluation Reports provide a thorough description of worker activities and how their numbers may vary from production area to production area (e.g. body shop versus assembly area); however, it is not clear how representative it is of industry. Comparison to U.S. Census data suggests that the number of workers per facility, when taken as an industry average, may actually be much lower. For this reason, EPA recommends using Table 5-4 as the basis for estimating the number of workers in the absence of specific data.

5.1.3 Flexible Packaging Manufacturing

179. Although some NAICS codes may include packaging materials (NAICS codes 322221 for Coated and Laminated Packaging Paper Manufacturing, NAICS code 322225 for Laminated Aluminum Foil Manufacturing for Flexible Packaging Uses, and NAICS code 326112 for Plastics Packaging Film and Sheet (including Laminated)), it is not immediately clear if and how adhesives are used in these products.

180. The FPA industry questionnaires (FPA, 2009) suggest 4 to 36 workers. These workers may conduct activities in which the chemical-containing adhesive is present. Direct contact activities include adhesive mixing, adhesive transfers to sumps, and equipment cleaning as well as less direct contact activities such as operating a forklift to transfer

adhesive drums. EPA recommends that 36 workers per site be used as the default number of workers for this industry to conservatively assess exposures to chemical-containing adhesives.

5.1.4 Labels and Tapes Manufacturing

181. The number of production workers and number of facilities is based on data from the U.S. Census Bureau. These data may be used to calculate the average number of workers per facility for the labels and tapes manufacturing industries. Table 5-5 presents the average number of workers per facility for the labels and tapes manufacturing industries.

Table 5-5. Number of Production Workers Potentially Exposed to Adhesives during Labels and Tapes Manufacturing

Industry	NAICS Code	Number of Establishments[a]	Number of Workers[a]	Average Number of Workers per Facility[a]
Coated and laminated paper manufacturing	322222	497	24,086	48

a – Average number of workers per facility is based on U.S. Census data. See Appendix C for derivation.

5.1.5 General Assembly/Binding

182. As discussed in Section 3.1.5, this end-use constitutes a wide variety of industry categories in which adhesives are used during the general assembly or binding of individual components into a final multi-component product. Because of the diversity of industries that may be associated with this end-use, it is not possible to establish the number of workers per site based on Census data that are specific to general assembly or binding. For this reason, PMN data submitted to EPA between 2007 and 2010 under section 5 of TSCA is used to estimate the number of workers per site. As described in Section 0, each PMN submission represents a distinct chemical substance that may be entering commerce in the United States (e.g. two submissions would typically not be received for the same substance). Based on reviewed PMN data (see Appendix D), the number of workers may range from 1 to 26 workers per site. In the absence of specific data from PMN submissions, EPA recommends the default number of workers at a general assembly/binding site be taken as 26 workers per site.

Exposure from Container Cleaning (Exposure A)

183. Workers may be exposed while rinsing containers used to transport adhesive products. If the concentration of the chemical in the adhesive product is unknown, see Sections 0, 0, and 0 to estimate: 1) the concentration of the chemical in the adhesive component, 2) the concentration of the adhesive component in the adhesive product, and 3) the resulting concentration of the chemical in the adhesive product, respectively. The default number of workers per site that may be exposed during this activity will depend on the end-use industry. The default number of workers is provided in Section 0.

5.1.6 Inhalation Exposure

184. The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility and the physical state of the chemical of interest. Inhalation exposure is assumed negligible for non-volatile liquids (e.g. the vapor pressure is < 0.001 torr) and solid rods, blocks, or pellets.

185. Using the vapor generation rate calculated in Release 2, the *EPA/OPPT Mass Balance Model* can be used to calculate worker inhalation exposure due to volatilization during container cleaning operations. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure. Table 5-6 lists the model inputs and default values. Note that the exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 0 calculations), but EPA assumes a maximum exposure duration of eight hours per day. Also, as discussed in Section 0, EPA assumes the lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ for the number of exposure days per year. $TIME_{app\_working\_days}$ will depend on the end-use industry; therefore, the reader should refer to Section 0 to identify the appropriate value for the industry being assessed. The reader should note that the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year. These exposure duration maximum defaults are based on fulltime employment and considers an individual worker's vacation, sick, and weekend time (e.g. a 40-hour work week over 50 weeks per year).

Table 5-6. *EPA/OPPT Mass Balance Model* Parameter Default Values During Container Cleaning

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (CEB, 1991a)
Exposure Days	The lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with the Frequency of Release determined in Section 0)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 0)
Exposure Duration	Consistent with the Operating Hours determined in Section 0, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991a)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 0
Ventilation Rate	EPA defaults 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991a) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

186. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends this software to calculate inhalation exposure to volatile chemicals during container cleaning. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

5.1.7 Dermal Exposure

187. Dermal exposure is expected during the cleaning of transport containers. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities. The rationale, defaults, and limitations of these models are explained in Appendix B. Dermal exposure to the chemical of interest in solid rods, blocks, or pellets is assumed negligible. Also, as discussed in Section 2.1.4, exposures are not expected for adhesives contained in syringes or tubes, since they are expected to be disposed directly to incineration or landfill.

188. To estimate the potential worker exposure to the chemical of interest in a liquid adhesive product for this activity, EPA recommends using the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \quad \text{(Eqn. 5-1)}$$

189. This exposure will occur over the lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with Section 0). $TIME_{app\_working\_days}$ will depend on the end-use industry; therefore, the reader should refer to Section 0 to identify the appropriate value for the industry being assessed.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
Q_{liquid_skin}	=	Quantity of liquid adhesive product remaining on skin (Defaults: 2.1 mg component/cm^2-incident (high-end) and 0.7 mg component/cm^2-incident (low-end) for routine or incidental contact (CEB, 2000))
$AREA_{surface}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands (CEB, 2000))
$N_{exp\_incident}$[17]	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem_form}	=	Mass fraction of the chemical of interest in the adhesive product (kg chemical/kg product) (See Section 0)

Exposure from Unloading and Transferring Adhesive Product (Exposure B)

190. Workers may connect transfer lines or manually unload chemicals from transport containers into mixing tanks. Dermal exposures will be to liquids or solids in the form of

[17] Only one contact per day ($N_{exp\_incident}$ = 1 event/worker-day) is assumed because Q_{liquid_skin}, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (e.g. wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

hot-melt blocks, rods, or pellets. If the concentration of the chemical in the adhesive product is unknown, see Sections 0, 0, and 0 to estimate: 1) the concentration of the chemical in the adhesive component, 2) the concentration of the adhesive component in the adhesive product, and 3) the resulting concentration of the chemical in the adhesive product, respectively. The default number of workers per site that may be exposed during this activity will depend on the end-use industry. The default number of workers is provided in Section 0.

5.1.8 Inhalation Exposure

191. The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility and the physical state of the chemical of interest. Inhalation exposure is assumed negligible for non-volatile liquids (e.g. the vapor pressure is < 0.001 torr) and solid rods, blocks, or pellets.

192. The vapor generation rate calculated in Release 3 and the EPA standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*) may be used to estimate the associated worker inhalation exposure to the chemical of interest during transfer operations. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during transfer operations. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

193. Table 5-7 lists the model inputs and default values. Note that the exposure hours per day is equivalent to the operating hours per day for this activity (consistent with Section Table 4-3 calculations), but EPA assumes an exposure duration of eight hours per day. For exposures days per year, EPA assumes the lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$, as discussed in Section 0. $TIME_{app\_working\_days}$ will depend on the end-use industry; therefore, the reader should refer to Section 0 to identify the appropriate value for the industry being assessed. The reader should note that the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year. These exposure duration maximum defaults are based on fulltime employment and considers an individual worker's vacation, sick, and weekend time (e.g. a 40-hour work week over 50 weeks per year).

Table 5-7. *EPA/OPPT Mass Balance Model* Parameter Default Values During Transfers

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (CEB, 1991a)
Exposure Days	The lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with the Frequency of Release determined in Section 0)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 0)
Exposure Duration	Consistent with the Operating Hours determined in Section 0, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991a)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 0
Ventilation Rate	EPA defaults 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991a) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

5.1.9 Dermal Exposure

194. Dermal exposure is expected for both automated and manual unloading activities. Automated systems may limit the extent of dermal exposure more than manual unloading; however, workers may still be exposed when connecting transfer lines or transferring liquid chemicals from transport containers to mixing vessels. Workers may manually scoop or pour solid or liquid adhesive product chemicals into the process equipment.

195. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities. The rationale, defaults, and limitations of these models are further explained in Appendix B. Dermal exposure to the chemical of interest in solid rods, blocks, or pellets is assumed negligible.

196. To estimate the potential worker exposure to the chemical of interest in a liquid adhesive product for this activity, EPA recommends using the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \qquad \text{(Eqn. 5-2)}$$

197. This exposure will occur over the lesser of $N_{bt\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with Section 0). $TIME_{app\_working\_days}$ will depend on the end-use industry; therefore, the reader should refer to Section 0 to identify the appropriate value for the industry being assessed.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)

Q_{liquid_skin}	=	Quantity of liquid adhesive product component remaining on skin (Defaults: 2.1 mg component/cm^2-incident (high-end) and 0.7 mg component/cm^2-incident (low-end) for routine or incidental contact (CEB, 2000))
$AREA_{surface}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands (CEB, 2000))
$N_{exp\_incident}$[18]	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem_form}	=	Mass fraction of the chemical of interest in the adhesive product (kg chemical/kg product) (See Section 0)

Exposure from Equipment Cleaning of Applicators and Other Process Equipment (Exposure C)

198. Workers may be exposed while cleaning the application process equipment with water or organic solvents. Because some equipment cleaning may be performed manually, exposures during equipment cleaning should be assessed. The default number of workers per site that may be exposed during this activity will depend on the end-use industry. The default number of workers is provided in Section 0.

5.1.10 Inhalation Exposure

199. The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility and the physical state of the chemical of interest. Inhalation exposure is assumed negligible for non-volatile liquids (e.g. the vapor pressure is < 0.001 torr) and solid rods, blocks, or pellets.

200. Using the vapor generation rate calculated in Release 5, the *EPA/OPPT Mass Balance Model* can be used to calculate worker inhalation exposure due to volatilization during equipment cleaning activities. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure. Table 5-8 lists the model inputs and default values. Note that the exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 0 calculations), but EPA assumes a maximum exposure duration of eight hours per day. EPA assumes these exposures will occur over $TIME_{app\_working\_days}$, which will depend on the end-use industry. The reader should refer to Section 0 to identify the appropriate value for $TIME_{app\_working\_days}$. The reader should note that the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year. These exposure duration maximum defaults are based on fulltime employment and considers an individual worker's vacation, sick, and weekend time (e.g. a 40-hour work week over 50 weeks per year).

201. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals

[18] Only one contact per day ($N_{exp\_incident}$ = 1 event/worker-day) is assumed because Q_{liquid_skin}, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (e.g. wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

during equipment cleaning. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5-8. ***EPA/OPPT Mass Balance Model*** **Parameter Default Values During Equipment Cleaning**

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (CEB, 1991a)
Exposure Days	The lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with the Frequency of Release determined in Section 0)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 0)
Exposure Duration	Consistent with the Operating Hours determined in Section 0, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991a)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 0
Ventilation Rate	EPA defaults 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (CEB, 1991a) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

5.1.11 Dermal Exposure

202. Dermal exposure to liquids is expected during the cleaning of process equipment. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities. The rationale, defaults, and limitations of this model are explained in Appendix B. Dermal exposure to the chemical of interest in solid rods, blocks, or pellets is assumed negligible.

203. To estimate the potential worker exposure to the chemical of interest in a liquid adhesive product for this activity, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \qquad \text{(Eqn. 5-3)}$$

204. This exposure will occur over $TIME_{app\_working\_days}$ (consistent with Section 0). $TIME_{app\_working\_days}$ will depend on the end-use industry; therefore, the reader should refer to Section 0 to identify the appropriate value for the industry being assessed.

Where:

EXP_{dermal} = Potential dermal exposure to the chemical of interest per day (mg chemical/day)

Q_{liquid_skin}	=	Quantity of liquid adhesive product remaining on skin (Defaults: 2.1 mg product/cm^2-incident (high-end) and 0.7 mg product/cm^2-incident (low-end) for routine or incidental contact (CEB, 2000))
$AREA_{surface}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands (CEB, 2000))
$N_{exp\_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day) (See footnote to Equation 5-3a)
F_{chem_form}	=	Mass fraction of the chemical of interest in the adhesive product (mg chemical/mg product) (See Section 0)

Exposure during Application of the Adhesive (Exposure D)

205. Worker exposure to the chemical contained in adhesive product formulations may vary according to the coating operations used. Table 4-5 presents a logic table that can be used to determine the appropriate application method to use for the chemical of interest. This assumption considers the fraction of the chemical of interest in the formulation.

206. Inhalation exposures are estimated below for mists or overspray generated during coating operations; however, these models are only applicable to liquid and solid chemicals contained within mist droplets and particulates.

207. While exposures to vapors from volatile chemicals are also likely during coating operations, EPA has not developed estimation methods to quantify these potential exposures. Of the reviewed PMNs submitted to EPA under section 5 of TSCA, 10 percent had vapor pressures between 0.001 and 35 torr. While most of the submitted chemicals were non-volatile, use of volatile chemicals is expected. The use of this ESD for assessing such volatile chemicals can result in significant exposure underestimates during application of adhesives containing the volatile chemical. The quantification of inhalation exposures to vapors would require specific information about the application process, such as the chemical evaporation rate and length of time over which evaporation occurs. Also, the proximity and extent of worker activity during application would need to be known. Such an assessment is beyond the scope of this ESD, which is intended to serve as a preliminary screening tool for assessing new chemicals. As a result, inhalation exposures to chemical vapors during adhesives application and drying are presented as a data gap in this ESD.

208. For completeness, a surrogate method for estimating inhalation exposures from volatile chemicals is presented below. This approach estimates the airborne concentration of the chemical from airborne concentrations of a known similar volatile compound (CEB, 1991a).

209. Dermal exposures during coating operations are estimated using Standard EPA models, such as the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model* (for spray coating) and the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* (roll coating).

210. The default number of workers per site that may be exposed during this activity will depend on the end-use industry. The default number of workers is provided in Section 0.

211. Note that the exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 0 calculations); however, EPA assumes a maximum exposure duration of eight hours per day. EPA assumes this occurs over $TIME_{app\_working\_days}$, which will depend on the end-use industry. The reader should refer to Section 0 to identify

the appropriate value for $TIME_{app\_working\_days}$. The reader should note that the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year. These exposure duration maximum defaults are based on fulltime employment and considers an individual worker's vacation, sick, and weekend time (e.g. a 40-hour work week over 50 weeks per year).

5.1.12 Inhalation Exposure

212. The method used to calculate inhalation exposure ($EXP_{inhalation}$) will depend on the volatility and the physical state of the chemical of interest. For EPA new chemical assessments, volatile chemicals are considered to be those whose vapor pressures are above 0.001 torr (CEB, 2008a). Vapor pressures exceeding 35 torr are outside the scope of this ESD. Chemicals with vapor pressures below 0.001 torr are included in the scope of this draft, but they are expected to result in negligible volatile releases and associated inhalation exposure to vapors (CEB, 1994 and 1995).

213. The estimation methods presented in the following subsections are applicable to non-volatile particulates only. For volatile chemicals, inhalation exposures can be estimated based on existing chemical data for an analogous chemical (CEB, 1991a). Using this approach, the airborne concentration for the chemical of interest is estimated using the following equation:

$$C_{v,s} = C_{v,k} \times \frac{Y_s}{Y_k} \quad \text{(Eqn. 5-4)}$$

Where:

$C_{v,s}$	=	Estimated airborne concentration of the chemical of interest (ppm)
$C_{v,k}$	=	Measured airborne concentration of the known chemical (ppm)
Y_s	=	Weight fraction of the chemical of interest in the adhesive mixture being assessed
Y_k	=	Weight fraction of the known chemical when used in adhesive mixtures

214. If no data are available to enter a value of $C_{v,k}$ for Equation 5-4, an assessment should note inhalation exposures to chemical vapors during adhesives application as a data gap. Furthermore, if inhalation exposures to mists containing an assessed volatile component are estimated using one of the methods discussed below, in lieu of Equation 5-4, an assessment should note that the inhalation estimate is likely an underestimate, because the method will account for mist inhalation exposures only and will not account for inhalation exposures to chemical vapors.

Spray Application

215. Spray application in the adhesive products industry is typically a controlled process conducted in a spray booth or an enclosed system. If chemical-specific information indicates spray application in a fully enclosed, automated system, negligible inhalation exposure to the chemical is expected from the spray application process.

216. If the process enclosure is unknown, assume the default system to be a manual or unenclosed application. Due to the lack of specific exposure data, this ESD conservatively

estimates exposures during spray coating using the *EPA/OPPT Automobile OEM Spray Coating Inhalation Exposure Model*[19]. This model is the default for calculating worker exposures to a non-volatile (e.g. < 0.001 torr) chemical during the spray coating and can be used to estimate the amount of non-volatile chemical in mist inhaled by a worker spray painting original equipment manufacturer (OEM) products in coating operations. Table 5-9 lists concentrations for using conventional air-atomized and high volume-low pressure (HVLP) spray guns during the application step. The mass concentration of particulate in air is further used to estimate the inhalation exposure and average and lifetime dosages.

Table 5-9. Mass Concentration of Total Particulate in Air, C_{part_air}, by Spray Gun Type

Spray Gun Type[a]	C_{part_air} (mg/m^3)
Conventional	2.3 mg/m^3 (Downdraft) (Default)[b]
	15 mg/m^3 (Crossdraft)
HVLP	1.9 mg/m^3 (Downdraft)
	15 mg/m^3 (Crossdraft)

a – If an alternate spray gun type is used, C_{part_air} values for conventional spray guns (downdraft) may be used.
b – This default was selected based on an internal EPA policy decision in July 2003 to use conventional spray guns (downdraft) as a default for all OEM spray coating operations, including applications outside the automotive industry.

217. To estimate the potential worker inhalation exposure to the chemical during coating operations, EPA recommends using the following equation:

$$EXP_{inhalation} = C_{part\_air} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem\_particulate} \qquad \text{(Eqn. 5-5)}$$

218. This exposure will occur over [$TIME_{app\_working\_days}$ (consistent with Section 4.7), up to 250] days per year.

Where:

$EXP_{inhalation}$	=	Inhalation potential dose rate of chemical during spray coating (mg chemical/day)
C_{part_air}	=	Mass concentration of total particulate in air (Default: 2.3 mg particulate/m^3 of air) (See Table 5-9)
$TIME_{exposure}$	=	Duration of exposure to the chemical during the coating process (Default: 8 hours/day)
$RATE_{breathing}$	=	Inhalation rate (CEB default: 1.25 m^3/hr) (CEB, 1991a)
$F_{chem\_particulate}$	=	The lesser of $F_{chem\_form}/F_{particulate\_prod}$ or 1.
F_{chem_form}	=	Mass fraction of chemical in the adhesive product (Default: 0.7 mg chemical/mg product) (See Section 0)

[19] Note that EPA recommends using the *EPA/OPPT Automobile OEM Spray Coating Inhalation Exposure Model* to estimate potential inhalation exposures from spray application and the *EPA/OPPT Automobile Refinish Spray Overspray Loss Model* to estimate environmental releases from the same operation. The *EPA/OPPT Automobile OEM Spray Coating Inhalation Exposure Model* was selected because the spray application of adhesive products will be in a more controlled OEM environment, rather than the less controlled automotive refinishing environment. However, the *EPA/OPPT Automobile Refinish Spray Overspray Loss Model* assumes the use of dry filters, which is more consistent with the adhesive products use industry than the use of water curtains (the default for the *EPA/OPPT Automobile OEM Spray Overspray Loss Model*).

