Bisphenol A Alternatives in Thermal Paper

Chapter 5

General Exposure and Lifecycle Information

FINAL REPORT

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U.S. Environmental Protection Agency

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List of Acronyms and Abbreviations

AIM	Analog Identification Methodology
ACR	Acute to Chronic Ratio
ADME	Absorption, Distribution, Metabolism, and Excretion
AIST	Advanced Industrial Science and Technology
ASTM	American Society for Testing and Materials
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BMD	Benchmark Dose
BMDL	Benchmark Dose Lower-confidence Limit
BPA	Bisphenol A
BPS	Bisphenol S
BOD	Biochemical Oxygen Demand
CASRN	Chemical Abstracts Service Registry Number
CDC	Centers for Disease Control and Prevention
CHO	Chinese Hamster Ovary Cells
ChV	Chronic Value
CPSC	Consumer Product Safety Commission
CVL	Crystal Violet Lactone
DfE	Design for the Environment
DOC	Dissolved Organic Carbon
dpi	Dots per inch
EC_{50}	Half Maximal Effective Concentration
ECHA	European Chemicals Agency
ECOSAR	Ecological Structure Activity Relationships
EDSP	Endocrine Disruptor Screening Program
EEC	European Economic Community
Eh	Redox potential
EKG	Electrocardiogram
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EPI	Estimations Program Interface
ERMA	Environmental Risk Management Authority
EU	European Union
EWG	Environmental Working Group
FDA	U.S. Food and Drug Administration
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
GLP	Good Laboratory Practice
HGPRT	Hypoxanthine-Guanine Phosphoribosyl-Transferase
HIPAA	Health Insurance Portability and Accountability Act of 1996
HPLC	High Performance Liquid Chromatography
HPV	High Production Volume
HSDB	Hazardous Substances Data Bank
IARC	International Agency for Research on Cancer
IR	Infrared

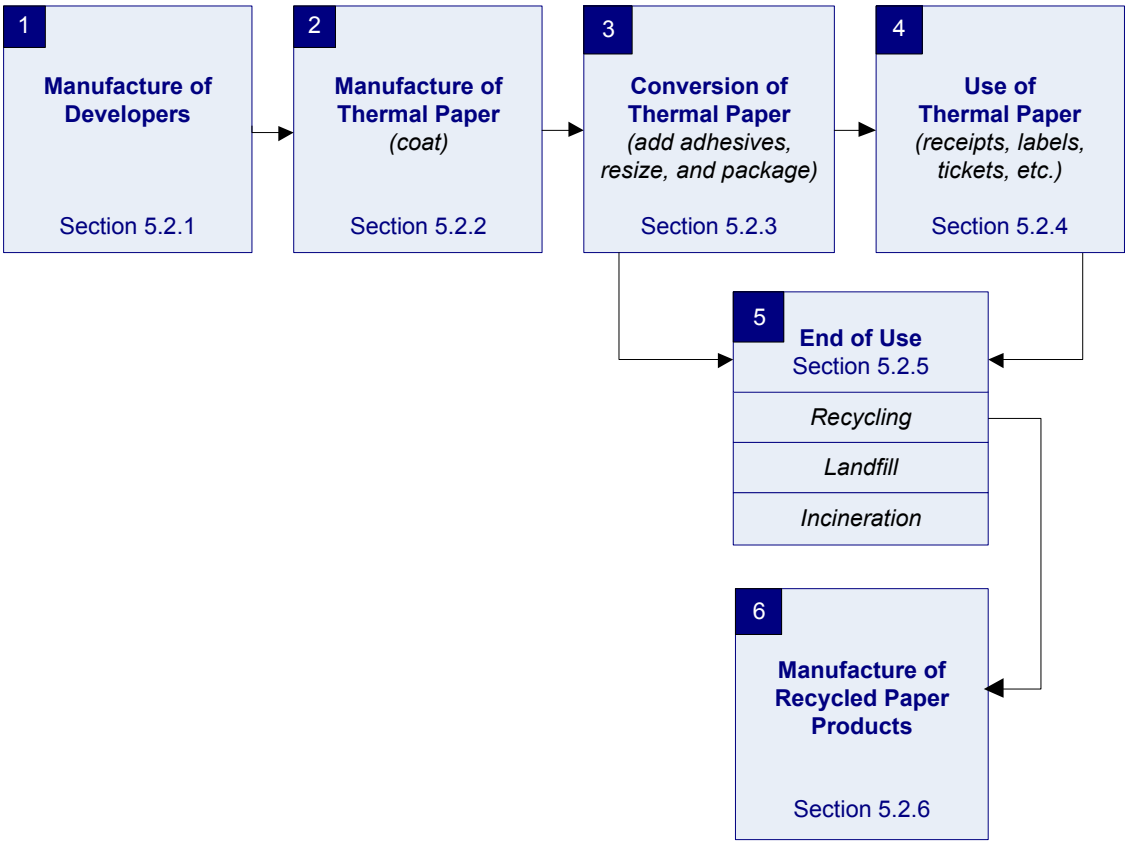
IRIS	Integrated Risk Information System
IUCLID	International Uniform Chemical Information Database
K_{oc}	Soil adsorption coefficient
K_{ow}	Octanol/water partition coefficient
LC_{50}	Median Lethal Concentration
LCA	Life-cycle Assessment
LD_{50}	Median Lethal Dose
LD	Lactation Day
LFL	Lower Limit of Flammability
LOAEL	Lowest Observed Adverse Effect Level
LOEC	Lowest Observed Effective Concentration
MDI	Mean Daily Intake
MF	Molecular Formula
MITI	Japanese Ministry of International Trade and Industry
MW	Molecular Weight
MSDS	Material Safety Data Sheet
NAICS	North American Industry Classification System
NES	No Effects at Saturation
NGO	Non-Governmental Organization
NHANES	National Health and Nutrition Examination Survey
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NIOSH	National Institute for Occupational Safety and Health
NIR	Near Infrared
NOAEL	No Observed Adverse Effect Level
NOEC	No Observed Effect Concentration
NOEL	No Observed Effect Level
NTP	National Toxicology Program
OECD	Organisation for Economic Cooperation and Development
OPPT	Office of Pollution Prevention and Toxics
P2	Pollution Prevention
PBB	Poly-Brominated Biphenyls
PBDE	Polybrominated Diphenyl Ether
PBT Profiler	Persistent, Bioaccumulative, and Toxic (PBT) Chemical Profiler
PMN	Premanufacture Notice
PNEC	Predicted No Effect Concentration
POS	Point-of-sale
ppb	parts per billion
ppm	parts per million
PVC	Polyvinyl Chloride
REACH	**R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances
RoHS	Restriction of Hazardous Substances
SAR	Structure Activity Relationship
SCAS	Semi-Continuous Activated Sludge
SF	Sustainable Futures
SMILES	Simplified Molecular-Input Line-Entry System
SPARC	Sparc Performs Automated Reasoning in Chemistry

TDI	Total Daily Intake
TOC	Total Organic Carbon
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
QSAR	Quantitative Structure Activity Relationships
UFL	Upper Limit of Flammability
USGS	U.S. Geological Survey
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

5. General Exposure and Life-cycle Information

The purpose of this chapter is to provide general information on exposure and life-cycle considerations of thermal paper developers. This discussion is framed in the context of six life-cycle stages: manufacture of developers (Section 5.2.1), manufacture of thermal paper (Section 5.2.2), conversion of thermal paper (Section 5.2.3), use of thermal paper (Section 5.2.4), end-of-life (Section 5.2.5), and manufacture of recycled paper products (Section 5.2.6), as shown in Figure 5-1. A quantitative exposure assessment is outside the scope of this project and not necessary for comparative hazard assessment. Rather, this chapter represents a qualitative review of potential environmental releases and exposures based on limited information from the published literature and publicly available sources (Section 5.3). Understanding the factors that affect exposure to bisphenol A (BPA) and alternative developers across the life-cycle provides additional context to the alternative selection process. This chapter includes information on the presence of BPA in people and the environment, with the understanding that thermal paper is only one of the sources of BPA. This type of information is generally not available for other chemicals in the assessment, however, the information on BPA in thermal paper can be considered as a surrogate for the other developers that have similar physical/chemical properties and behaviors and use patterns.