$F_{particulate\_prod}$ = Mass fraction of particulate in the adhesive product (CEB default: 0.25 mg particulate/mg product) (OECD, 2004)

219. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to spray coating activities. The *Generic Scenario for Automobile Spray Coating* (CEB, 1996) provides additional information about this model.

Roll Coating

220. The *EPA/OPPT UV Roll Coating Inhalation Model* is the default model for calculating worker inhalation exposures to the mist that may be generated by roll coating. This model estimates the amount of chemical inhaled by a worker who conducts activities near roll coater(s) using adhesives containing the chemical.

221. The equation for the *EPA/OPPT UV Roll Coating Inhalation Model* is the same as Equation 5-5 but uses a different set of default values for mass concentrations of total particulate air. For this model, the default low- and high-end mass concentrations of total particulate in air, C_{part_air}, are 0.04 mg/m^3 and 0.26 mg/m^3, respectively. The *Generic Scenario for Roll Coating of UV-Curable Coatings* (CEB, 1994) provides additional information on the *UV/EB Roll Coating Inhalation Model*.

Curtain Coating or Syringe/Bead Application

222. Inhalation exposures may result during curtain coating or syringe/bead application if the chemical of interest is volatile. In such instances, exposures should be assessed as discussed at the beginning of Section 0.

223. Inhalation exposures to non-volatiles are not expected during curtain coating or syringe/bead application. During curtain coating applications, a stream of adhesive flows at a controlled rate as the substrate is conveyed across the stream. Unlike roll coating processes, which involve high line speeds that can splatter and generate mist, curtain coating is not expected to generate mist or overspray. Similarly, during syringe/bead application, the adhesive is extruded at a controlled rate and highly localized manner; therefore, the potential does not exist for the generation of mist or overspray.

5.1.13 Dermal Exposure

Spray Application

224. Dermal exposure is expected during the application of adhesive formulations by spray, roll, or curtain coating. Hand held spray application is commonly used in furniture, automobile, and airplane manufacturing (EPA, 1995a; EPA, 1998). Based on PMN data (see Appendix D), this application method may be employed in each of the end-use industries covered in this ESD. For spray applications, the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these application activities.

225. To estimate the potential worker exposure to the chemical of interest in a liquid adhesive product formulation for this activity, EPA recommends using the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \qquad \text{(Eqn. 5-6)}$$

226. This exposure will occur over [$TIME_{app\_working\_days}$ (consistent with Section 0), up to 250] days per year.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
Q_{liquid_skin}	=	Quantity of liquid adhesive formulation remaining on skin (Defaults: 10.3 mg component/cm^2-incident (high-end) and 1.3 mg component/cm^2-incident (low-end) for routine or incidental contact (CEB, 2000))
$AREA_{surface}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands (CEB, 2000))
$N_{exp\_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day) (See the footnote to Equation 5-3a)
F_{chem_form}	=	Mass fraction of the chemical of interest in the adhesive product (mg chemical/mg product) (See Section 0)

Roll Coating or Curtain Coating

227. Dermal exposure is also expected during the application of adhesive formulations by roll and curtain coating. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* uses the same equation as Equation 5-6 but with a different set of default values for the quantity of liquid remaining on the skin. For this model, the default low- and high-end values for Q_{liquid_skin} are 0.7 mg/cm^2-incident and 2.1 mg/cm^2-incident, respectively. These values may be substituted in Equation 5-6 to estimate dermal exposure to the chemical of interest in a liquid formulation during roll or curtain coating application activities.

Syringe or Bead Application

228. Based on engineering judgment, dermal exposures are not expected. This is because this application type utilizes automated equipment or mechanical tools (e.g. glue guns) to apply adhesives in a controlled and highly localized manner. In such instances, these adhesives are extruded directly onto substrates from syringes/glue guns and then dried/cured; therefore, the potential for direct dermal contact during application is negligible.

229. For hot-melt adhesives, the potential for dermal exposure is further mitigated by the fact that it must be heated during application. Application temperatures may range from 150-190°C (Ullman, 1985). Per CEB qualitative assessments, dermal exposures to chemicals handled at temperatures exceeding 140°F (60°C) are assessed as negligible (CEB, 1991a).

Exposure during Curing/Drying (Exposure E)

230. Inhalation exposures during curing/drying operations can occur; however, EPA has not developed estimation methods to quantify these potential exposures. The quantification

of inhalation exposures would require specific information about the evaporation process, such as the chemical evaporation rate and length of time over which evaporation occurs. Also, the proximity and extent of worker activity during evaporation would need to be known. Such an assessment is beyond the scope of this ESD, which is intended to serve as a preliminary screening tool for assessing new chemicals. Furthermore, the Paper and Other Web Coating Operations NESHAP states that, typically, drying ovens will immediately follow adhesive application stations (EPA, 2000); therefore, exposures during curing/drying are expected to be limited. As a result, methods to quantify inhalation exposures during curing/drying operations are not provided in this ESD.

231. If desired, inhalation exposures can be estimated using the analogous chemical method, as discussed in Section 0. Using this approach, the airborne concentration for the chemical of interest is estimated using the following equation:

$$C_{v,s} = C_{v,k} \times \frac{Y_s}{Y_k} \quad \text{(Eqn. 5-7)}$$

Where:

$C_{v,s}$	=	Estimated airborne concentration of the chemical of interest (ppm)
$C_{v,k}$	=	Measured airborne concentration of the known chemical (ppm)
Y_s	=	Weight fraction of the chemical of interest in the adhesive mixture being assessed
Y_k	=	Weight fraction of the known chemical when used in adhesive mixtures

6 SAMPLE CALCULATIONS

232. This section presents an example of how the equations introduced in Sections 3, 4, and 5 might be used to estimate releases of and exposures to a volatile chemical present in an adhesive product that is spray applied onto a substrate. The default values used in these calculations are presented in Sections 3 through 5 and should be used only in the absence of site-specific information. The following data are used in the example calculations:

1. Chemical of interest production volume (Q_{chem_yr}) is *10,000 kg chemical/yr* and is used as an elastomer in an adhesive formulation.

2. Chemical of interest has a molecular weight ($MW_{chem.}$) of 100 g/mol and a vapor pressure ($VP_{chem.}$) of 0.1 torr @ 25^{o}C (e.g. the chemical is volatile for the purposes of the assessment). Note that this molecular weight and vapor pressure may not be typical for elastomers. However, the molecular weight value is chosen as a simplistic assumption, and the non-negligible vapor pressure is chosen for the exercise of performing volatile release and exposure calculations.

3. Chemical of interest is distributed to the end-use sites in *liquid* form to be applied to substrates as an *unknown adhesive product*.

4. The chemical assessment must address environmental release and exposure concerns.

233. To better visualize the example scenario, the reader is encouraged to refer to Figure 2-1. This figure provides a visual representation of the potential release and exposure points that must be considered during a new chemical assessment.

General Facility Information for Application of Adhesive Products

6.1.1 Annual Adhesive Product Use Rate ($Q_{app\_site\_yr}$)

234. Aside from the annual production volume and physical state of the chemical of interest, no other site-specific information or data are known for the Equation 3-6 parameters (e.g. $Q_{app\_site\_yr}$, Q_{chem_yr}, and F_{chem_form}) used to estimate the number of end-use sites using the chemical (N_{app_sites}). Therefore, use of the default assumptions is appropriate. Using Figure 3-1, for an unknown adhesive product with both release and exposure concerns, the *Motor and Non-Motor Vehicle, Vehicle Parts, and Tires Manufacturing (Except Retreading)* end-use industry was used. The following default assumptions about the type of use and adhesive product are made from Table 3-4:

235. Type of end-use industry: Motor and Non-Motor Vehicle, Vehicle Parts, and Tires Manufacturing (Except Retreading)

236. The resulting default production rate ($Q_{app\_site\_use\_rate}$) from Table 3-4 is 13,500 kg product used/site-yr:

$$Q_{app\_site\_yr} = Q_{app\_site\_use\_rate} \times F_{app\_adhesive} \qquad \text{(Eqn. 3-1)}$$

$$Q_{app\_site\_yr} = 13{,}500 \text{ kg product used/site-yr} \times 1 \text{ kg product containing the chemical/kg total product used}$$

$$Q_{app\_site\_yr} = 13{,}500 \text{ kg product containing the chemical/site-yr}$$

6.1.2 Concentration (Mass Fraction) of the Chemical of Interest in the Adhesive Component (F_{chem_comp})

237. If the concentration of the chemical of interest in the adhesive component (F_{chem_comp}) is not known, assume 100 percent (or *1 kg chemical/kg component*).

6.1.3 Concentration (Mass Fraction) of the Adhesive Component in the Product (F_{comp_form})

238. The concentration of the adhesive component in the adhesive product, if not provided in the PMN submission, may be chosen appropriately from Table 1-3, Table 1-4, or Table 1-5. Since it is known that the chemical is used as an elastomer within an unknown adhesive product, and since the concentration of the component in the final product is not known, the high-end concentration (weight fraction) for an elastomer, as presented in Table 1-3 is assumed. The chemical is known to be an elastomer for spray-applied adhesives; therefore, the most appropriate high-end concentration is based on organic- or water-based solvent adhesives (e.g. not hot-melts). The high-end concentration for elastomers and polymers used in adhesives is *0.61 kg component/kg adhesive*.

6.1.4 Concentration (Mass Fraction) of the Chemical of Interest in the Adhesive Product (F_{chem_form})

239. The concentration of the chemical of interest in the adhesive product can be calculated from the concentration of the chemical of interest in the component and the concentration of the component in the product.

$$F_{chem\_form} = F_{chem\_comp} \times F_{comp\_form} \qquad \text{(Eqn. 3-2)}$$

$$F_{chem\_form} = 1 \text{ kg chemical/1 kg component} \times 0.61 \text{ kg component/1 kg adhesive product}$$

$$F_{chem\_form} = 0.61 \text{ kg chemical/ kg adhesive product}$$

6.1.5 Number of Application Sites (N_{app_sites})

240. The number of application sites may be calculated using the submission-specified production volume, the facility use rate, and the concentration of the chemical of interest in the adhesive product.

$$N_{app\_sites} = \frac{Q_{chem\_yr}}{Q_{app\_site\_yr} \times F_{chem\_form}} \qquad \text{(Eqn. 3-6)}$$

$$N_{app\_sites} = \frac{10{,}000\,\text{kg chem./yr}}{13{,}500\,\text{kg coating/site - yr} \times 0.61\,\text{kg chem./kgproduct}}$$

$$N_{app\_sites} = 1.2\,\text{sites}$$

Round N_{app_sites} to nearest non-zero integer (1 *application site*) and recalculate $Q_{app\_site\_yr}$:

$$Q_{app\_site\_yr} = \frac{10{,}000\,\text{kg chem./yr}}{1\,\text{site} \times 0.61\,\text{kg chem/kgproduct}}$$

$$Q_{app\_site\_yr} = 16{,}400\,\text{kg product/site - yr}$$

6.1.6 Days of Operation (TIME$_{app_working_days}$)

241. Per Table 3-4, the number of operating days (e.g. $TIME_{app\_working\_days}$) is 260 days per year.

6.1.7 Daily Use rate of the Chemical of Interest (Q$_{app_chem_site_day}$)

242. The daily use rate of the chemical of interest may be calculated from the days of operation and the annual facility use rate.

$$Q_{app\_chem\_site\_day} = \frac{Q_{app\_site\_yr} \times F_{chem\_form}}{TIME_{app\_working\_days}} \qquad \text{(Eqn. 3-5)}$$

$$Q_{app\_chem\_site\_day} = \frac{\dfrac{16{,}400\,\text{kg prod.}}{\text{site - yr}} \times \dfrac{0.61\,\text{kg chem.}}{\text{kg prod.}}}{260\,\text{days/yr}}$$

$$Q_{app\_chem\_site\_day} = \frac{38\,\text{kg chem.}}{\text{site} - \text{day}}$$

6.1.8 Annual Number of Product Containers Emptied per Site (N$_{form_cont_empty_site_yr}$)

243. It is assumed that the adhesive product (which is 61% chemical of interest) is shipped to the applicators in 55-gallon drums, by default. A density of 1 kg/L is also assumed for the product. The mass capacity for each of the drums is calculated as:

$$Q_{cont\_empty} = V_{cont\_empty} \times RHO_{product} = \frac{208\text{ L prod.}}{\text{container}} \times \frac{1\,\text{kg prod.}}{\text{L prod.}} = \frac{208\text{ kg prod.}}{\text{container}}$$

244. The number of shipping containers that are emptied per site, per year is calculated as:

$$N_{form\_cont\_empty\_site\_yr} = \frac{Q_{app\_chem\_site\_day} \times TIME_{app\_working\_days}}{F_{chem\_form} \times Q_{cont\_empty}} \qquad \text{(Eqn. 3-7)}$$

$$N_{form\_cont\_empty\_site\_yr} = \frac{38\ \text{kg chem./site-day} \times 260\ \text{days/yr}}{0.61\ \text{kg chem./kg prod.} \times 208\ \text{kg prod./container}}$$

$$N_{form\_cont\_empty\_site\_yr} = 78\ \text{containers/site-yr}$$

Release Assessments for Application of Adhesive Products

6.1.9 Adhesives Product Container Residue Released to Water, Incineration, or Landfill (Release 1)

245. Since $N_{form\_cont\_empty\_site\_yr}$ is less than $TIME_{app\_working\_days}$, the days of release from container residue is equal to $N_{form\_cont\_empty\_site\_yr}$ (e.g. 78 containers/site-yr, as calculated in the previous section). The daily release is calculated using the following equation:

$$Elocal_{form\_cont\_residue\_disp} = Q_{cont\_empty} \times F_{chem\_form} \times F_{container\_residue} \times N_{form\_cont\_empty\_site\_day} \qquad \text{(Eqn. 4-1a)}$$

246. Since it is known that the adhesive product is in a liquid form when shipped to the application site, and the container is assumed to be a 55-gallon drum by default, the *EPA/OPPT Drum Residual Model* is used to estimate this release. The default fraction of liquid chemical that remains in the empty container ($F_{container\_residue}$) is 0.03 kg chemical remaining/kg chemical in full container (see Table B-3 in Appendix B):

$$Elocal_{form\_cont\_residue\_disp} = Q_{cont\_empty} \times F_{chem\_form} \times F_{container\_residue} \times N_{form\_cont\_empty\_site\_day}$$

$$Elocal_{app\_container\_residue\_disp} = \frac{208\ \text{kg prod.}}{\text{container}} \times \frac{0.61\ \text{kg chemical}}{\text{kg prod.}} \times \frac{0.03\ \text{kg prod.}}{\text{kg prod.}} \times \frac{1\ \text{container}}{\text{site-day}}$$

$$Elocal_{app\_container\_residue\_disp} = \frac{3.8\ \text{kg chem. released}}{\text{site} - \text{day}}$$

…over 78 days/year from 1 site.

6.1.10 Open Surface Losses to Air During Container Cleaning (Release 2)

247. Since the chemical of interest is volatile, it will be emitted from the process while the emptied containers are cleaned. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

$$Q_{vapor\_generation} = \frac{(8.24 \times 10^{-8}) \times MW_{chem}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left(\frac{1}{29} + \frac{1}{MW_{chem}} \right)^{0.25} \times RATE_{air\_speed}^{0.5} \times AREA_{opening}}{TEMP_{ambient}^{0.05} \times D_{opening}^{0.5} \times P_{ambient}^{0.5}}$$

(Eqn. B-1)

Table 6-1. Summary of ChemSTEER Inputs for Release 2

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	$VP_{chem.}$	Torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	100
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	20.3
Temperature	$TEMP_{ambient}$	K	298
Diameter of Pool Opening	$D_{opening}$	Cm	5.08
Pressure	$P_{ambient}$	Atm	1

Therefore:

$$Q_{vapor\_generation} = 1.2 \times 10^{-5} \text{g/s}$$

248. Using $Q_{vapor\_generation}$ calculated in Equation B-1 and the other standard default values presented in Table 4-4 for container cleaning, the model then estimates the daily release to air using the following equation:

$$Elocal_{air\_cleaning} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \qquad \text{(Eqn. B-2)}$$

$$Elocal_{air\_cleaning} = 1.2 \times 10^{-5} \text{ g chem./sec} \times \left(\frac{78 \text{ containers/site} - \text{yr}}{260 \text{ days/yr} \times 20 \text{ containers/hr}} \right) \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$Elocal_{air\_cleaning} = 6.5 \times 10^{-7} \text{ kg chem. emitted/ site} - \text{day}$$

…over 260 days/year from 1 site.

6.1.11 Transfer Operation Losses to Air from Unloading Adhesive Product (Release 3)

249. Since the chemical of interest is volatile, it will be emitted from the process from the displacement of saturated air when the chemical is transferred. The *EPA/OAQPS AP-42 Loading Model* is used to estimate the rate at which the chemical is emitted during this activity:

$$Q_{vapor\_generation} = \frac{F_{saturation\_factor} \times MW_{chem} \times \left(V_{cont\_empty} \times \frac{3785.4 cm^3}{gal} \right) \times \left(\frac{RATE_{fill}}{3600 \text{ sec/hour}} \right) \times F_{correction\_factor} \times \left(\frac{VP_{chem}}{760 \text{ torr/atm}} \right)}{R \times TEMP_{ambient}}$$

(Eqn. B-5)

Table 6-2. Summary of ChemSTEER Inputs for Release 3

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Saturation Factor	$F_{saturation\_factor}$	Dimensionless	Typical = 0.5 Worst Case = 1
Vapor Pressure	$VP_{chem.}$	Torr	0.1
Container Volume	V_{cont_empty}	Gal	55
Fill Rate	$RATE_{fill}$	containers/hour	20
Temperature	$TEMP_{ambient}$	K	298
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Gas Constant	R	$Atm \cdot cm^3/K \cdot mol$	82.05

Therefore:

$$Q_{vapor\_generation} = 3.1\times10^{-4}\ \text{g/s} \text{ for typical and } Q_{vapor\_generation} = 6.2\times10^{-4}\ \text{g/s} \text{ for worst case}$$

250. Using $Q_{vapor\_generation}$ calculated in Equation B-5 and the other standard default values presented in Table 4-2 for container unloading, the model then estimates the daily release to air using the following equation:

$$Elocal_{app\_air\_transfers} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600\ \text{sec/hour}}{1000\ \text{g/kg}} \qquad \text{(Eqn. B-6)}$$

$$Elocal_{app\_air\_transfers} = \left(3.1\times10^{-4} \text{ to } 6.2\times10^{-4}\right)\text{g chem./sec} \times \left(\frac{78\ \text{containers/site - yr}}{260\ \text{days/yr} \times 20\ \text{containers/hr}}\right) \times \frac{3600\ \text{sec/hr}}{1000\ \text{g/kg}}$$

$$Elocal_{app\_air\_transfers} = 1.7\text{x}10^{-5} \text{ to } 3.3 \text{ x } 10^{-5} \text{ kg chem. emitted/site-day}$$

…over 260 days/year from 1 site.