Figure 5-1: Summary of Life-cycle of Developers in Thermal Paper



5.1 Potential Exposure Pathways and Routes (General)

Exposure to developers can occur at many points in the life-cycle of thermal paper. There is a potential for occupational exposures during chemical and product manufacturing and product end-of-life (i.e., recycling, landfilling, or incineration). Additionally, there may be exposures to workers and consumers while thermal paper is being used and to the general population and the environment from releases during product manufacturing, use, and end-of-life.

The risk associated with a given chemical or substance is influenced by how exposure occurs. For example, the level of exposure associated with inhaling the chemical can be different from exposure via ingestion, in turn influencing the toxic outcome. As a result, exposure is typically characterized by different pathways and routes. An exposure pathway is the physical course a chemical takes from the source of release to the organism that is exposed, whereas the exposure route is how the chemical gets inside the organism. The three primary routes of exposure are inhalation, dermal absorption, and ingestion. The physical/chemical properties of the chemical influence the pathways and routes of exposure.

The physical state of the chemical during chemical manufacturing, downstream processing, incorporation into consumer use products, and after release to the environment significantly influences the potential for inhalation exposure. In particular, there are three types of inhalation exposures to consider: dust, vapor, and mist.

5.1.1 Inhalation Exposures

Dust: Chemicals that are manufactured, processed, and used as solids have the potential to result in occupational and consumer exposures to fugitive dusts. The potential for fugitive dust formation depends on whether the solid chemical is handled in the crystalline form, as an amorphous solid, or as a fine powder, as well as the particle size distribution and solids handling techniques. It is important to note the physical state of the chemical at the potential point of release and contact. The pure chemical may be manufactured as a solid powder, indicating a potential occupational exposure to dust. However, it may be formulated into solution before anyone comes in contact with it, thereby eliminating inhalation exposure to dust as a potential route. If there is exposure to dust, particle size influences the degree to which the chemical enters the body. Particles less than 10 microns in diameter are “respirable” with potential to reach and attach to tissues in the respiratory tract and deep lung where they may irritate lung tissue or be absorbed into the body. Once released into air or other media, the chemical can associate with particulate material through sorption onto particles or as particulates. For example, vapor phase chemicals can partition onto house dust and contribute to ingestion and dermal exposure pathways as well as inhalation.

Vapor: Exposure to vapors can occur when chemicals volatilize during manufacturing, processing, and use, or are associated with particulates in air. Most chemical manufacturing operations occur in closed systems. However, fugitive emissions are expected during manufacturing processes if there are open mixing operations, transfer operations, and loading/unloading of raw materials. The more volatile the chemical, the greater the fugitive releases and higher the potential occupational and consumer exposures. Therefore, vapor pressure (a measure of volatility) is a key indicator of potential exposures to vapors. Particulate exposures can result from physical breakdown of products, erosion of materials from surfaces, etc.

Mist: Both volatile and nonvolatile liquids can result in inhalation exposure if manufacturing operations or use results in the formation of mist. Droplet size is an important consideration in determining exposure to chemicals released as a mist; as with dust, mist particles less than 10 microns in diameter are "respirable" with potential to be absorbed in the respiratory tract.

5.1.2 Dermal Exposures

Dermal exposure is also affected by the physical state of the chemical at the point of release and contact. For example, the likelihood of liquids being splashed or spilled during sampling and drumming operations is different than for similar operations involving polymerized solids, powders, or pellets. Dermal exposure is also generally assumed to be proportional to the concentration of chemical in the formulation. For example, the dermal exposure from contacting a pure chemical is generally greater than the exposure from contacting a solution that contains only 10 percent of the chemical (unless the formulation contains penetration enhancers). Screening-level evaluations of dermal exposure can be based on worker activities involving the chemical, consumer uses, and contact. For instance, there may be significant exposure when workers handle bags of solid materials during loading and transfer operations. Maintenance and cleanup activities during shutdown procedures, connecting transfer lines, and sampling activities also result in potential for dermal exposures. In the case of thermal paper, workers may be exposed to high concentrations of developer while changing cash register receipt rolls or cleaning machines. Consumer exposure from dermal contact will be dependent upon the amount and availability of the chemical in the product.

5.1.3 Ingestion Exposures

Exposures via ingestion typically occur when individuals eat food or drink water that has become contaminated with chemicals. Dust particles may spread throughout the facility and settle (or deposit) on tables, on lunchroom surfaces, or even on food itself. Vapors may similarly spread throughout the facility and may be adsorbed onto food or particles in drinking water or dissolved in the drinking water. Another potential pathway for ingestion occurs from dust particles that are too large to be absorbed through the lungs. These "non-respirable particles" are often swallowed, resulting in exposures from this route. Children and others can be exposed by transfer from dust or other media to hands to mouth. Compared to inhalation and dermal exposures, ingestion is typically considered a less significant exposure pathway from an occupational and consumer health standpoint. However, ingestion is often an equally or more significant exposure route for the general population, and especially for children that ingest house dust, than inhalation and dermal exposure, as described in the next section.

5.1.4 Environmental and General Population Exposures

Releases to the environment can result in contamination of environmental media, leading to exposures in the general population and environmental organisms. In general, exposure concentrations to humans and other organisms by this route may be relatively low, but they may be most widespread, and may occur over a lifetime. Also, wildlife may be impacted by direct contact with contaminated media. If a chemical is bioaccumulative, it may concentrate in the animal and reach higher trophic levels and people through the food chain. Food contamination can also come from contaminants in biosolids derived from wastewater treatment plants (WWTP) that are applied to agricultural fields or the ingestion of contaminated feed by livestock.

Direct human contact with contaminated environmental media, such as soil, sediment, house dust, and surface water, can lead to dermal exposure and incidental ingestion. Contact with contaminated drinking water can result in dermal and inhalation exposures, via washing and showering, as well as ingestion through consumption.

Products used in the home can lead to exposures in the general population. Chemicals can volatilize from products and become incorporated into indoor air, or dust in the home, office, car, or other locations where products are used. Inhalation of contaminants in air, dermal contact with contaminated surfaces and dust, and incidental ingestion of dust or hand-to-mouth contact are all viable exposure pathways in the home. The physical properties of the chemical, along with how the chemical is incorporated into the product, influence how much of a chemical will enter the dust in a consumer's environment. A person who does not have direct contact with products containing a particular chemical still has the potential to be exposed to them once the chemical is released.

5.1.5 Exposures to Susceptible Populations

Susceptibility and exposure can vary for individuals within a population. Variability can be characterized but not reduced, and therefore it can be helpful to consider potentially exposed susceptible populations when considering chemical alternatives. Genetics, gender, life stage, pregnancy status, lifestyle, predisposition to diseases and other medical conditions, and other chemical exposures are examples of factors that lead to differential susceptibility (National Academy of Sciences 2008).

For example, children may be more susceptible to environmental exposures than adults because:

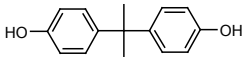
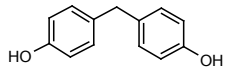
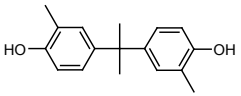
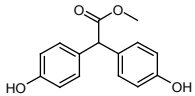
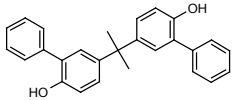
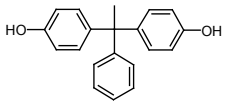
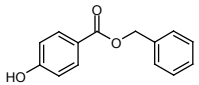
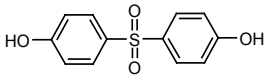
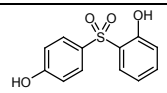
- Their bodily systems are still developing;
- They eat more, drink more, and breathe more in proportion to their body size;
- Their behavior can expose them more to chemicals and organisms, for example, hand-to-mouth and object-to-mouth behaviors (Xue, Zartarian et al. 2007); and
- They may be exposed to chemicals, including BPA, in human milk (Landrigan, Sonawane et al. 2002) and infant formula (Cao, Dufresne et al. 2008).