6.1.12 Equipment Cleaning Releases to Water, Incineration or Landfill (Release 4)

$$Elocal_{equipment\_cleaning} = Q_{app\_chem\_site\_day} \times F_{equipment\_cleaning} \qquad \text{(Eqn. 4-5)}$$

$$Elocal_{equipment\_cleaning} = \frac{38\ \text{kg chem.}}{\text{site} - \text{day}} \times \frac{0.01\ \text{kg chem released}}{\text{kg chem used}}$$

$$Elocal_{equipment\_cleaning} = \frac{0.4\ \text{kg chem. released}}{\text{site} - \text{day}}$$

…over 260 days/year from 1 site.

6.1.13 Open Surface Losses to Air During Equipment Cleaning (Release 5)

251. Since the chemical of interest is volatile, it will be emitted from the process during process equipment cleaning. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

$$Q_{vapor\_generation} = \frac{(8.24\times10^{-8})\times MW_{chem}^{0.835}\times F_{correction\_factor}\times VP_{chem}\times\left(\frac{1}{29}+\frac{1}{MW_{chem}}\right)^{0.25}\times RATE_{air\_speed}^{0.5}\times AREA_{opening}}{TEMP_{ambient}^{0.05}\times D_{opening}^{0.5}\times P_{ambient}^{0.5}}$$

(Eqn. B-1)

Table 6-3. Summary of ChemSTEER Inputs for Release 5

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW_{chem}	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	VP_{chem}	Torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	100
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	6,648
Temperature	$TEMP_{ambient}$	K	298
Diameter of Pool Opening	$D_{opening}$	cm	92
Pressure	$P_{ambient}$	Atm	1

Therefore:

$$Q_{vapor\_generation} = 9.2\times10^{-4}\text{ g/s}$$

252. Using $Q_{vapor\_generation}$ calculated in Equation B-1 and the other standard default values presented in Table 4-6 for process equipment cleaning, the model then estimates the daily release to air using the following equation:

$$Elocal_{air\_eqpt\_deaning} = Q_{vapor\_generation}\times TIME_{activity\_hours}\times\frac{3600\text{ sec/hour}}{1000\text{ g/kg}} \quad \text{(Eqn. B-2)}$$

$$Elocal_{air\_eqpt\_deaning} = 9.2\times10^{-4}\text{ g chem./sec}\times(4\text{ hrs/bt}\times1\text{ bt/site}-\text{day})\times\frac{3600\text{ sec/hour}}{1000\text{ g/kg}}$$

$$Elocal_{air\_sample} = 0.013\text{ kg chem.emitted/ site}-\text{day}$$

…over 260 days/year from 1 site.

6.1.14 Process Releases to Air or Incineration or Landfill During Application Process (Release 6)

253. It is known that the chemical is spray-applied onto substrates at the application sites; however, spray technologies are not known. Therefore, a default assumption can be made to estimate particulate releases from spray coating. From Table 4-5, the following information is obtained:

Spray Coating

254. The transfer efficiency of the resulting process: *25 to 60% (conservative: 25%)*

$$\text{Elocal}_{\text{application\_losses}} = Q_{\text{app\_chem\_site\_day}} \times (1 - F_{\text{transfer\_eff}}) \qquad \text{(Eqn. 4-3)}$$

$$\text{Elocal}_{\text{application\_losses}} = 38\ \text{kg / site - day} \times (1 - 0.25\ \text{kg adhesive transferred/kg sprayed})$$

$$\text{Elocal}_{\text{application\_losses}} = 28\ \text{kg/site - day}$$

…over 260 days/yr from 1 site.

255. The partitioning of the releases can be calculated based on assumptions that the spray booth technology has 90% capture efficiency with a dry filter.

Air Releases: $$\%_{\text{air}} = (1 - F_{\text{capture\_ef}}) \times 100 \qquad \text{(Eqn. 4-4a)}$$

$$\%_{\text{air}} = (1 - 0.90\ \text{kg captured/kg released}) \times 100$$

$$\%_{\text{air}} = 10\%$$

Land or Incineration Releases: $$\%_{\text{land\_inc}} = F_{\text{capture\_ef}} \times 100 \qquad \text{(Eqn. 4-4b)}$$

$$\%_{\text{land\_inc}} = 0.90\ \text{kg captured/kg released} \times 100$$

$$\%_{\text{land\_inc}} = 90\%$$

256. This would result in a release of 2.8 kg/site-day to air and 25.2 kg/site-day to land or incineration.

257. The reader should note that the release estimates calculated above are specific only to particulate releases. Although volatile releases are also expected to occur during spray coating, not assessed in this ESD because, as discussed in Section 0, EPA has not developed estimation methods to quantify potential vapor releases of volatile chemicals during application to substrates. As a simplifying assumption, volatile releases to air can be assumed to occur to completion during curing/drying and can be estimated using the method presented in the following subsection.

6.1.15 Process Releases to Air During Curing/Drying Evaporation (Release 7)

258. Since the assessed chemical is volatile, it is necessary to calculate evaporative losses from drying/curing. These can be calculated using the following equation:

$$\text{Elocal}_{\text{evaporation\_losses}} = Q_{\text{app\_chem\_site\_day}} \times \left(1 - F_{\text{container\_residue}} - (1 - F_{\text{transfer\_eff}}) - F_{\text{equipment\_cleaning}}\right) \qquad \text{(Eqn. 4-6)}$$

$$\text{Elocal}_{\text{evaporation\_losses}} = 38\ \text{kg / site - day} \times \left(1 - \frac{0.03\ \text{kg prod.}}{\text{kg prod.}} - \left(1 - \frac{0.25\ \text{kg adhesive transferred}}{\text{kg sprayed}}\right) - \frac{0.01\ \text{kg chem released}}{\text{kg chem used}}\right)$$

$$\text{Elocal}_{\text{evaporation\_losses}} = 8.0\ \text{kg/site - day}$$

…over 260 days/yr from 1 site.

Occupational Exposure Assessments for Application of Adhesive Products

6.1.16 Total Number of Workers Potentially Exposed to the Chemical

259. As discussed in Section 6.1.1, it is assumed that the chemical is used in a coating formulation falling under the *Motor and Non-Motor Vehicle, Vehicle Parts, and Tires Manufacturing (Except Retreading)* end-use market. Per Table 5-4, 90 workers are potentially exposed to the chemical at each site; therefore, the total number of workers is calculated as:

$$90\ \frac{\text{workers}}{\text{site}} \times N_{app\_sites} = 90\ \frac{\text{workers}}{\text{site}} \times 1\ \text{site} = 90\ \text{adhesives application workers}$$

260. Note that all 90 workers are assumed to be exposed during each of the exposure activities performed at the application site.

6.1.17 Exposure to Liquids During Container Cleaning (Exposure A)

Inhalation Exposure to Liquids

261. Using the vapor generation rate calculated in Release 2 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 6-4. Summary of ChemSTEER Inputs for Exposure A

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	1.2×10^{-5}
Breathing Rate	$RATE_{breathing}$	m^3/hour	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}} \quad \text{(Eqn. B-7)}$$

$C_{chem\_volumetric} = 4.0 \times 10^{-3}$ ppm for typical and $C_{chem\_volumetric} = 0.12$ ppm for worst case

262. Next, the volumetric concentration is converted to a mass concentration (C_{chem_mass}) by the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}} \quad \text{(Eqn. B-9)}$$

$C_{chem\_mass} = 1.7 \times 10^{-2}$ mg/m^3 for typical and $C_{chem\_mass} = 0.5$ mg/m^3 for worst case

263. Finally, the mass concentration of the chemical and the standard default values presented in Table 5-6 for the container cleaning activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure} \quad \text{(Eqn. B-10)}$$

$$EXP_{inhalation} = (0.017 \text{ to } 0.49)\text{ mg/m}^3 \times 1.25\text{ m}^3\text{/hr} \times \left(\frac{78 \text{ containers/site - yr}}{260 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$EXP_{inhalation} = 0.0003 \text{ to } 0.009 \text{ mg chem./day}$$

…over 260 days/year.

Dermal Exposure to Liquids

264. The potential worker exposure to the chemical within the liquid adhesive is calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \quad \text{(Eqn. 5-1)}$$

$$= \left[\frac{0.7 \text{ to } 2.1 \text{ mg comp.}}{\text{cm}^2 \text{ - incident}} \right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.61 \text{ mg chem.}}{\text{mg comp.}}$$

$$EXP_{dermal} = \frac{353 - 1{,}058 \text{ mg chem.}}{\text{day}}$$

…over 260 days/year.

6.1.18 Exposure During Loading/Unloading Liquid Formulations (Exposure B)

Inhalation Exposure to Liquids

265. The density of the liquid product is assumed to 1 kg/L and will likely be unloaded at ambient temperatures. Using the vapor generation rate calculated in Release 3 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 6-5. Summary of ChemSTEER Inputs for Exposure B

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	Typical = 3.1×10^{-4} Worst Case = 6.2×10^{-4}
Breathing Rate	$RATE_{breathing}$	$m^3/hour$	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20
Duration of Exposure	$TIME_{exposure}$	hours/day	0.03

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}} \qquad \text{(Eqn. B-7)}$$

$C_{chem\_volumetric}$ = 0.1 ppm for typical and 6.3 ppm for worst case

266. Next, the volumetric concentration is converted to a mass concentration (C_{chem_mass}) by the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}} \qquad \text{(Eqn. B-9)}$$

C_{chem_mass} = 0.4 mg/m^3 for typical and C_{chem_mass} = 25.8 mg/m^3 for worst case

267. Finally, the mass concentration of the chemical and the standard default values presented in Table 5-3 for the container unloading activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure} \qquad \text{(Eqn. B-10)}$$

$$EXP_{inhalation} = (0.41 \text{ to } 25)\ mg/m^3 \times 1.25\ m^3/hr \times \left(\frac{78 \text{ containers/site-yr}}{260 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$EXP_{inhalation} = 7.6x10^{-3} - 4.6x10^{-1} \text{ mg chem./day}$$

…over 260 days/year.

Dermal Exposure to Liquids:

268. The potential worker exposure to the chemical within the liquid adhesive is calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \quad \text{(Eqn. 5-2)}$$

$$= \left[\frac{0.7 \text{ to } 2.1 \text{ mg comp.}}{\text{cm}^2 \text{ - incident}}\right] \times 840\ \text{cm}^2 \times \frac{1\ \text{incident}}{\text{day}} \times \frac{0.61 \text{ mg chem.}}{\text{mg comp.}}$$

$$EXP_{dermal} = \frac{353 - 1{,}058 \text{ mg chem.}}{\text{day}}$$

…over 260 days/year.

6.1.19 Exposure to Liquids During Equipment Cleaning (Exposure C)

Inhalation Exposure

269. Using the vapor generation rate calculated in Release 4 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 6-6. Summary of ChemSTEER Inputs for Exposure C

Input Parameter	Variable	Units	ChemSTEER Input
Mixing Factor	F_{mixing_factor}	dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	9.2×10^{-4}
Breathing Rate	$RATE_{breathing}$	m^3/hour	1.25
Molar Volume	V_{molar}	L/mol	24.45
Duration of Exposure	$TIME_{exposure}$	hours/day	1

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}} \quad \text{(Eqn. B-7)}$$

$$C_{chem\_volumetric} = 0.31 - 9.3 \text{ ppm}$$

270. Next, the volumetric concentration is converted to a mass concentration (C_{chem_mass}) by the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}} \quad \text{(Eqn. B-9)}$$

$$C_{chem\_mass} = \frac{(0.31 \text{ to } 9.3) \text{ ppm} \times 100 \text{ g/mol}}{24.45 \text{ L/mol}}$$

$$C_{chem\_mass} = 1.3 \text{ - } 38.2 \text{ mg/m}^3$$

271. Finally, the mass concentration of the chemical and the standard default values presented in Table 5-7 for the process equipment cleaning activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure} \quad \text{(Eqn. B-10)}$$

$$EXP_{inhalation} = (1.3 \text{ to } 38.2) \text{ mg/m}^3 \times 1.25 \text{ m}^3\text{/hr} \times 1 \text{ hrs/site} - \text{day}$$
$$EXP_{inhalation} = 6.4\text{-}191.2 \text{ mg chem./day}$$
…over 260 days/year.

Dermal Exposure

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \quad \text{(Eqn. 5-3)}$$

$$= \left[\frac{0.7 \text{ to } 2.1 \text{ mg prod.}}{\text{cm}^2 \text{ - incident}}\right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.61 \text{ mg chem.}}{\text{mg prod.}}$$
$$EXP_{dermal} = \frac{353 - 1{,}058 \text{ mg chem.}}{\text{day}}$$
…over 260 days/year.

6.1.20 Exposure During Coating Operations (Exposure D)

Inhalation Exposure to Liquid Produc

272. During coating operations, inhalation exposures to the assessed chemical could occur from breathing mists containing the assessed chemical and from breathing chemical vapors. To estimate exposures to mists that contain the assessed chemical, EPA recommends using Equation 5-5. Since the spray coating technology is not known, the default particulate concentration in air for a conventional spray gun can be used (see Table 5-9).

Table 6-7. Summary of ChemSTEER Inputs for Exposure D

Input Parameter	Variable	Units	ChemSTEER Input
Breathing Rate	$RATE_{breathing}$	m^3/hour	1.25
Mass Concentration of Particulate in Air	C_{part_air}	mg/m^3	2.3
Duration of Exposure	$TIME_{exposure}$	hrs/day	8

273. The mass concentration of the chemical in air and the standard default values presented in Table 5-9 for the spray coating activity are used to estimate the amount of inhalation exposures per worker using the following equation:

$$EXP_{inhalation} = C_{part\_air} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem\_particulate} \quad \text{(Eqn. 5-5)}$$

$$EXP_{inhalation} = 2.3 \text{ mg product/m}^3 \times 8\text{hr/day} \times 1.25 \text{ m}^3\text{/hr} \times 0.61 \text{ mg chemical/mg product}$$
$$EXP_{inhalation} = 11.2 \text{ mg chem./worker} - \text{day}$$
…over 260 days/yr.

274. The assessment should note that this inhalation estimate is likely an underestimate, as the method only accounts for inhalation exposures to mists containing the assessed chemical. It does not account for inhalation exposures to the chemical vapors that also will be generated during coating operations.

Dermal Exposure to Liquids

275. The potential worker exposure to the chemical within the adhesive component is calculated using the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model*:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \quad \text{(Eqn. 5-6)}$$

$$= \left[\frac{0.7 \text{ to } 2.1 \text{ mg prod.}}{\text{cm}^2 \text{ - incident}}\right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.61 \text{ mg chem.}}{\text{mg prod.}}$$

$$EXP_{dermal} = \frac{353 - 1{,}058 \text{ mg chem.}}{\text{day}}$$

…over 260 days/year.

6.1.21 Exposure During Curing/Drying (Exposure E)

Inhalation Exposure to Liquids

276. As discussed in Section, this ESD is intended to provide screening-level inhalation exposure estimates. Quantification of inhalation exposures during solvent operation requires detailed information about the operation being assessed, which is beyond the scope of this ESD. Furthermore, drying ovens are expected to immediately follow adhesives application stations (EPA, 2000); therefore, exposures during curing/drying are expected to be limited.

7 DATA GAPS/UNCERTAINTIES AND FUTURE WORK

277. This ESD relies on industry data and information gathered from various sources to generate general facility estimates, release estimates, and exposure estimates. This ESD should be as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. This ESD could be improved by collecting measured data and associated information to verify or supersede the anecdotal data and information.

278. It is our interests in obtaining information about the adhesive products use industry that is characterized as "typical" or "conservative" (e.g. worse case), and is applicable to an industrial use site. While site-specific information are welcomed as valuable to this ESD, additional qualifiers of how reflective it is to the industry are needed to ensure its transparency if used in the ESD. Reviewers should also feel free to recommend additional resources that may be useful to the development of this ESD.

279. The key data gaps are summarized below. Note that the data gaps are listed in order of importance (the first being most important):

1. The ESD incorporates average facility production rates that are estimated using adhesive products industry market data and U.S. Census data for the number of U.S. formulation sites. The quality of these production rates could be improved with additional data on typical site component use rates for the various types of adhesives (e.g. kg/batch, kg/site-day).

2. The ESD assumes that applicators use a single component product (containing the chemical of interest) for all adhesive products of the same type. Additional information on the validity of these assumptions would improve the quality of the estimates. In other words, might applicators alternately use one of several available types of stabilizers when applying an adhesive product?

3. No specific information was found on the typical release control technologies (e.g. wastewater treatment, air release controls) utilized by three of the five industries within the scope of this ESD. The specific industries for which no information was found are:

   - Computer/electronic and electrical product manufacturing;
   - Motor and non-motor vehicle, vehicle parts, and tire manufacturing (except retreading); and
   - General assembly/binding.

4. The releases calculated in this ESD reflect the amount of chemical released directly from the process. Information on control technologies and the prevalence of their use in these industries would further improve this ESD.

5. Specific data on the numbers of workers performing the various exposure activities in the adhesive application processes were not found. Therefore, the ESD assumed that the number of workers per facility estimated for each adhesive product and market perform each of the exposure activities. Additional information on the numbers workers performing each exposure activity would further enhance the calculations.

6. Specific input on the reasonableness of the default values used in the general facility estimates (e.g. batch duration, number of operating days per year) would enhance the quality of the calculations.

7. Specific input on estimation methods for inhalation exposures to volatile chemicals generated during coating application or curing/drying operations would address this existing data gap and further improve the ESD.

8. Industry-specific monitoring data for operations involving volatile liquids would enhance the estimates for vented or fugitive releases and associated worker inhalation exposures.

9. Industry-specific dermal monitoring data for all operations involving workers manually handling the adhesive products would enhance the estimates.

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APPENDIX A

ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

Summary of Release and Exposure Estimation Equations for Application Sites

Table A-1 summarizes the equations introduced in Sections 3, 4, and 5 of this document. These equations may be used in evaluating releases of and exposures to chemicals used in the application of adhesives to substrates. A description of each input variable and associated default is provided in Table A-2.

Table A-1. Adhesives Application Release and Exposure Calculation Summary

General Facility Estimates

Annual Facility Use Rate ($Q_{app\_site\_yr}$):

$$Q_{app\_site\_yr} = Q_{app\_site\_use\_rate} \times F_{app\_adhesive} \quad \text{(Eqn. 3-1)}$$

Mass Fraction of Chemical in Radiation Curable Product (F_{chem_form}):

$$F_{chem\_form} = F_{chem\_comp} \times F_{comp\_form} \quad \text{(Eqn. 3-2)}$$

Annual Number of Batches ($N_{bt\_site\_yr}$):

To estimate the annual number of batches, a batch size must be calculated. Batch size can be estimated using the following equation:

$$Q_{app\_bt} = \frac{Q_{app\_site\_yr}}{TIME_{app\_working\_days} \times N_{bt\_site\_day}} \quad \text{(Eqn. 3-3)}$$

Once the batch size has been calculated, the annual number of batches can be estimated using the following equation:

$$N_{bt\_site\_yr} = \frac{Q_{app\_site\_yr}}{Q_{app\_bt}} \quad \text{(Eqn. 3-4)}$$

Daily Use Rate of the Chemical of Interest (kg chemical/site-day) ($Q_{app\_chem\_site\_day}$):

$$Q_{app\_chem\_site\_day} = \frac{Q_{app\_site\_yr} \times F_{chem\_form}}{TIME_{app\_working\_days}} \quad \text{(Eqn. 3-5)}$$

Number of Application Sites (N_{app_sites}):

$$N_{app\_sites} = \frac{Q_{chem\_yr}}{Q_{app\_site\_yr} \times F_{chem\_form}} \quad \text{(Eqn. 3-6)}$$

The value for N_{app_sites}, calculated using Equation 3-3, should be rounded to the nearest non-zero integer value. $Q_{app\_site\_yr}$ and $TIME_{app\_working\_days}$ should then be adjusted for the N_{app_sites} integer value (to avoid errors due to rounding) while maintaining the same value of $Q_{app\_chem\_site\_day}$ calculated in Section 0. First, $TIME_{app\_working\_days}$ is recalculated using $Q_{chem\_site\_day}$ and the rounded number of sites:

$$TIME_{app\_working\_days} = \frac{Q_{chem\_yr}}{N_{app\_sites} \times Q_{app\_chem\_site\_day}}$$

Next, $TIME_{app\_working\_days}$ is rounded to the nearest non-zero integer. Then, $Q_{app\_site\_yr}$ is recalculated using the rounded number of application days:

$$Q_{app\_site\_yr} = \frac{Q_{app\_chem\_site\_day} \times TIME_{app\_working\_days}}{F_{chem\_form}}$$

Annual Number of Adhesive Product Containers Emptied per Facility (containers/site-year) ($N_{form\_cont\_emtpy\_site\_\_yr}$):

$$N_{form\_cont\_empty\_site\_yr} = \frac{Q_{app\_chem\_site\_day} \times TIME_{app\_working\_days}}{F_{chem\_form} \times Q_{cont\_empty}} \quad \text{(Eqn. 3-7)}$$

Release Calculations		
Source	**Possible Medium**	**Daily Release Rates (kg/site-day), Elocal (for Given Sources)**
Container Residue	Water Landfill Incineration	If $N_{form\_cont\_empty\_site\_yr}$ is fewer than $TIME_{app\_working\_days}$: $Elocal_{form\_cont\_residue\_disp} = Q_{cont\_empty} \times F_{chem\_comp} \times F_{container\_residue} \times N_{form\_cont\_empty\_site\_day}$ … released over [$N_{form\_cont\_empty\_site\_yr}$] days/year from [$N_{app\_sites}$] sites(E If $N_{form\_cont\_empty\_site\_yr}$ is greater than $TIME_{app\_working\_days}$: $Elocal_{form\_cont\_residue\_disp} = Q_{app\_chem\_site\_day} \times F_{container\_residue}$ … released over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites (Eqn. 4-1b)
Container Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.5)

Release Calculations		
Source	**Possible Medium**	**Daily Release Rates (kg/site-day), Elocal (for Given Sources)**
Transfer Operations (Volatile Releases)	Air	EPA/OAQPS AP-42 Loading Model (See Section 0)
Equipment Cleaning	Water Landfill Incineration	If $N_{bt\_site\_yr}$ or known number of cleanings is fewer than $TIME_{app\_working\_days}$: $Elocal_{equipment\_cleaning} = Q_{app\_bt} \times F_{chem\_form} \times N_{bt\_site\_day} \times F_{equipment\_cleaning}$ … released over [$N_{bt\_site\_yr}$] days/year from [N_{app_sites}] sites (Eqn. 4-2a) If $N_{bt\_site\_yr}$ is greater than $TIME_{app\_working\_days}$: $Elocal_{equipment\_cleaning} = Q_{app\_chem\_site\_day} \times F_{equipment\_cleaning}$ … released over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites (Eqn. 4-2b)
Equipment Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 0)
Process Releases During Operations	Water Air Landfill Incineration	*Spray Coating* $Elocal_{application\_losses} = Q_{app\_chem\_site\_day} \times (1 - F_{transfer\_eff})$ (Eqn. 4-3) … released over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites The releases can be partitioned to multi-media: $\%_{air} = (1 - F_{capture\_ef}) \times 100$ (Eqn. 4-4a) $\%_{land\_inc} = F_{capture\_ef} \times 100$ (Eqn. 4-4b) *Roll or Curtain Coating* EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations (See Section 4.7) $Elocal_{application\_losses} = Q_{app\_chem\_site\_day} \times (1 - F_{transfer\_eff})$ (Eqn. 4-5) … released over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites
Volatile Releases During Curing/ Drying	Air Incineration	$Elocal_{evaporation\_losses} = Q_{app\_chem\_site\_day} \times (1 - F_{container\_residue} - F_{transfer\_eff} - F_{equipment\_cleaning})$ (Eqn. 4-6) … released over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites The releases can be partitioned to multi-media: $\%_{air} = (1 - F_{capture\_ef}) \times 100$ (Eqn. 4-7a) $\%_{inc} = F_{capture\_ef} \times 100$ (Eqn. 4-7b)

Release Calculations		
Source	**Possible Medium**	**Daily Release Rates (kg/site-day), Elocal (for Given Sources)**
Trimming Wastes	Landfill Incineration	$Elocal_{trimming\_release} = Q_{app\_chem\_site\_day} \times F_{trimming\_generation}$ … released over [$TIME_{app\_working\_days}$] days/year from [N_{app_sites}] sites (Eqn. 4-8)

Occupational Exposure Calculations
Number of Workers Exposed Per Site: See Section 0.
Exposures During Container Cleaning: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 0) *Dermal:* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form}$ (Eqn. 5-1) … over the lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with Section 0)
Exposure from Unloading Liquid Formulations: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 0) *Dermal* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form}$ (Eqn. 5-2) … over the lesser of $N_{form\_cont\_empty\_site\_yr}$ or $TIME_{app\_working\_days}$ (consistent with Section 4.2)
Exposure to Liquids During the Equipment Cleaning of Process Equipment: *Inhalation Exposure:* EPA/OPPT Mass Balance Inhalation Model (See Section 0) *Dermal Exposure:* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form}$ (Eqn. 5-3) … over the number of cleanings per year (consistent with Section 0)

Occupational Exposure Calculations

Exposure During the Coating Process:

Inhalation Exposure:

$$C_{v,s} = C_{v,k} \times \frac{Y_s}{Y_k} \qquad \text{(Eqn. 5-4)}$$

… over $TIME_{app\_working\_days}$ (consistent with Section 4.7)

$$EXP_{inhalation} = C_{part\_air} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem\_form} \qquad \text{(Eqn. 5-5)}$$

… over [$TIME_{app\_working\_days}$ (consistent with Section 4.7)

Dermal Exposure:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_form} \qquad \text{(Eqn. 5-6)}$$

… over $TIME_{app\_working\_days}$ (consistent with Section 4.7)

Table A-2. Summary of Equation Parameter Default Values Used in the ESD

Variable	Variable Description	Default Value	Data Source
$AREA_{surface}$	Surface area of contact (cm^2)	840 cm^2 (2 hands) 420 cm^2 (1 hand)	CEB, 2000
C_{part_air}	Mass concentration of particulate in air (based on application method)	2.3 mg/m^3 (conventional spray gun); for roll-coating, 0.04 mg/m^3 (low end) and 0.26 mg/m^3 (high end)	CEB, 1996 CEB, 1994
$F_{app\_adhesive}$	Fraction of the total adhesive product that contains the chemical of interest (kg product containing the chemical/kg total product used)	1	EPA assumption
$F_{capture\_eff}$	Fraction of mist captured in spray booth technology (kg mist captured/kg released)	0.90	CEB, 1996
$F_{capture\_eff}$	Fraction of volatile chemical captured by control system (kg volatile chemical captured/kg volatile chemical released)	0.90	EPA, 2000
F_{chem_comp}	Mass fraction of the chemical of interest in the adhesive component (kg chemical/kg component)	1	EPA assumption
F_{comp_form}	Mass fraction of the component used in the formulated adhesive product (kg component/kg product)	0.61 For an elastomer for water-borne adhesives (see Section 0)	See Table 2-4
$F_{container\_residue}$	Fraction of adhesive component remaining in the container as residue (kg component remaining/kg component in full container)	0.03	CEB, 2002a
$F_{equipment\_cleaning}$	Fraction of adhesive product released as residual in process equipment (kg product released/kg batch holding capacity)	0.01	CEB, 1992
$F_{capture\_eff}$	Fraction of spray mist (kg mist captured/kg released for dry filter)	0.90	CEB, 1996
$F_{transfer\_eff}$	Transfer efficiency of spray coating applications (kg adhered /kg applied)	0.25	CEB, 1996
$N_{exp\_incident}$	Number of exposure incidents per day (incidents/day)	1	CEB, 2000
$Q_{app\_site\_use\_rate}$	Total annual facility adhesive product use rate (kg used/site-yr)	Default use rates vary by application method. The defaults are provided in Section 0.	U.S. Census and industry data. See Section 0.

Variable	Variable Description	Default Value	Data Source
Q_{liquid_skin}	Quantity of liquid component or product remaining on skin (mg/cm^2-incident)	0.7 - 2.1 (dermal contact) 1.3 - 10.3 (dermal immersion)	CEB, 2000
$RATE_{breathing}$	Typical worker breathing rate (m^3/hr)	1.25	CEB, 1991a
$RHO_{formulation}$	Density of the adhesive formulation (kg/L)	1	EPA assumption
$TIME_{exposure}$	Duration of exposure (hrs/day)	8	EPA assumption
$TIME_{app\_working\_days}$	Annual number of days the formulation product is applied at each facility (days/yr)	See Section 3.2 for most appropriate value for the end use being assessed.	EPA assumption

APPENDIX B

BACKGROUND INFORMATION AND EQUATIONS/DEFAULTS FOR THE STANDARD EPA ENVIRONMENTAL RELEASE AND WORKER EXPOSURE MODELS

B.1 Introduction

This appendix provides background information and a discussion of the equations, variables, and default assumptions for each of the standard release and exposure models used by EPA in estimating environmental releases and worker exposures. The models described in this appendix are organized into the following four sections:

- Section B.2: Chemical Vapor Releases & Associated Inhalation Exposures;
- Section B.3: Container Residue Release Models (non-air);
- Section B.4: Process Equipment Residue Release Models (non-air); and
- Section B.5: Dermal Exposure Models.

Please refer to the guidance provided in the ESD for estimating environmental releases and worker exposures using these standard models, as it may suggest the use of certain overriding default assumptions to be used in place of those described for each model within this appendix.

This appendix includes a list of the key reference documents that provide the background and rationale for each of the models discussed. These references may be viewed in their entirety through the ChemSTEER Help System. To download and install the latest version of the ChemSTEER software and Help System, please visit the following EPA web site:

http://www.epa.gov/opptintr/exposure/docs/chemsteer.htm

B.2 Chemical Vapor Releases & Associated Inhalation Exposures

This section discusses the models used by EPA to estimate chemical vapor generation rates and the resulting volatile releases to air and worker inhalation exposures to that chemical vapor. The volatile air release models (discussed in B.2.1) calculate both a vapor generation rate ($Q_{vapor\_generation}$; g/sec) and the resulting daily release rate of the chemical vapors to air. The *EPA/OPPT Mass Balance Inhalation Model* (discussed in Section B.2.2) uses the value of $Q_{vapor\_generation}$, calculated by the appropriate release model, to estimate the resulting inhalation exposure to that released vapor.

B.2.1 Vapor Generation Rate and Volatile Air Release Models

The following models utilize a series of equations and default values to calculate a chemical vapor generation rate ($Q_{vapor\_generation}$; g/sec) and the resulting daily volatile air release rate ($Elocal_{air}$; kg/site-day):

- *EPA/OPPT Penetration Model* – evaporative releases from an exposed liquid surface located indoors;
- *EPA/OPPT Mass Transfer Coefficient Model* – evaporative releases from an exposed liquid surface located outdoors; and

- *EPA/OAQPS AP-42 Loading Model* – releases of volatile chemical contained in air that is displaced from a container being filled.

Each of these models is described in greater detail in the following sections.

B.2.1.1 EPA/OPPT Penetration Model

B.2.1.1.1 Model Description and Rationale

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*[20] or when air velocities are expected to be *less than or equal to 100 feet per minute*.

A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this model and the *Mass Transfer Coefficient Model* against experimentally measured evaporation rates described laminar airflow conditions existing up to 100 feet per minute. The paper compared the *Penetration Model* to experimental evaporation rate data measured under laminar (less than 100 feet per minute) and turbulent (above 100 feet per minute) airflow conditions. While the *Penetration Model* did not provide accurate estimates of evaporation rates under turbulent air flow conditions (relative to the *Mass Transfer Coefficient Model*), the results modeled under laminar flow conditions were found to more closely approximate the experimental data (usually within 20 percent). It is assumed that the conditions of an indoor work area most closely approximate laminar airflow conditions.

The model was originally developed using Fick's second law of diffusion. Model results were tested against experimental results of a study on evaporation rates for 15 compounds studied at different air velocities and temperatures in a test chamber. The experimental data confirmed the utility and accuracy of the model equation. Sample activities in which the *Penetration Model* may be used to estimate volatile releases to air are sampling liquids and cleaning liquid residuals from smaller transport containers (e.g. drums, bottles, pails).

B.2.1.1.2 Model Equations

The model first calculates the average vapor generation rate of the chemical from the exposed liquid surface using the following equation:

$$Q_{vapor\_generation} = \frac{(8.24 \times 10^{-8}) \times MW_{chem}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left(\frac{1}{29} + \frac{1}{MW_{chem}} \right)^{0.25} \times RATE_{air\_speed}^{0.5} \times AREA_{opening}}{TEMP_{ambient}^{0.05} \times D_{opening}^{0.5} \times P_{ambient}^{0.5}}$$

(Eqn. B-1)

Where:

$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)

[20]Similar air releases from surfaces located at *outdoor* locations (air speeds > 100 ft/min) are calculated using the *Mass Transfer Coefficient Model* (see the description provided in this section of Appendix B).

$F_{correction\_factor}$	=	Vapor pressure correction factor (EPA default =1)[21]
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{air\_speed}$	=	Air speed (EPA default = 100 feet/min; value must be $\leq$ 100 feet/min for this model)
$AREA_{opening}$	=	Surface area of the static pool or opening (cm^2; $B \times D_{opening}^2 / 4$)
$TEMP_{ambient}$	=	Ambient temperature (EPA default = 298 K)
$D_{opening}$	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)
$P_{ambient}$	=	Ambient pressure (EPA default = 1 atm)

Note: The factor 8.24×10^{-8} in Equation B-1 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapor generation rate ($Q_{vapor\_generation}$) calculated in Equation B-1, the model then estimates the daily release to air for the activity using the following equation:

$$Elocal_{air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \qquad \text{(Eqn. B-2)}$$

Where:

$Elocal_{air}$	=	Daily release of the chemical vapor to air from the activity (kg/site-day)
$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-1)
$TIME_{activity\_hours}$	=	Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

References:

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-24 and Appendix K). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.2 EPA/OPPT Mass Transfer Coefficient Model

B.2.1.2.1 Model Description and Rationale

[21] The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material $\times$ VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

The *EPA/OPPT Mass Transfer 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*[22] or when air velocities are expected to be *greater than 100 feet per minute*. A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this and the *Penetration Model* against experimentally measured evaporation rates, described laminar airflow conditions existing up to 100 feet per minute. It is assumed that the conditions of an indoor process area most closely approximate laminar air flow conditions, while outdoor conditions approximate turbulent airflow conditions above 100 feet per minute.

As discussed in the draft paper, the model is predicated on the solution of the classical mass transfer coefficient model with the gas-phase mass transfer coefficient estimated by the correlation of Mackay and Matsugu. Results were tested against experimental results on 19 compounds generated by four different experimenters over a wide range of experimental conditions. While the *Mass Transfer Coefficient Model* matched the data well (usually within 20 percent), it was found that the *Penetration Model* (see description in previous section) outperformed the *Mass Transfer Coefficient Model* under laminar flow (e.g. "indoor") conditions. Therefore, the *Penetration Model* is used as a default for estimating indoor evaporation rates, while the *Mass Transfer Coefficient Model* is used for outdoor rates. Sample activities in which the *Mass Transfer Coefficient Model* may be used to estimate volatile releases to air are cleaning liquid residuals from process equipment and bulk transport containers (e.g. tank trucks, rail cars).

B.2.1.2.2 Model Equations:

The model first calculates the average vapor generation rate of the chemical from the shallow pool using the following equation:

(Eqn. B-3)

$$Q_{vapor\_generation} = \frac{(1.93 \times 10^{-7}) \times MW_{chem}^{0.78} \times F_{correction\_factor} \times VP_{chem} \times \left(\frac{1}{29} + \frac{1}{MW_{chem}} \right)^{0.33} \times RATE_{air\_speed}^{0.78} \times AREA_{opening}}{TEMP_{ambient}^{0.4} \times D_{opening}^{0.11} \times \left(TEMP_{ambient}^{0.5} - 5.87 \right)^{2/3}}$$

Where:

$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical of interest/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$F_{correction\_factor}$	=	Vapor pressure correction factor (EPA default =1)[23]
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{air\_speed}$	=	Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)

[22] Similar air releases from surfaces located at *indoor* locations (air speeds ≤ 100 ft/min) are calculated using the *Penetration Model* (see the description provided in this section of Appendix B).

[23] The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

$AREA_{opening}$	=	Surface area of the static pool or opening (cm^2; $B \times D_{opening}^2 / 4$)
$TEMP_{ambient}$	=	Ambient temperature (EPA default = 298 K)
$D_{opening}$	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)

Note: The factor 1.93×10^{-7} in Equation B-3 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapor generation rate ($Q_{vapor\_generation}$) calculated in Equation B-3, the model then estimates the daily release to air for the activity using the following equation:

$$Elocal_{air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad \text{(Eqn. B-4)}$$

Where:

$Elocal_{air}$	=	Daily release of the chemical vapor to air from the activity (kg/site-day)
$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-3)
$TIME_{activity\_hours}$	=	Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

References:

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.3 EPA/OAQPS AP-42 Loading Model

B.2.1.3.1 Model Description and Rationale:

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.

This model 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* is used because it provides a more conservative estimate than either the *EPA/OPPT Penetration Model* or the *Mass Transfer Coefficient Model* for unloading activities.

B.2.1.3.2 Model Equations:

The model first calculates the average vapor generation rate of the chemical from the displacement during loading/filling operation using the following equation:

$$Q_{vapor\_generation} = \frac{F_{saturation\_factor} \times MW_{chem} \times \left(V_{cont\_empty} \times \frac{3785.4 cm^3}{gal} \right) \times \left(\frac{RATE_{fill}}{3600 sec/hour} \right) \times F_{correction\_factor} \times \left(\frac{VP_{chem}}{760 \ torr/atm} \right)}{R \times TEMP_{ambient}}$$

(Eqn. B-5)

Where:

$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec)
$F_{saturation\_factor}$	=	Saturation factor (See Table B-1 for appropriate EPA default values)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
V_{cont_empty}	=	Volume of the container (gallons; see Table B-1 for appropriate EPA default values)
$RATE_{fill}$	=	Fill rate (containers/hour; see Table B-1 for appropriate EPA default values)
$F_{correction\_factor}$	=	Vapor pressure correction factor (EPA default =1)[24]
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
R	=	Universal Gas Constant (82.05 atm-cm^3/mol-K)
$TEMP_{ambient}$	=	Ambient temperature (EPA default = 298 K)

Using the vapor generation rate ($Q_{vapor\_generation}$) calculated in Equation B-5, the model then estimates the daily release to air for the activity using the following equation:

$$Elocal_{air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \ sec/hour}{1000 \ g/kg} \quad \text{(Eqn. B-6)}$$

Where:

$Elocal_{air}$	=	Daily release of the chemical vapor to air from the activity (kg/site-day)
$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-5)
$TIME_{activity\_hours}$	=	Operating hours for the release activity per day (hours/site-day; see Table B-1 for appropriate EPA default values)

Reference:

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

[24]The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

Table B-1. Standard EPA Default Values Used in Vapor Generation Rate/Volatile Air Release Models

Activity Type (Location)	V_{cont_empty} (gallons)	$D_{opening}$ (cm)	$RATE_{fill}$ (containers/hour)	$F_{saturation\_factor}$	$TIME_{activity\_hours}$ (hours/site-day)
Container-Related Activities (e.g. filling, unloading, cleaning, open surface/evaporative losses):					
Bottles (Indoors)	1 (Range: <5)	5.08 (<5,000 gals)	60	Typical: 0.5 Worst Case: 1	Number of containers handled per site-day_) $RATE_{fill}$
Small Containers (Indoors)	5 (Range: 5 to <20)				
Drums (Indoors)	55 (Range: 20 to <100)		20		
Totes (Indoors)	550 (Range: 100 to <1,000)				
Tank Trucks (Outdoors)	5,000 (Range: 1,000 to <10,000)	7.6 ($\geq$5,000 gals)	2	1	
Rail Car (Outdoors)	20,000 (Range: 10,000 and up)		1		
Equipment Cleaning Activities:					
Multiple Vessels (Outdoors)	Not applicable	92	Not applicable	1	4
Single, Large Vessel (Outdoors)					1
Single, Small Vessel (Outdoors)					0.5
Sampling Activities:					

Activity Type (Location)	**V_{cont_empty} (gallons)**	**$D_{opening}$ (cm)**	**$RATE_{fill}$ (containers/hour)**	**$F_{saturation\_factor}$**	**$TIME_{activity\_hours}$ (hours/site-day)**
Sampling Liquids (Indoors)	Not applicable	Typical: 2.5[a] Worst Case: 10	Not applicable	1	1
Other Activities:					
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate/air release models described in this section, the ESD will describe the model and provide appropriate default values for the model parameters.			1	24
Batch Operation					Lesser of: (Hours/batch × Batches/site-day) or 24

a - The "typical" diameter default value of 2.5 cm was adopted as a policy decision in 2002, which supersedes the previous default value of 7 cm shown in the 1991 U.S. EPA reference document.

B.2.2 Chemical Vapor Inhalation Model

The following sections describe the EPA standard model for estimating worker inhalation exposures to a chemical vapor, utilizing a vapor generation rate ($Q_{vapor\_generation}$).

B.2.2.1 EPA/OPPT Mass Balance Model

B.2.2.1.1 Model Description and Rationale:

The *EPA/OPPT Mass Balance Model* estimates a worker inhalation exposure to an estimated concentration of chemical vapors within the worker's breathing zone. 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 ($Q_{vapor\_generation}$). This generation rate may be calculated using an appropriate standard EPA vapor generation model (see Equation B-1, Equation B-3, or Equation B-5) or may be an otherwise known value.

The *EPA/OPPT Mass Balance Model* also utilizes the volumetric ventilation rate within a given space and includes simplifying assumptions of steady state (e.g. a constant vapor generation rate and a constant ventilation rate) and an assumed mixing factor for non-ideal mixing of air. The default ventilation rates and mixing factors provide a typical and worst case estimate for each exposure. The airborne concentration of the chemical cannot exceed the level of saturation for the chemical.

An evaluation of the model was performed against collected monitoring data for various activities (see the 1996 AIHA article). This evaluation confirmed that the Mass Balance Model is able to conservatively predict worker inhalation exposures within one order of magnitude of actual monitoring data and is an appropriate model for screening-level estimates.

B.2.2.1.2 Model Equations:

The model first calculates the volumetric concentration of the chemical vapor in air using the following equation:

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}} \qquad \text{(Eqn. B-7)}$$

Where:

$C_{chem\_volumetric}$	=	Volumetric concentration of the chemical vapor in air (ppm)
$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-1, Equation B-3, or Equation B-5, as appropriate)
$TEMP_{ambient}$	=	Ambient temperature (EPA default = 298 K)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$RATE_{ventilation}$	=	Ventilation rate (ft^3/min; see Table B-2 for appropriate EPA default values)
F_{mixing_factor}	=	Mixing factor (dimensionless; see Table B-2 for appropriate EPA default values)

Note: The factor 1.7×10^5 in Equation B-7 accounts for various unit conversions. See Fehrenbacher and Hummel, 1996, for the derivation of this constant.

Note that the airborne concentration of the chemical vapor cannot exceed the saturation level of the chemical in air. Equation B-8 calculates the volumetric concentration at the saturation level based on Raoult's Law. Use the lesser value for the volumetric concentration of the chemical vapor ($C_{chem\_volumetric}$) calculated in either Equation B-7 or Equation B-8 in calculating the mass concentration of the chemical of interest in the air (see Equation B-9).

$$C_{chem\_volumetric} = F_{correction\_factor} \times VP_{chem} \times \frac{10^6 \text{ ppm}}{P_{ambient}} \qquad \text{(Eqn. B-8)}$$

Where:

$C_{chem\_volumetric}$	=	Volumetric concentration of the chemical of interest in air (ppm)
$F_{correction\_factor}$	=	Vapor pressure correction factor (EPA default =1)[25]
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$P_{ambient}$	=	Ambient pressure (Default = 760 torr)

Note: Raoult's law calculates the airborne concentration as a mole fraction. The factor 10^6 in Equation B-8 accounts for the unit conversion from mole fraction to ppm.

The volumetric concentration of the chemical of interest in air (calculated in either Equation B-7 or Equation B-8) is converted to a mass concentration by the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}} \qquad \text{(Eqn. B-9)}$$

Where:

C_{chem_mass}	=	Mass concentration of the chemical vapor in air (mg/m^3)
$C_{chem\_volumetric}$	=	Volumetric concentration of the chemical vapor in air (ppm, see Equation B-7 or B-8, as appropriate)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
V_{molar}	=	Molar volume (Default = 24.45 L/mol at 25ºC and 1 atm)

Assuming a constant breathing rate for each worker and exposure duration for the activity, the inhalation exposure to the chemical vapor during that activity can be estimated using the following equation:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure} \qquad \text{(Eqn. B-10)}$$

Where:

$EXP_{inhalation}$	=	Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)
C_{chem_mass}	=	Mass concentration of the chemical vapor in air (mg/m^3; see Equation B-9]
$RATE_{breathing}$	=	Typical worker breathing rate (EPA default = 1.25 m^3/hr)
$TIME_{exposure}$	=	Duration of exposure for the activity (hours/worker-day; see Table B-2 for appropriate EPA default values ($\leq$ 8 hours/worker-day))

[25] The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

References:

Fehrenbacher, M.C. and Hummel, A.A[26]. "Evaluation of the Mass Balance Model Used by the EPA for Estimating Inhalation Exposure to New Chemical Substances". *American Industrial Hygiene Association Journal*. June 1996. 57: 526-536.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

[26]Note: This reference is currently not available for viewing in the ChemSTEER Help System.

Table B-2. Standard EPA Default Values Used in the *EPA/OPPT Mass Balance Inhalation* Model

Activity Type (Location)	V_{cont_empty} (gallons)	$RATE_{fill}$ (containers/hour)	$RATE_{air\_speed}$ (feet/min)	$RATE_{ventilation}$ [a]	F_{mixing_factor}	$TIME_{exposure}$ (hours/day)
Container-Related Activities (e.g. filling, unloading, cleaning, open surface/evaporative losses):						
Bottles (Indoors)	1 Range: <5	60	100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	Lesser of: (Number of containers handled per site-day)) $RATE_{fill}$ or 8
Small Containers (Indoors)	5 Range: 5 to <20					
Drums (Indoors)	55 Range: 20 to <100	20				
Totes (Indoors)	550 Range: 100 to <1,000					
Tank Trucks (Outdoors)	5,000 Range: 1,000 to <10,000	2	440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × $RATE_{air\_speed}$) 5,280)^3 (Outdoors)		
Rail Car (Outdoors)	20,000 Range: 10,000 and up	1				
Equipment Cleaning Activities:						
Multiple Vessels (Outdoors)	Not applicable		440 (Outdoors)	Average: 237,600 Worst Case: 26,400 ×	Typical: 0.5 Worst Case: 0.1	4
Single, Large Vessel (Outdoors)						1

Activity Type (Location)	V_{cont_empty} (gallons)	$RATE_{fill}$ (containers/hour)	$RATE_{air\_speed}$ (feet/min)	$RATE_{ventilation}$ [a]	F_{mixing_factor}	$TIME_{exposure}$ (hours/day)
Single, Small Vessel (Outdoors)				$(60 \times RATE_{air\_speed}) 5{,}280)^3$ (Outdoors)		0.5
Sampling Activities:						
Sampling Liquids (Indoors)	Not applicable		100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	1
Other Activities:						
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate models with the *Mass Balance Inhalation Model* described in this section, the ESD will describe the models and provide appropriate default values for the model parameters.				Typical: 0.5 Worst Case: 0.1	$\leq$8
Batch Operation						

a - If the appropriate vapor generation rate model is the *EPA/OAQPS AP-42 Loading Model* (see Equation B-5) for an outdoor activity, the $RATE_{air\_speed}$ should be set to 440 feet/min, as a default in determining the worst case $RATE_{ventilation}$.

B.3 Container Residue Release Models (non-air)

B.3.1. Model Description and Rationale:

EPA has developed a series of standard models for estimating the quantity of residual chemical remaining in emptied shipping containers that is released to non-air media (e.g. water, incineration, or landfill) when the container is either rinsed or disposed. All of the residue models assume a certain portion or fraction of the chemical remains in the emptied container to be later rinsed or discarded with the empty container.

The default parameters of model are defined based upon the particular size/type of container (e.g. small containers, drums, or large bulk), as well as the physical form of the chemical residue (e.g. liquid or solid). These defaults are based upon data collected during a 1988 EPA-sponsored study of residuals in containers from which materials have been poured or pumped.

B.3.2 Model Equation:

All of the models discussed in this section utilize the following common equation for calculating the amount of chemical residue:

$$Elocal_{container\_residue\_disp} = F_{container\_residue} \times Q_{total\_daily\_container} \quad \text{(Eqn. B-11)}$$

Where:

$Elocal_{container\_residue\_disp}$	=	Daily release of the chemical residue to water, incineration, or landfill from the cleaning or disposal of empty shipping containers (kg/site-day)
$F_{container\_residue}$	=	Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-3 for appropriate EPA default values)
$Q_{total\_daily\_container}$	=	Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table B-4 for appropriate EPA default values)

Each model, however, utilizes unique default values within that equation based upon the relative size of the container and the physical form of the chemical residue. These default values are summarized in Table B-3 and Table B-4. The following models are the standard EPA models for estimating container residues:

- EPA/OPPT Small Container Residual Model;
- EPA/OPPT Drum Residual Model;
- EPA/OPPT Bulk Transport Residual Model; and
- EPA/OPPT Solid Residuals in Transport Containers Model.

The default frequency with which the container residues are released ($TIME_{days\_container\_residue}$, days/site-year) must be appropriately "paired" with the total daily quantity of chemical contained in the containers ($Q_{total\_daily\_container}$) used in calculating the daily release. Thus, Table B-4 also contains the appropriate EPA default values for $TIME_{days\_container\_residue}$.

References:

U.S. EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments*. From the CEB Quality Panel to CEB Staff and Management. October 1992.

U.S. EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment.* July 1988.

Table B-3. Standard EPA Default Values for Use in the Container Residual Release Models

Chemical Form	Container Type	V_{cont_empty} (gallons)	Model Title	$F_{container\_residue}$[a]
Liquid	Bottle	1 Range: <5	*EPA/OPPT Small Container Residual Model*	Central Tendency: 0.003 High End: 0.006
	Small Container	5 Range: 5 to <20		
	Drum	55 Range: 20 to <100	*EPA/OPPT Drum Residual Model*	Central Tendency: 0.025 High End[b]: 0.03 (for pumping liquid out of the drum) Alternative defaults: Central Tendency: 0.003 High End: 0.006 (for pouring liquid out of the drum)
	Tote	550 Range: 100 to <1,000	*EPA/OPPT Bulk Transport Residual Model*	Central Tendency: 0.0007 High End: 0.002
	Tank Truck	5,000 Range: 1,000 to <10,000		
	Rail Car	20,000 Range: 10,000 and up		
Solid	Any	Any	*EPA/OPPT Solid Residuals in Transport Containers Model*	0.01

a - These defaults are based on the 1988 EPA study investigating container residue and summarized in the 1992 internal EPA memorandum (see *References* in this section for the citations of these sources).

b - The 1992 EPA memorandum reference document contains the previous default of 0.04 for the high-end loss fraction ($F_{container\_residue}$) for the *Drum Residual Model*; however, this value was superseded by an internal policy decision in 2002. Per 40 CFR 261.7(b)(1) of the Resource Conservation and Recovery Act (RCRA), "a container or an inner liner removed from a container that has held any hazardous wastes, except waste that is a compressed gas or that is identified as an acute hazardous waste…is empty if…(ii) no more than 2.5 centimeters (1 inch) remain on the bottom of the container or liner or (iii)(A) no more than 3 percent by weight of the total capacity of the container remains in the container or inner liner if the container is equal to or less than 110 gallons in size…". The 3 percent high-end default is consistent with the range of experimental results documented in the 1988 EPA study (see *References* in this section for a citation of this study).

Table B-4. Standard EPA Methodology for Calculating Default $Q_{total\_daily\_container}$ and $TIME_{days\_container\_residue}$ Values for Use in the Container Residual Models

Number of Containers Emptied per Day	$Q_{total\_daily\_container}$ (kg/site-day)	$TIME_{days\_container\_residue}$ (days/year)
1 or more	(Mass quantity of chemical in each container (kg/container)) × (Number of containers emptied per day)	Total number of operating days for the facility/operation
Less than 1	Mass quantity of chemical in each container (kg/container)	Total number of containers emptied per site-year

B.3.4 Process Equipment Residue Release Models (non-air)

B.3.4.1 Model Description and Rationale:

EPA has developed two standard models for estimating the quantity of residual chemical remaining in emptied process equipment that is released to non-air media (e.g. water, incineration, or landfill) when the equipment is periodically cleaned and rinsed. The residue models assume a certain portion or fraction of the chemical remains in the emptied vessels, transfer lines, and/or other equipment and is later rinsed from the equipment during cleaning operations and discharged with the waste cleaning materials to an environmental medium.

The default parameters of the model are defined based upon whether the residues are being cleaned from a *single* vessel or from *multiple* pieces of equipment. These defaults are based upon data collected during an EPA-sponsored study of residuals in process equipment from which materials have pumped or gravity-drained.

B.3.4.2 Model Equation:

The models discussed in this section utilize the following common equation for calculating the amount of chemical residue:

$$Elocal_{equip\_cleaning} = F_{equip\_residue} \times Q_{total\_chem\_capacity} \qquad \text{(Eqn. B-12)}$$

Where:

$Elocal_{equip\_cleaning}$	=	Daily release of the chemical residue to water, incineration, or landfill from cleaning of empty process equipment (kg/site-day)
$F_{equip\_residue}$	=	Fraction of the amount of the total chemical in the process equipment remaining in the emptied vessels, transfer lines, and/or other pieces (dimensionless; see Table B-5 for appropriate EPA default values)
$Q_{equip\_chem\_capacity}$	=	Total capacity of the process equipment to contain the chemical in question, prior to emptying (kg of chemical/site-day; see Table B-6 for appropriate EPA default values)

Each model, however, utilizes unique default values within that equation based upon whether the residues are cleaned from a single vessel or from multiple equipment pieces. These default values are summarized in Table B-5 and Table B-6. The following models are the standard EPA models for estimating process equipment residues:

- EPA/OPPT Single Process Vessel Residual Model; and
- EPA/OPPT Multiple Process Vessel Residual Model.

The default frequency with which the equipment residues are released ($TIME_{days\_equip\_residue}$, days/site-year) must be appropriately “paired” with the total capacity of the equipment to contain the chemical of interest ($Q_{equip\_chem\_capacity}$) used in calculating the daily release. Thus, Table B-6 also contains the appropriate EPA default values for $TIME_{days\_equip\_residue}$.

References:

U.S. EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments*. From the CEB Quality Panel to CEB Staff and Management. October 1992.

U.S. EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment.* July 1988.

Table B-5. Standard EPA Default Values for Use in the Process Equipment Residual Release Models

Model Title	$F_{equip\_residue}$ [a]
EPA/OPPT Single Process Vessel Residual Model	Conservative: 0.01 (for pumping process materials from the vessel) *Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for gravity-draining materials from the vessel)
EPA/OPPT Multiple Process Vessel Residual Model	Conservative: 0.02

a - These defaults are based on the 1988 EPA study investigating container residue and summarized in the 1992 internal EPA memorandum (see *References* in this section for the citations of these sources).

Table B-6. Standard EPA Methodology for Calculating Default $Q_{equip\_chem\_capacity}$ and $TIME_{days\_equip\_residue}$ Values for Use in the Process Equipment Residual Models

Process Type	Number of Batches per Day	$Q_{equip\_chem.\_capacity}$ (kg/site-day)	$TIME_{days\_equip\_residue}$ (days/year)
Batch	1 or more	(Mass quantity of chemical in each batch (kg/batch)) × (Number of batches run per day)	Total number of operating days for the facility/operation
	Less than 1	Mass quantity of chemical in each batch (kg/batch)	Total number of batches run per site-year
Continuous	Not applicable	Daily quantity of the chemical processed in the equipment (kg/site-day)	Total number of operating days for the facility/operation

Note: Please refer to the ESD for any overriding default assumptions to those summarized above. Equipment cleaning may be performed periodically throughout the year, as opposed to the default daily or batch-wise cleaning frequencies shown above. For example, facilities may run dedicated equipment for several weeks, months, etc within a single campaign before performing equipment-cleaning activities, such that residuals remaining in the emptied are released less frequently than the standard default $TIME_{days\_equip\_residue}$ summarized above in Table B-6. Care should be given in defining the appropriate $Q_{total\_daily\_container}$ and $TIME_{days\_container\_residue}$ to be used in either of the standard EPA process equipment residue models.

B.5 Dermal Exposure Models

B.5.1 Model Description and Rationale:

EPA has developed a series of standard models for estimating worker dermal exposures to liquid and solid chemicals during various types of activities. All of these dermal exposure models assume a specific surface area of the skin that is contacted by a material containing the chemical of interest, as well as a specific surface density of that material in estimating the dermal exposure. The models also assume *no use of controls or gloves* to reduce the exposure. These assumptions and default parameters are defined based on the nature of the exposure (e.g. one hand or two hand, immersion in material, contact with surfaces) and are documented in the references listed in this section.

In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities described in this section can be used. The models for exposures to liquid materials are based on experimental data with liquids of varying viscosity and the amount of exposure to hands was measured for various types of contact. Similar assessments were made based on experimental data from exposure to solids.

B.5.2 Model Equation:

All of the standard EPA models utilize the following common equation for calculating worker dermal exposures:

$$EXP_{dermal} = AREA_{surface} \times Q_{remain\_skin} \times F_{chem} \times N_{event} \qquad \text{(Eqn. B-13)}$$

Where:

EXP_{dermal}	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$AREA_{surface}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm^2; see Table B-7 for appropriate EPA default values)
Q_{remain_skin}	=	Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm^2-event; see Table B-7 for appropriate EPA default values)
F_{chem}	=	Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
N_{event}[27]	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

Each model, however, utilizes unique default values within that equation based upon the nature of the contact and the physical form of the chemical material. These default values are summarized in Table B-7. The following models are the standard EPA models for estimating worker dermal exposures:

- *EPA/OPPT 1-Hand Dermal Contact with Liquid Model*;
- *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*;
- *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model*;
- *EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model;* and
- *EPA/OPPT 2-Hand Dermal Contact with Solids Model*.

For several categories of exposure, EPA uses qualitative assessments to estimate dermal exposure. Table B-8 summarizes these categories and the resulting qualitative dermal exposure assessments.

References:

U.S. EPA. Chemical Engineering Branch. *Options for Revising CEB's Method for Screening-Level Estimates of Dermal Exposure – Final Report*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. June 2000.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

[27] Only one contact per day (N_{event} = 1 event/worker-day) is assumed because Q_{remain_skin}, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (e.g. wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

Table B-7. Standard EPA Default Values for Use in the Worker Dermal Exposure Models

Default Model	Example Activities	$AREA_{surface}$[a] (cm^2)	Q_{remain_skin}[b] (mg/cm^2-event)	Resulting Contact $AREA_{surface} \times Q_{remain\_skin}$ (mg/event)
Physical Form: Liquids				
EPA/OPPT 1-Hand Dermal Contact with Liquid Model	• Liquid sampling activities • Ladling liquid/bench-scale liquid transfer	420 (1 hand mean)	Low: 0.7 High: 2.1	Low: 290 High: 880
EPA/OPPT 2-Hand Dermal Contact with Liquid Model	• Maintenance • Manual cleaning of equipment and containers • Filling drum with liquid • Connecting transfer line	840 (2 hand mean)	Low: 0.7 High: 2.1	Low: 590 High: 1,800
EPA/OPPT 2-Hand Dermal Immersion in Liquid Model	• Handling wet surfaces • Spray painting	840 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 8,650
Physical Form: Solids				
EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model	• Handling bags of solid materials (closed or empty)	No defaults	No defaults	< 1,100[c]
EPA/OPPT 2-Hand Dermal Contact with Solids Model	• Solid sampling activities • Filling/dumping containers of powders, flakes, granules • Weighing powder/scooping/mixing (e.g. dye weighing) • Cleaning solid residues from process equipment • Handling wet or dried material in a filtration and drying process	No defaults	No defaults	< 3,100[23]

a - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citations of this sources) and are the mean values for men taken from the EPA Exposure Factors Handbook, 1997.

b - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived the selected ranges of values for liquid handling activities from: U.S. EPA. A Laboratory Method to Determine the Retention of Liquids on the Surface of Hands. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Exposure Evaluation Division. EPA 747-R-92-003. September 1992.

c - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived values for dermal contact for solids handling activities from: Lansink, C.J.M., M.S.C. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modeling of Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

Table B-8. EPA Default Qualitative Assessments for Screening-Level Estimates of Dermal Exposure

Category	Dermal Assessment
Corrosive substances (pH>12, pH<2)	Negligible
Materials at temperatures >140°F (60°C)	Negligible
Cast Solids (e.g. molded plastic parts, extruded pellets	Non-Quantifiable (Some surface contact may occur if manually transferred)
"Dry" surface coatings (e.g. fiber spin finishes, dried paint)	Non-Quantifiable (If manual handling is necessary and there is an indication that the material may abrade from the surface, quantify contact with fingers/palms as appropriate)
Gases/Vapors	Non-Quantifiable (Some contact may occur in the absence of protective clothing)

Source: U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

APPENDIX C

METHODOLOGY TO DERIVE THE TOTAL ANNUAL FACILITY USE RATE FOR APPLICATION SITES

Introduction

Facility-specific information on the use rate of adhesives was not available. This appendix presents two options that may be used to determine a typical total annual facility use rate ($Q_{app\_site\_yr}$) at industrial adhesives application sites. Option 1 presents a "top-down" approach that estimates the facility use rate based on total market production data. Option 1 also provides a method for estimating the number of workers exposed per site for each general end-use category. Option 2 presents a "bottom-up" approach based on site-specific data obtained from industry. Option 2 is application method-specific and is an alternative approach to estimate the total annual facility use rate if facility parameters are known. Option 1 is used for the following end-uses: Computer/Electronic and Electrical Product Manufacturing; Motor and Non-Motor Vehicle, Vehicle Parts, and Tires Manufacturing (Except Retreading); and Labels and Tapes Manufacturing. Option 2 is used for the Flexible Packaging Manufacturing category. The General Assembly category uses a method that is not covered in this Appendix but is shown in Appendix D.

Option 1

Option 1 presents a "top-down" methodology that is independent of the application method and can be used to derive the total annual facility use rate. The following resources were referenced for end-use market production and facility data to generate the estimates presented in this ESD:

- 2002 U.S. Census Bureau Economic Census Data – Provides data on the total number of U.S. sites and workers for several end-use categories;
- 2007 U.S. Census Bureau Economic Census Data – Provides data on the total number of U.S. sites and workers for several end-use categories;
- 2005 Impact Marketing – Provides U.S. production information for the adhesive market; and

In lieu of facility-specific use data for adhesives, the methodology discussed below is an attempt to capture the adhesive products market within the various industries. The following general assumptions were made when developing this methodology:

1. A relationship can be developed between the data sources.
2. Production data were unchanging between the range of data (e.g. between 2002 and 2003).

A publication by Impact Marketing provided the total volume of adhesives used by end-use market; however, the number of adhesive application sites is not known and the facility use-rate could not be determined. Therefore, to estimate the facility use-rate, the number of adhesive application sites needed to be determined. In conjunction with Impact Marketing's adhesives use data and the total number of application sites estimated from readily available sources, the total annual facility use rate ($Q_{app\_site\_use\_rate}$) for adhesives can be derived.

The steps taken to estimate the number of adhesives application sites (and to ultimately calculate the total annual facility use rate) are:

1. Aggregate adhesive consumption volumes for the given end-uses (in Table 1-6) into general end-use categories. These general categories help to consolidate data between the different sources identified previously.

2. Determine the related consumption volumes for subcategories that fall under the general end-use categories and determine the market share of adhesive products used in the motor and non-motor vehicle, vehicle parts, and tires (except retreading); computer/electronic; and labels and tapes manufacturing industries.

3. Determine the total number of adhesives application sites based on the market share of adhesive products and total number of application sites. For the computer/electronics and vehicle, vehicle parts, and tire (except retreading) end-uses, calculate the facility use rate based on the end-use consumption volumes provided by Impact Marketing (in Table 1-6) and the number of adhesives application sites. For labels and tapes manufacturing, calculate the facility use rate based on the product type consumption volumes provided by Impact Marketing (in Table 1-7) and the number of adhesives application sites.

Step 1:

Table 1-6 and Table 1-7 present detailed information on the current U.S. market for adhesive products provided by Impact Marketing. The end-use markets were then grouped into general end-use categories as shown in Table C-1. The total U.S. consumption volume for each general category is the sum of the production volumes for each end-use market.

Table C-1. Total 2003 U.S. Consumption of Adhesives by General End-Use

End-Use Market	Total U.S. Adhesive Consumption Volume (million kg/yr) [a]	General End-Use Category
Electrical and Electronic	34	Computer/Electronic and Electrical Products Manufacturing
Transportation[b]	172	Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)
Pressure Sensitive Adhesive Products	318	Labels and Tapes Manufacturing

a – Impact Marketing, 2005. See Table 1-6 and Table 1-7.
b – This end-use market was further subdivided to determine what proportion of adhesives consumption corresponded to motor and non-motor vehicle manufacturing. See Table C-4.

Step 2:

The Impact Marketing report provided data for U.S. consumption volumes of adhesives but not the number of sites. The number of sites for each general end-use category is based on 2002 Economic Census data, which provided site numbers by industry (e.g. NAICS code). Since each general end-use category may apply to more than one NAICS code, the total number of sites is taken as an aggregated sum of each applicable NAICS code (as shown in Table C-2). 2007 Economic Census data are also shown in Table C-2. These data were collected for the purposes of determining the number of workers per site using the most recently available Census data (see Tables C-6 and C-7).

Due to the various sources of information that were referenced, several assumptions were made in selecting appropriate NAICS codes for each general end-use category. Selection of NAICS codes was based on the following criteria:

1. The NAICS code fit within the description of the general end-use markets identified in the Impact Marketing source.

2. The NAICS code appeared to fit with the description of the general end-use markets identified in the Impact Marketing source, but required further verification through a web-based search.

Table C-3 provides justification for the inclusion (or exclusion) of individual NAICS codes selected for each general end-use category.

Table C-2. Total U.S Application Sites by General End-Use

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Sites in 2002	Total U.S. Sites in 2002	Number of Sites in 2007	Total U.S. Sites in 2007
Computer/Electronic and Electrical Product Manufacturing	334111	Electronic computer mfg	485	22,294	421	20,649
	334112	Computer storage device mfg	170		116	
	334113	Computer terminal mfg	71		42	
	334119	Other computer peripheral equipment mfg	860		670	
	334210	Telephone apparatus mfg	518		391	
	334220	Radio and television broadcasting and wireless communications equip. mfg	1,041		919	
	334290	Other communications equip. mfg	503		452	
	334310	Audio and video equip. mfg	571		491	
	334411	Electron tube mfg	102		85	
	334412	Bare printed circuit board mfg	936		726	
	334413	Semiconductor and related device mfg	1,032		954	
	334414	Electronic capacitor mfg	104		77	
	334415	Electronic resistor mfg	79		67	
	334416	Electronic coil, transformer, and other inductor mfg	355		318	
	334417	Electronic connector mfg	321		229	
	334418	Printed circuit assembly (electronic assembly) mfg	868		1,008	
	334419	Other electronic component mfg	1,627		1,349	
	334510	Electromedical and electrotherapeutic apparatus mfg	546		660	
	334511	Search, detection, navigation, guidance, aeronautical, and nautical system and instrument mfg	653		662	
	334512	Automatic environmental control manufacturing for residential, commercial, and appliance use	339		313	
	334513	Instruments and related products mfg for measuring, displaying, and controlling industrial process variables	986		842	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Sites in 2002	Total U.S. Sites in 2002	Number of Sites in 2007	Total U.S. Sites in 2007
	334514	Totalizing fluid meter and counting device mfg	233		225	
	334515	Instrument mfg for measuring, testing electricity, elect. Signals	791		826	
	334516	Analytical laboratory instrument mfg	563		613	
	334517	Irradiation apparatus mfg	169		180	
	334518	Watch, clock, and part mfg	126		121	
	334519	Other measuring and controlling device mfg	825		857	
	334611	Software reproducing	190		202	
	334612	Prerecorded CD (except software), Tape, and Record Repro.	576		492	
	334613	Magnetic and optical recording media mfg	173		122	
	335110	Electric lamp bulb and part mfg	80		88	
	335121	Residential electric lighting fixture mfg	481		407	
	335122	Commer., industrial, and instit. electric lighting fixture mfg	356		402	
	335129	Other lighting equipment mfg	318		313	
	335211	Electric housewares and household fan mfg	101		101	
	335212	Household vacuum cleaner mfg	37		37	
	335221	Household cooking appliance mfg	97		117	
	335222	Household refrigerator and home freezer mfg	23		25	
	335224	Household laundry equip mfg	18		19	
	335228	Other major household appliance mfg	34		41	
	335311	Power, distribution, and specialty transformer mfg	296		285	
	335312	Motor and generator mfg	594		523	
	335313	Switchgear and switchboard apparatus mfg	528		493	
	335314	Relay and industrial control mfg	1,137		1,096	
	335911	Storage battery mfg	130		119	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Sites in 2002	Total U.S. Sites in 2002	Number of Sites in 2007	Total U.S. Sites in 2007
	335912	Primary battery mfg	42		49	
	335921	Fiber optic cable mfg	96		96	
	335929	Other communications equipment mfg	356		335	
	335931	Current-carrying wiring device mfg	459		479	
	335932	Noncurrent-carrying wiring device mfg	166		175	
	335991	Carbon and graphite product mfg	129		143	
	335999	All other misc. electrical equipment and component mfg	1,003		876	
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	336111	Automobile mfg	176	8,366	193	8,377
	336112	Light truck & utility vehicle mfg	97		91	
	336120	Heavy duty truck mfg	99		100	
	336211	Motor vehicle body mfg	847		826	
	336212	Truck trailer mfg	397		405	
	336213	Motor home mfg	93		80	
	336214	Travel trailer & camper mfg	809		862	
	336311	Carburetor, piston, piston ring, & valve mfg	132		119	
	336312	Gasoline engine and engine parts mfg	918		862	
	336321	Vehicular lighting equipment mfg	95		108	
	336322	Other motor vehicle electrical and electronic equip. mfg	782		703	
	336330	Motor vehicle steering and suspension component mfg	236		255	
	336340	Motor vehicle brake system mfg	275		241	
	336350	Motor vehicle transmission and power train parts mfg	542		531	
	336360	Motor vehicle seating and interior trim mfg	384		429	
	336370	Motor vehicle metal stamping	798		815	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Sites in 2002	Total U.S. Sites in 2002	Number of Sites in 2007	Total U.S. Sites in 2007
	336391	Motor vehicle air-conditioning mfg	81		81	
	336399	All other motor vehicle parts mfg	1,447		1,539	
	326211	Tire Manufacturing (except Retreading)	158		137	
Labels and Tapes Manufacturing	322222	Coated and laminated paper manufacturing	541	541	497	497

a – USCB, 2002
Note: “Mfg” = manufacturing

Table C-3. Justification for the Inclusion (or Exclusion) of NAICS Categories

General End-Use Category	Applicable NAICS[a]	NAICS Category	Justification for the Inclusion of the NAICS Categories
Computer/Electronic and Electrical Product Manufacturing	334111	Electronic computer mfg	Based on end-use market information from Impact Marketing (shown in Table C-1). All NAICS categories involving electrical and computer/electronic products were included.
	334112	Computer storage device mfg	
	334113	Computer terminal mfg	
	334119	Other computer peripheral equipment mfg	
	334210	Telephone apparatus mfg	
	334220	Radio and television broadcasting and wireless communications equip. mfg	
	334290	Other communications equip. mfg	
	334310	Audio and video equip. mfg	
	334411	Electron tube mfg	
	334412	Bare printed circuit board mfg	
	334413	Semiconductor and related device mfg	
	334414	Electronic capacitor mfg	
	334415	Electronic resistor mfg	
	334416	Electronic coil, transformer, and other inductor mfg	
	334417	Electronic connector mfg	
	334418	Printed circuit assembly (electronic assembly) mfg	
	334419	Other electronic component mfg	
	334510	Electromedical and electrotherapeutic apparatus mfg	
	334511	Search, detection, navigation, guidance, aeronautical, and nautical system and instrument mfg	
	334512	Automatic environmental control manufacturing for residential, commercial, and appliance use	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Justification for the Inclusion of the NAICS Categories
	334513	Instruments and related products mfg for measuring, displaying, and controlling industrial process variables	
	334514	Totalizing fluid meter and counting device mfg	
	334515	Instrument mfg for measuring, testing electricity, elect. Signals	
	334516	Analytical laboratory instrument mfg	
	334517	Irradiation apparatus mfg	
	334518	Watch, clock, and part mfg	
	334519	Other measuring and controlling device mfg	
	334611	Software reproducing	
	334612	Prerecorded CD (except software), Tape, and Record Repro.	
	334613	Magnetic and optical recording media mfg	
	335110	Electric lamp bulb and part mfg	
	335121	Residential electric lighting fixture mfg	
	335122	Commer., industrial, and instit. electric lighting fixture mfg	
	335129	Other lighting equipment mfg	
	335211	Electric housewares and household fan mfg	
	335212	Household vacuum cleaner mfg	
	335221	Household cooking appliance mfg	
	335222	Household refrigerator and home freezer mfg	
	335224	Household laundry equip mfg	
	335228	Other major household appliance mfg	
	335311	Power, distribution, and specialty transformer mfg	
	335312	Motor and generator mfg	
	335313	Switchgear and switchboard apparatus mfg	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Justification for the Inclusion of the NAICS Categories
	335314	Relay and industrial control mfg	
	335911	Storage battery mfg	
	335912	Primary battery mfg	
	335921	Fiber optic cable mfg	
	335929	Other communications equipment mfg	
	335931	Current-carrying wiring device mfg	
	335932	Noncurrent-carrying wiring device mfg	
	335991	Carbon and graphite product mfg	
	335999	All other misc. electrical equipment and component mfg	
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	336111	Automobile mfg	Based on end-use market information from Impact Marketing (shown in Table C-1). All NAICS categories involving motor and non-motor vehicle manufacturing were included. Additionally, the NAICS category for tire manufacturing was included based on literature from Kusumgar, which identified automotive applications of water-based adhesives for vehicle interiors and tire manufacturing.[b]
	336112	Light truck & utility vehicle mfg	
	336120	Heavy duty truck mfg	
	336211	Motor vehicle body mfg	
	336212	Truck trailer mfg	
	336213	Motor home mfg	
	336214	Travel trailer & camper mfg	
	336311	Carburetor, piston, piston ring, & valve mfg	
	336312	Gasoline engine and engine parts mfg	
	336321	Vehicular lighting equipment mfg	
	336322	Other motor vehicle electrical and electronic equip. mfg	
	336330	Motor vehicle steering and suspension component mfg	
	336340	Motor vehicle brake system mfg	
	336350	Motor vehicle transmission and power train parts mfg	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Justification for the Inclusion of the NAICS Categories
	336360	Motor vehicle seating and interior trim mfg	
	336370	Motor vehicle metal stamping	
	336391	Motor vehicle air-conditioning mfg	
	336399	All other motor vehicle parts mfg	
	326211	Tire Manufacturing (except Retreading)	
Labels and Tapes Manufacturing	322222	Coated and laminated paper manufacturing	Based on end-use market information from Impact Marketing (shown in Table C-1) . All NAICS categories involving labels and tape manufacturing were identified through the Paper and Other Web Coating NESHAP, which provides NAICS codes applicable to this industry.[c]

Note: “Mfg” = manufacturing

As noted in Table C-1, the volume of adhesives consumed by the transportation end-use market is used as the basis for estimating adhesives consumption for motor and non-motor vehicle, vehicle parts, and tire manufacturing (except retreading). To make this estimate, U.S. Economic Census data was collected for all NAICS categories associated with the transportation end-use. The proportion of automobile manufacturing to transportation end-use sites was then calculated, as shown in Table C-5. This proportion was then multiplied by the consumption volume for the transportation industry (172 million kg/yr, as shown in Table C-1) to estimate the volume of adhesives consumed in motor and non-motor vehicle, vehicle parts, and tire manufacturing (except retreading). Using this approach, an annual end-use volume of 113 million kg/yr is calculated.

Using the known adhesives consumption volumes from Tables C-1 and C-5 and the number of adhesives application sites estimated in the previous steps, the average annual facility use rates were calculated as shown below in Table C-4.

Table C-4. Average Annual Facility Use Rate of Adhesives Based on 2002 Economic Census Data

General End-Use Category	Total U.S. Adhesives Consumption Volume (million kg/yr)	Total U.S. Adhesives Application Sites (sites)	Average Annual Facility Use Rate ($Q_{app\_site\_use\_rate}$)
Computer/Electronic and Electrical Product Manufacturing	34	22,294	1,525
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	113	8,366	13,504
Labels and Tapes Manufacturing	318	541	587,800

Table C-5. Average Annual Facility Use Rate of Adhesives for the Transportation Industry Based on 2002 Economic Census Data

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Sites	Number of End-Use Sites	End-Use Sites as a Percent of Industry	Total U.S. Adhesives Consumption Volume (million kg/yr)
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	336111	Automobile mfg	176	8,366	66%	113
	336112	Light truck & utility vehicle mfg	97			
	336120	Heavy duty truck mfg	99			
	336211	Motor vehicle body mfg	847			
	336212	Truck trailer mfg	397			
	336213	Motor home mfg	93			
	336214	Travel trailer & camper mfg	809			
	336311	Carburetor, piston, piston ring, & valve mfg	132			
	336312	Gasoline engine and engine parts mfg	918			
	336321	Vehicular lighting equipment mfg	95			
	336322	Other motor vehicle electrical and electronic equip. mfg	782			
	336330	Motor vehicle steering and suspension component mfg	236			
	336340	Motor vehicle brake system mfg	275			
	336350	Motor vehicle transmission and power train parts mfg	542			
	336360	Motor vehicle seating and interior trim mfg	384			
	336370	Motor vehicle metal stamping	798			
	336391	Motor vehicle air-conditioning mfg	81			
	336399	All other motor vehicle parts mfg	1,447			
	326211	Tire Manufacturing (except Retreading)	158			

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Sites	Number of End-Use Sites	End-Use Sites as a Percent of Industry	Total U.S. Adhesives Consumption Volume (million kg/yr)
Ship	336611	Ship building and repairing	639	1,762	14%	24
	336612	Boat building	1,123			
Aerospace	336411	Aircraft mfg	219	1,585	12%	21
	336412	Aircraft engine and engine parts mfg	412			
	336413	Other aircraft part and auxiliary equipment mfg	854			
	336414	Guided missile and space vehicle mfg	19			
	336415	Guided missile, space vehicle propulsion unit, propulsion unit parts mfg	27			
	336419	Other guided missile, space vehicle, auxiliary equip. mfg	54			
Other Transportation	336991	Motorcycle, bicycle, and parts mfg	355	825	6%	11
	336992	Military armored vehicle, tank, and tank component mfg	39			
	336999	All other transportation equipment mfg	431			
Railroad	336510	Railroad rolling stock mfg	199	199	2%	3
Total				**12,737**	**100%**	**172**

a – USCB, 2002.
Note: "Mfg" = manufacturing

Several key assumptions are inherent in these default use rates:

Assumption #1: All adhesives formulations used at application sites contain the chemical of interest (e.g. F_{chem_comp} = 1 kg product incorporating the chemical/kg total product applied).

Some sites may apply multiple formulations at a site; however, no information or data were found that could be used to determine the extent to which this is the case. Therefore, an estimate for the number of different formulations used at a site containing the chemical of interest versus the total number of formulations used at the site (i.e. the fraction of the formulations containing the chemical) cannot be quantified. In lieu of site-specific information, it is assumed that all formulations used at the site contain the chemical. It is possible that the formulation containing the chemical of interest is not used in all of a particular product type, which would make the default production rate in Table C-4 trend toward the high end (e.g. less conservative for exposures, more conservative for releases).

Assumption #2: All adhesives formulations used at applications sites contain the chemical of interest (e.g. F_{chem_comp} = 1 kg product containing the chemical/kg total product applied).

Some sites may apply multiple formulations at a site; however, no information or data were found that could be used to determine the extent to which this is the case. Therefore, an estimate for the number of different formulations used at a site containing the chemical of interest versus the total number of formulations used at the site (i.e. the fraction of the formulations containing the chemical) cannot be quantified. In lieu of site-specific information, it is assumed that all formulations used at the site contain the chemical. It is possible that the formulation containing the chemical of interest is not used in all of a particular product type, which would make the default production rate in Table C-4 trend toward the high end (e.g. less conservative for exposures, more conservative for releases).

Referring to Step 2, the 2007 Economic Census data provided the total number of production workers for each applicable NAICS code, which are included in Table C-6. 2007 Economic Census data were used instead of 2002 data to ensure that the estimated number of workers per site is based on the most recently available data, so that it may reflect current industrial trends more closely. The total production workers column is a sum of all the applicable NAICS codes for each general category. The total number of production workers can be used in conjunction with the total number of U.S. sites calculated in Table C-2 to estimate the number of production workers per site (shown in Table C-7). Note that the number of production workers per site is assumed to be constant throughout the adhesives application industry.

Table C-6. Number of Workers by General End Use Based on 2007 Economic Census Data

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Production Workers	Total Number of Production Workers
Computer/Electronic and Electrical Product Manufacturing	334111	Electronic computer mfg	12,653	794,086
	334112	Computer storage device mfg	7,790	
	334113	Computer terminal mfg	495	
	334119	Other computer peripheral equipment mfg	12,958	
	334210	Telephone apparatus mfg	12,888	
	334220	Radio and television broadcasting and wireless communications equip. mfg	33,778	
	334290	Other communications equip. mfg	7,988	
	334310	Audio and video equip. mfg	8,651	
	334411	Electron tube mfg	3,674	
	334412	Bare printed circuit board mfg	26,272	
	334413	Semiconductor and related device mfg	82,031	
	334414	Electronic capacitor mfg	4,235	
	334415	Electronic resistor mfg	3,260	
	334416	Electronic coil, transformer, and other inductor mfg	8,220	
	334417	Electronic connector mfg	15,654	
	334418	Printed circuit assembly (electronic assembly) mfg	47,233	
	334419	Other electronic component mfg	32,275	
	334510	Electromedical and electrotherapeutic apparatus mfg	26,405	
	334511	Search, detection, navigation, guidance, aeronautical, and nautical system and instrument mfg	47,000	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Production Workers	Total Number of Production Workers
	334512	Automatic environmental control manufacturing for residential, commercial, and appliance use	7,786	
	334513	Instruments and related products mfg for measuring, displaying, and controlling industrial process variables	17,603	
	334514	Totalizing fluid meter and counting device mfg	9,042	
	334515	Instrument mfg for measuring, testing electricity, elect. Signals	16,582	
	334516	Analytical laboratory instrument mfg	11,785	
	334517	Irradiation apparatus mfg	5,453	
	334518	Watch, clock, and part mfg	1,516	
	334519	Other measuring and controlling device mfg	15,450	
	334611	Software reproducing	1,672	
	334612	Prerecorded CD (except software), Tape, and Record Repro.	14,611	
	334613	Magnetic and optical recording media mfg	2,935	
	335110	Electric lamp bulb and part mfg	7,438	
	335121	Residential electric lighting fixture mfg	7,804	
	335122	Commer., industrial, and instit. electric lighting fixture mfg	13,514	
	335129	Other lighting equipment mfg	9,716	
	335211	Electric housewares and household fan mfg	6,108	
	335212	Household vacuum cleaner mfg	4,636	
	335221	Household cooking appliance mfg	13,084	
	335222	Household refrigerator and home freezer	13,045	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Production Workers	Total Number of Production Workers
		mfg		
	335224	Household laundry equip mfg	10,864	
	335228	Other major household appliance mfg	9,579	
	335311	Power, distribution, and specialty transformer mfg	16,519	
	335312	Motor and generator mfg	31,102	
	335313	Switchgear and switchboard apparatus mfg	24,433	
	335314	Relay and industrial control mfg	23,206	
	335911	Storage battery mfg	15,029	
	335912	Primary battery mfg	4,510	
	335921	Fiber optic cable mfg	3,592	
	335929	Other communications equipment mfg	21,276	
	335931	Current-carrying wiring device mfg	22,859	
	335932	Noncurrent-carrying wiring device mfg	11,902	
	335991	Carbon and graphite product mfg	6,287	
	335999	All other misc. electrical equipment and component mfg	19,688	
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	336111	Automobile mfg	61,312	750,650
	336112	Light truck & utility vehicle mfg	72,307	
	336120	Heavy duty truck mfg	23,007	
	336211	Motor vehicle body mfg	37,095	
	336212	Truck trailer mfg	24,193	
	336213	Motor home mfg	14,152	
	336214	Travel trailer & camper mfg	39,282	
	336311	Carburetor, piston, piston ring, & valve mfg	7,397	
	336312	Gasoline engine and engine parts mfg	42,333	

General End-Use Category	Applicable NAICS[a]	NAICS Category	Number of Production Workers	Total Number of Production Workers
	336321	Vehicular lighting equipment mfg	10,201	
	336322	Other motor vehicle electrical and electronic equip. mfg	41,135	
	336330	Motor vehicle steering and suspension component mfg	26,344	
	336340	Motor vehicle brake system mfg	22,500	
	336350	Motor vehicle transmission and power train parts mfg	57,180	
	336360	Motor vehicle seating and interior trim mfg	38,179	
	336370	Motor vehicle metal stamping	77,853	
	336391	Motor vehicle air-conditioning mfg	12,287	
	336399	All other motor vehicle parts mfg	102,515	
	326211	Tire Manufacturing (except Retreading)	41,378	
Labels and Tapes Manufacturing	322222	Coated and laminated paper manufacturing	24,086	24,086

Note: “Mfg” = manufacturing

Table C-7. Number of Workers per Site by General End Use Based on 2007 Economic Census Data

General End-Use Category	Total Number of Production Workers	Total Number of Sites	Number of Production Workers per Site
Computer/Electronic and Electrical Product Manufacturing	794,086	20,649	38
Motor and Non-Motor Vehicle, Vehicle Parts, and Tire Manufacturing (Except Retreading)	750,650	8,377	90
Labels and Tapes Manufacturing	24,086	497	48

Option 2

This option is an alternative "bottom-up" approach that estimates the daily use rate of the chemical of interest ($Q_{app\_site\_use\_rate}$) from a known, site-specific annual use rate ($Q_{app\_site\_yr}$) by dividing by the number of annual operating days. For example, data from the FPA questionnaire (FPA, 2009), which includes $Q_{app\_site\_yr}$ for four different facilities that use different adhesives types, is divided by their respective number of operating days to estimate $Q_{app\_site\_use\_rate}$ (see Table C-8). The number of operating days is based on data obtained from industry questionnaires conducted by FPA (FPA, 2009).

Table C-8. Facility Use Rate of Adhesive for Flexible Packaging Sites

Adhesive Type	Adhesive Use Rate (kg/site-year)[a]	Days/Year (*Default*)	Adhesive Use Rate (kg/site-day)
Hot melts	9,100,000	300	30,300
Solventless	110,000	365	300
Organic-based	2,300	200	11.5
Water-based	240,000	260	920

Source: FPA, 2009

a – Original data presented in pounds. Converted to kilograms by dividing by 2.2046 lb/kg.

If $Q_{app\_site\_yr}$ for a facility is known, a similar "bottom-up" approach may be used for other application sites (including spray and curtain coating sites). For example, at a furniture manufacturing site, if the annual amount of adhesive used by a site is known, a daily use rate can be determined from those parameters.

APPENDIX D

PMN DATA GATHERING METHODOLOGY AND SUMMARY DATA

Introduction

PMN data were collected from various past new chemical submissions submitted to EPA, including Premanufacture Notices (PMNs), Low Volume Exemptions (LVEs), and Test Market Exemptions (TMEs) to direct the scope of the Adhesives Use ESD and to fill any data gaps during ESD development. This appendix describes how the data were identified, reviewed, and collected from past new chemical submissions. EPA is in possession of the complete data set, which contains confidential business information (CBI). The summary data presented herein contains only the non-CBI data.

Identifying the Scope of the ESD

In order to identify which specific past new chemical submissions contained useful information about the use of industrial adhesives, EPA queried the Initial Review Engineering Report (IRER) Entry and Search System (IESS) for all past new chemical IRERs (e.g. PMNs, LVEs, and TMEs) containing the term “adhesive” in its use description. This query, which was conducted in June 2010, returned all IRERs for which EPA assessed an end use related to industrial adhesives. The time frame of these IRERs was from 2007 to June 2010. IRERs reviewed before 2007 were excluded from the scope of the PMN data review to ensure the review captured current industrial practices and trends.

To determine which end-use industries would be most applicable to the scope of the ESD, EPA conducted a screening-level review of the IRERs to determine which end uses were assessed by EPA for the adhesives-related chemicals. During this cursory review, EPA also identified submissions that were out-of-scope. Specifically, EPA excluded commercial and consumer uses of adhesives; UV and radiation curable adhesives; and uses in which adhesives are pulped together with other materials and extruded or molded into objects. In total, excluding out-of-scope assessments, EPA identified 125 past assessments that contained applicable and relevant information about industrial adhesives use.

Once the cursory review of the IRERs was completed, EPA summarized which end-use industries were identified during the IRER review. The results are reproduced below in Table D-1. Based on this table, the scope of the Adhesives Use ESD was set to cover the top five end-use industries (e.g. computer/electronics; general assembly/binding; flexible packaging/lamination; tapes/labels; and automotive).

Table D-1. Summary of Adhesives PMN Submissions by End Use Industry

End-Use Industry	No. of Submissions
Computer/Electronics	33
General Assembly/Binding	23
Flexible Packaging/Lamination	16
Tapes / Labels	8
Automotive	6
Aerospace/Marine	4
Metal	2
Paper	2
Textiles	1
Tiles	1
Films	1
Unspecified	28
Total	**125**

PMN Data Gathering Methodology

After the initial IRER review, EPA conducted subsequent data gathering efforts for the five end-use industries included in the scope of the ESD. This phase of the PMN data development was conducted exclusively through detailed reviews of PMN submissions. No data were gathered from IRERs; instead, only PMN submissions were reviewed and referenced. Upon review of the PMN submissions, seven of the 86 submissions were found to be for adhesive uses that fall outside of the scope of this ESD. Therefore, a final 77 submissions were reviewed for information for the ESD. During this final review, EPA collected the following information from the PMN submissions:

1. Adhesive application methods;
2. Three-year PMN production volumes of the submitted new chemicals used in adhesives;
3. Chemical concentration, as used in the applied adhesives (low- and high-end);
4. Number of application sites;
5. Number of exposure days per year; and
6. Total number of application workers potentially exposed to the submitted new chemicals.

A non-CBI summary of the information collected from PMN submissions during the final PMN data review is provided in Table D-2. This information was collected for the specific purposes of filling information gaps associated with the General Assembly end use (e.g. adhesives use rate and number of workers per site) and to provide a quantitative basis for end-use assumptions that may be necessary for any of the end uses covered in the ESD when site-specific information is not available to the assessor. Specifically, this includes data regarding most typical application methods, number of exposure days, or number of workers per application site.

The reader should note that none of the entries listed in the end-use industry column of Table D-2 are bolded even though they are based directly on information from PMN submissions. This is because the end uses identified or described in the submissions have been grouped by EPA into the general end-use categories presented in Table D-2. For example, no submission stated “general assembly” as a category of use; therefore, no entries were bolded. However, a review of a submission’s end-use process description would clearly indicate that the adhesive was used for the general assembly of a final product or article.

Table D-2. Non-CBI Data Summary of Information Collected or Calculated from the 2010 PMN Data Review[1,2,3]

Non-CBI ID	End-Use Industry	Application Method	3-Year PMN Production Volume (kg/yr)	Weight Fraction PMN in Adhesive (low)	Weight Fraction PMN in Adhesive (high)	Adhesives Use Volume (kg/yr)[4]	No. of Use Sites	No. of Exposure Days	Facility Adhesives Throughput (kg/st-day)[5]	Total No. of Workers Exposed	Workers Exposed per Site[6]
3	Automotive	**Syringe or Bead**	**270,000**		**0.75**	360,000	**20**	**50**	360	**10**	1
34	Automotive	**Spray Coating**	**154,760**	**0.1**	**0.11**	1,406,909	**16**				
80	Automotive	**Dip Coating**	**1,000**	**0.01**	**0.02**	50,000	**12**				
109	Automotive	**Syringe or Bead**	**1,850**		**0.35**	5,286	**1**	**8**	661		
119	Automotive	**Syringe or Bead**	**34,050**	**0.03**	**0.07**	486,429	**1,050**	**260**	2	**500**	1
152	Automotive	**Syringe or Bead**	**100**	**0.01**	**0.05**	2,000					
2	Electronics	Unknown	**1,000**		**0.25**	4,000					
12	Electronics	**Die Coating**	**1,675**		**0.25**	6,700	**20**	**73**	5	**2**	1
14	Electronics	**Syringe or Bead**	**144**		**0.4**	360					
16	Electronics	**Syringe or Bead**	**144**		**0.4**	360					
18	Electronics	**Syringe or Bead**	**144**		**0.4**	360					
19	Electronics	**Syringe or Bead**	**500**		**0.1**	5,000					
21	Electronics	**Syringe or Bead**	**315**		**0.65**	485	**4**			**12**	3
25	Electronics	**Syringe or Bead**	**15,000**		**0.2**	75,000	**10**	**200**	38	**10**	1
30	Electronics	Spray Coating	**45,359**		**0.25**	181,436	**14**				
37	Electronics	**Syringe or Bead**	**40**	**0.01**	**0.02**	2,000	**1**				
40	Electronics	Unknown	**90,750**		**0.7**	129,643	**2**	**250**	259	**2**	1
48	Electronics	**Syringe or Bead**	**50**		**0.007**	7,143	**10**	**200**	4	**10**	1
52	Electronics	**Roll Coating**	**770**		**0.37**	2,081	**2**	**160**	7	**2**	1
53	Electronics	**Syringe or Bead**	**6,000**		**0.4**	15,000					
54	Electronics	Unknown	**2,039**		**0.35**	5,826					
57	Electronics	**Roll Coating**	**3,000**	**0.1**	**0.2**	15,000	**5**	**200**	15	**50**	10
59	Electronics	**Syringe or Bead**	**1,000**		**0.1**	10,000	**15**	**365**	2	**400**	27
61	Electronics	**Syringe or Bead**	**2,000**		**0.3**	6,667	**10**	**200**	3	**10**	1
74	Electronics	Spray Coating	**8,000**		**0.48**	16,667	**5**	**54**	62	**4**	1
76	Electronics	**Roll Coating**	**100**		**0.66**						
78	Electronics	**Syringe or Bead**	**6,000**		**0.4**	15,000					

Non-CBI ID	End-Use Industry	Application Method	3-Year PMN Production Volume (kg/yr)	Weight Fraction PMN in Adhesive (low)	Weight Fraction PMN in Adhesive (high)	Adhesives Use Volume (kg/yr)[4]	No. of Use Sites	No. of Exposure Days	Facility Adhesives Throughput (kg/st-day)[5]	Total No. of Workers Exposed	Workers Exposed per Site[6]
89	Electronics	**Syringe or Bead**	**2,800**		**0.4**	7,000					
93	Electronics	**Syringe or Bead**	**10,000**	**0.1**	**0.8**	12,500					
100	Electronics	**Syringe or Bead**	**2,000**		**0.08**	25,000					
112	Electronics	**Syringe or Bead**	**3,000**		**0.4**	7,500					
113	Electronics	**Syringe or Bead**	**1,000**	**0.1**	**0.8**	1,250	**5**	**240**	1	**8**	2
122	Electronics	**Syringe or Bead**	**10**		**0.005**	2,000					
131	Electronics	Unknown	**264**		**0.2**	1,320	**10**	**12**	11	**2**	1
142	Electronics	Unknown	**200**	**0.11**	**0.13**	1,538	**10**	**100**	2	**100**	10
159	Electronics	Unknown	**3,000**		**0.88**	3,409	**250**	**250**	0.05	**2**	1
13	Flexible Packaging / Lamination	Spray Coating	**500,000**		0.85	588,235					
31	Flexible Packaging / Lamination	**Roll Coating**	**700,000**		**0.85**	823,529	**1**	**50**	16,471	**9**	9
81	Flexible Packaging / Lamination	**Roll Coating**	**180,000**		**0.4**	450,000	**10**	**250**	180	**2**	0
101	Flexible Packaging / Lamination	**Roll Coating**	**200,000**	**0.6**	**0.8**	250,000	**6**				1
105	Flexible Packaging / Lamination	**Roll Coating**	**200,000**	**0.4**	**0.7**	285,714	**6**				
110	Flexible Packaging / Lamination	**Roll Coating**	**200,000**	**0.6**	**0.85**	235,294	**6**				
120	Flexible Packaging /	**Roll Coating**	**140,250**	**0.31**	**0.51**	275,000	**5**	**120**	458	**4**	1

Non-CBI ID	End-Use Industry	Application Method	3-Year PMN Production Volume (kg/yr)	Weight Fraction PMN in Adhesive (low)	Weight Fraction PMN in Adhesive (high)	Adhesives Use Volume (kg/yr)[4]	No. of Use Sites	No. of Exposure Days	Facility Adhesives Throughput (kg/st-day)[5]	Total No. of Workers Exposed	Workers Exposed per Site[6]
	Lamination										
123	Flexible Packaging / Lamination	**Roll Coating**	**350,000**	**0.94**	**1**	350,000	**40**	**220**	40	**4**	1
127	Flexible Packaging / Lamination	**Roll Coating**	**149,000**		**0.42**	354,762	**16**	**220**	101	**64**	4
145	Flexible Packaging / Lamination	**Roll Coating**	**82,000**		**1**	82,000		**100**			
148	Flexible Packaging / Lamination	**Roll Coating**	**16,250**		**0.059**	275,424	**9**	**220**	139	**4**	1
150	Flexible Packaging / Lamination	**Roll Coating**	**340,000**		**1**	340,000	**3**				
151	Flexible Packaging / Lamination	**Roll Coating**	**82,000**		**1**	82,000		**100**		**4**	
156	Flexible Packaging / Lamination	**Roll Coating**	**48,000**		**1**	48,000		**100**		**2**	
6	General Assembly	Unknown	**5,000**		**0.01**	500,000	**3**	**240**	694	**3**	1
10	General Assembly	**Syringe or Bead**	**1,000**	**0.01**	**0.05**	20,000					
22	General Assembly	**Syringe or Bead**	**10,000**	**0.01**	**0.05**	200,000	**5**	**200**	200	**1**	1
29	General	**Dip Coating**	**320**		**0.1**	3,200		**260**		**3**	

Non-CBI ID	End-Use Industry	Application Method	3-Year PMN Production Volume (kg/yr)	Weight Fraction PMN in Adhesive (low)	Weight Fraction PMN in Adhesive (high)	Adhesives Use Volume (kg/yr)[4]	No. of Use Sites	No. of Exposure Days	Facility Adhesives Throughput (kg/st-day)[5]	Total No. of Workers Exposed	Workers Exposed per Site[6]
	Assembly										
33	General Assembly	Unknown	**45,400**	**0.9**	**1**	45,400	**1**	**250**	182	**2**	2
43	General Assembly	**Roll Coating/Syringe or Bead**	**2,000,000**		**0.763**	2,621,232	**20**	**50**	2,621	**10**	1
49	General Assembly	**Roll Coating/Syringe or Bead**	**2,000,000**		**0.763**	2,621,232	**20**	**50**	2,621	**10**	1
51	General Assembly	**Die or Roll Coating**	**100,000**		**0.98**	102,041	**1**				
56	General Assembly	Unknown	**200,000**								
70	General Assembly	**Syringe or Bead**	**860,000**		**0.43**	2,000,000	**2**	**200**	5,000	**52**	26
87	General Assembly	**Syringe or Bead**	**250,000**		**0.9**	277,778	**20**	**100**	139	**2**	1
106	General Assembly	**Syringe or Bead**	**18,182**	**0.15**	**0.3**	60,607	**20**	**250**	12	**28**	1
118	General Assembly	Syringe or Bead	**45,400**	**0.9**	**1**	45,400	**2**	**250**	91	**2**	1
137	General Assembly	Syringe or Bead	**2,500**								
138	General Assembly	Syringe or Bead	**2,500**								
139	General Assembly	**Syringe or Bead**	**20,000**	**0.02**	**0.2**	100,000	**20**				
140	General Assembly	**Syringe or Bead**	**2,500**	**0.02**	**0.2**	12,500	**20**				

Non-CBI ID	End-Use Industry	Application Method	3-Year PMN Production Volume (kg/yr)	Weight Fraction PMN in Adhesive (low)	Weight Fraction PMN in Adhesive (high)	Adhesives Use Volume (kg/yr)[4]	No. of Use Sites	No. of Exposure Days	Facility Adhesives Throughput (kg/st-day)[5]	Total No. of Workers Exposed	Workers Exposed per Site[6]
141	General Assembly	**Syringe or Bead**	**1,000**		**0.05**	20,000	**20**	**240**	4	**8**	1
147	General Assembly	**Syringe or Bead**	**1,000**		**0.6**	1,667	**1**	**50**	33	**2**	2
153	General Assembly	**Roll Coating**	**100,000**	**0.99**	**1**	100,000	**5**				
5	Tapes / Labels	**Roll Coating**	**200,000**		**0.37**	540,541	**1**	**200**	2,703	**2**	2
128	Tapes / Labels	**Roll Coating**	**6,000**		**0.1**	60,000	**4**	**60**	250	**7**	2
129	Tapes / Labels	**Doctor blade, wire, air brush, reverse roll, reverse gravure, curtain, jet**	**12,000,000**	**0.1**	**0.3**	40,000,000	**30**	**100**	13,333	**4**	
130	Tapes / Labels	**Roll Coating**	**2,540,000**	**0.1**	**0.3**	8,466,667	**30**	**100**	2,822	**4**	
132	Tapes / Labels	**Curtain Coating**	**6,000**		**0.1**	60,000	**4**	**60**	250	**7**	2
136	Tapes / Labels	Unknown	**10,000**		**0.0002**	50,000,000	**10**	**250**	20,000	**40**	4
157	Tapes / Labels	Curtain Coating	**6,000**		**0.1**	60,000	**4**	**60**	250	**7**	2

Notes:
1. Bold cells denote data collected directly from new chemical submissions.
2. Un-bolded cells denote either: (1) summary information based on new chemical submission reviews (e.g. assigning an end-use industry or application method to a chemical based on reviewed submission descriptions) or (2) calculations derived directly from collected PMN data (e.g. adhesive use volume, adhesive facility throughput, and workers exposed per site).

3. Blank cells denote information that was not provided in new chemical submissions.
4. The adhesives use volume column was calculated by dividing the 3-year PMN production volume by the weight fraction of PMN in adhesive (high).
5. The facility adhesives throughput was calculated by dividing the adhesives use volume by the number of use sites and number of exposure days.
6. The number of workers exposed per site was calculated by dividing the total number of workers exposed by the number of use sites and rounding up to the nearest whole-number integer.

General Assembly/Binding End Use Data

In order to fill the data gaps associated with this end-use industry, EPA took an average of the values presented above in Table D-2, which are used in the ESD as the bases for "what-if" estimates for $Q_{app\_site\_use\_rate}$. What-if estimates are used when data representative of real industry use rates cannot be found. Although 20 past submissions related to general assembly were identified, only 11 of these submissions provided all data necessary to allow the calculation of the adhesive daily use rate. The resulting facility use rate estimates are provided below in Table D-3. The facility use rates were calculated by dividing the annual adhesive use volume by the number of sites and operating days specified in the PMN submissions. The number of operating days per year is based on the number of exposure days per year. The two are assumed to be equal in this ESD.

Table D-3. Summary of PMN Data Used for ESD "What-If" Estimates for the General Assembly End-Use Industry[1,2]

Non-CBI ID	Application Method	3-Year PMN Production Volume (kg/yr)	Weight Fraction PMN in Adhesive (high)	Adhesive Use Volume (kg/yr)[3]	No. of Use Sites	No. of Operating Days per Year[4]	Adhesive Annual Use Rate (kg/site-yr)[5]	Adhesive Daily Use Rate (kg/site-day)[6]	Total No. of Workers Exposed[7]	EPA-Calculated Total No. of Workers Exposed	Workers Exposed per Site[8]
6	Unknown	**5,000**	**0.01**	500,000	**3**	**240**	166,667	694	**3**	NA	1
22	**Syringe or Bead**	**10,000**	**0.05**	200,000	**5**	**200**	40,000	200	**1**	5	1
33	Unknown	**45,400**	**1**	45,400	**1**	**250**	45,400	182	**2**	NA	2
43	**Roll Coating/ Syringe or Bead**	**2,000,000**	**0.763**	2,621,232	**20**	**50**	131,062	2,621	**10**	200	10
49	**Roll Coating/ Syringe or Bead**	**2,000,000**	**0.763**	2,621,232	**20**	**50**	131,062	2,621	**10**	200	10
70	**Syringe or Bead**	**860,000**	**0.43**	2,000,000	**2**	**200**	1,000,000	5,000	**52**	NA	26
87	**Syringe or Bead**	**250,000**	**0.9**	277,778	**20**	**100**	13,889	139	**2**	40	2
106	**Syringe or Bead**	**18,182**	**0.3**	60,607	**20**	**250**	3,030	12	**28**	NA	2
118	Syringe or Bead	**45,400**	**1**	45,400	**2**	**250**	22,700	91	**2**	NA	1
141	**Syringe or Bead**	**1,000**	**0.05**	20,000	**20**	**240**	1,000	4	**8**	160	8
147	**Syringe or Bead**	**1,000**	**0.6**	1,667	**1**	**50**	1,667	33	**2**	NA	2
Average				763,029	10	171	141,498	1,054	**--**	**--**	**--**

Notes:
NA – Not Applicable

1. Bold cells denote data collected directly from new chemical submissions.
2. Un-bolded cells denote either: (1) summary information based on new chemical submission reviews (e.g. assigning an end-use industry or application method to a chemical based on reviewed submission descriptions) or (2) calculations derived directly from collected PMN data (e.g. adhesive use volume, adhesive facility throughput, and workers exposed per site).
3. The adhesives use volume column was calculated by dividing the 3-year PMN production volume by the weight fraction of PMN in adhesive (high).
4. The number of operating days per year is assumed to be equal to the number of exposure days per year, which was collected from the PMN data.
5. The facility adhesive annual use rate was calculated by dividing the adhesives use volume by the number of sites.
6. The facility adhesives throughput was calculated by dividing the adhesives use volume by the number of use sites and number of exposure days.
7. Five of the new chemical submissions provided total number of workers estimates that yielded less than one worker per site. New chemical submissions request worker estimates as a total across all sites; however, many submissions erroneously provide estimates on a per site basis. For these five submissions, EPA assumed the total number of workers was erroneously reported on a per site basis. This value was then multiplied by the total number of sites to provide the EPA-calculated total number of workers, which is provided in the following column.
8. The number of workers exposed per site was calculated by dividing the total number of workers exposed (based on either new chemical submission values or EPA-calculated values) by the number of use sites and rounding up to the nearest whole-number integer.

APPENDIX E

FEICA FACT SHEET ON EXPOSURE SCENARIOS FOR ADHESIVES AND SEALANTS

FEICA FACT SHEET on Exposure Scenarios ('ES') for Adhesives and Sealants

FEICA 'ES' Projects Version 03/05/2013

Background

The fundamental aim of the REACH Regulation is to ensure that all uses are safe to both human health and environment. For that purpose, one 'communication tool' requested by REACH is the Exposure Scenarios ('ES'), or set of information that describes how to use a substance safely**.** An **'**ES' covers, therefore, either exposure assessments for the different uses (industrial, professional and consumer) or the environment.

FEICA is currently carrying out three projects to develop the information on operational conditions and risk management measures for typical adhesive and sealants (A&S) applications. The projects address worker, consumer, and environmental safety by the so-called Generic Exposure Scenarios (GES), Specific Consumer Exposure Determinants (SCEDs), and Specific Environmental Release Categories (SPERCs) respectively. This document provides an overview of such activities and their current status.

Similar activities are currently on-going in other industry sectors (formulators). These activities are coordinated either by the Downstream Users of Chemicals Co-ordination Group (DUCC) in the case of the SCEDs and GES, or the European Chemical Industry Council (CEFIC) for the SPERCs. FEICA provides its input to both.

Goal of the Projects

The main goal is to develop a set of information for the end users of mixtures, that:

- Covers the majority of the adhesives and sealants applications.
- Ensures a consistent translation of the substance exposure scenarios provided within the safety data sheet, into meaningful information for the end users of mixtures.
- Simplifies the communication with the raw material suppliers.

Scope of the Projects:

All areas of *major A&S applications* in global terms (i.e. industrial, professional and consumers uses), and both *human health and environmental safety* (all chemical and physical risks are considered).

FEICA GES - overview

FEICA 'GES' are sets of simplified descriptions of the operational conditions (OC) and Risk Management Measures (RMM) used in major *A&S* applications. They address occupational safety in professional and industrial A&S uses.

How to develop the FEICA GES - Approach

1. Identify and group major A&S applications – based on similar RMMs/OCs, and describe the process for both professional and industrial uses.

2. Define the FEICA 'GES' by describing the application process in terms of so-called PROCs (process categories), OCs, and RMMs.

3. Identify the lead substances[28] relevant for the defined A&S applications.

4. For the lead substances, check whether the set of RMMs and OCs in the SDS received by the supplier, covers the respective RMMs/OCs outlined for the GES.

Status

- The draft process descriptions for industrial applications of adhesives and sealants are currently being checked by the company experts.

- The evaluation of the RMMs and OCs for professional applications of A&S is almost complete. As a follow-up, several suppliers of lead substances will be contacted.

- As soon as the human health part of the project is completed, FEICA will organise a workshop to outline the results and the implications for next steps.

SCEDs - overview

SCEDs are sets of specific consumer determinants to be used as "information input" in the consumer exposure assessment. The objective of the FEICA SCEDs project is to develop a set of refined exposure determinants (realistic parameters relevant to the consumer use of A&S), and to make them available in assessment and reporting tools (e.g. ECETOC TRA and CHESAR).

In the development of SCEDs for adhesives and sealants, FEICA profits from the Adhesives Exposure Assessment Tool (AEAT). AEAT is a Tier 2 assessment tool developed in 2010, to get successful assessments of chemical substances used in consumer adhesives products. The parameters set in the AEAT were adopted for the FEICA SCEDs for the consumer use of adhesives.

How to develop the FEICA SCEDs - Approach

1. Identify and group major A&S applications for consumer uses, based on similar exposure conditions.

2. Select and compile relevant pieces of information (use conditions and risk management measures) from reliable reference documents for documentation into the SCEDs fact sheets. These pieces of information include for example:

    - Product ingredient fraction

[28] Lead Substance = the lead substance approach foresees that risk management of a product is based on the substance with the highest concern. The lead substance is defined per product and endpoint (e.g. inhalation and dermal exposure).

- Frequency of use and duration of exposure
- Relevant route(s) of exposure (dermal, inhalation, oral)
- Skin contact area and transfer factor (dermal specific)
- Amount of product used per application
- Room volume (inhalation specific)

3. These parameters can be used e.g. in the consumer part of the tier 1 risk assessment ECETOC TRA v.3 program to overwrite the conservative preset of default values (so called Tier 1.5).

Status

- Guidance on SCEDs has been drafted at DUCC level, and is currently under discussion. It will be published soon. It includes a template for standardized documentation of SCEDs.
- The determinants refining the exposure assessment of the consumer use of A&S are completed. Four SCEDs have been developed on Glues DIY-use, Joint sealants, Spray glues and Universal glues.
- The process for building acceptance is ongoing.

SPERCs - overview

SPERCs are sets of specific environmental release categories, to be used in the environmental exposure assessments. The objective of the FEICA SPERCs project was to develop standardized and refined exposure values (realistic parameters) relevant for the environmental emission estimations of A&S formulation and application. This set of information is documented in a SPERC factsheet, and included in the 'ES' library.

FEICA has recently revised the 3 factsheets developed (formulation of adhesives, industrial uses of substances in adhesives, wide dispersive use of A&S by professional users and consumers), and an 'explanatory document' to outline the main differences with previous versions was also published.

How to develop the FEICA SPERCs - Approach

1. Identify and group operations for typical/major A&S applications – based on similar conditions for environmental releases.
2. Define the environmental releases categories to perform the emission estimations- including realistic release factors, and efficiencies of both OCs (e.g. site tonnage, release fractions, etc.) and RMMs

Status:

- The SPERC project is completed.
- All SPERCs are available in the FEICA website, together with the CHESAR SPERC files that allows them to be directly uploaded into the CHESAR tool that can be used by registrants.

Contacts for more info

This document was developed by the FEICA's ES Technical Task Force (GES team).

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