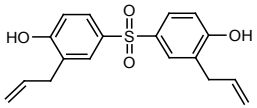
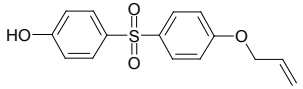
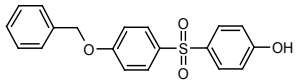
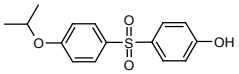
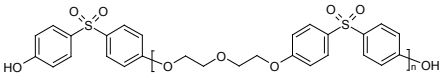
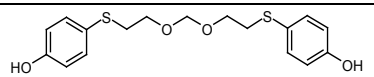
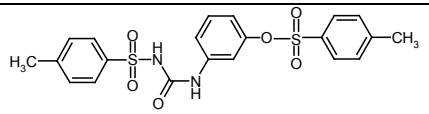
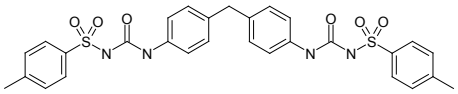
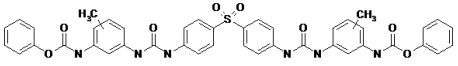
Prenatal development represents a potential window of susceptibility whereby exposures to chemicals in the environment can contribute to adverse pregnancy and developmental outcomes (Stillerman 2008). During prenatal development, biological systems are forming, and disruption of these processes can have consequences later in life. While the placenta is designed to protect the fetus from stressors, including chemical exposures, chemicals (including BPA) have been shown to pass through this organ resulting in prenatal exposures (Perera, Rauh et al. 2003; Myren, Mose et al. 2006).

Potential perinatal and childhood exposures to thermal paper chemicals can occur via exposure pathways that are unique to, or more common during early life, including:

- Maternal consumer and occupational exposures resulting in exposures to the fetus;
- Maternal consumer and occupational exposures resulting in ingestion via human milk;
- Transfer of thermal paper chemicals on hands to mouth; and
- Mouthing of thermal paper (chew and/or swallow).

5.1.6 Physical/Chemical Properties for that May Impact Exposure to BPA and Alternatives

CASRN	Chemical Name	Common Name	Molecular Formula	Structure	MW	pK_a	MP (°C)	BP (°C)	VP (mmHg @ 25 °C)	H_2O_{sol} (g/L)	Henry's Law (atm•m^3/mole)	Log K_{ow}
80-05-7	**2,2-bis(p-hydroxyphenyl)propane**	**Bisphenol A**	$C_{15}H_{16}O_2$		228.29	9.59-11.30	55	60.5	3.99×10^{-8}	120-300	$<1\times10^{-8}$ [a]	3.32
620-92-8	**Bis(4-hydroxyphenyl)methane**	**Bisphenol F**	$C_{13}H_{12}O_2$		200.24	7.55	162.5	sub	3.73×10^{-7} [a]	190[a]	$<1\times10^{-8}$ [a]	2.91
79-97-0	**2,2'-Bis(4-hydroxy-3-methylphenyl)propane**	**Bisphenol C**	$C_{17}H_{20}O_2$		256.35	10.5[a]	138-140	368[b]	2.3×10^{-6} [b]	4.7 [a]	$<1\times10^{-8}$ [a]	4.7
5129-00-0	**Methyl bis(4-hydroxyphenyl)acetate**	**MBHA**	$C_{15}H_{14}O_4$		258.28	9.7-9.9	ND	>300[a]	3.3×10^{-8}[a]	360[a]	$<1\times10^{-8}$ [a]	2.8[a]
24038-68-4	**4,4'-Isopropyllidenebis(2-phenylpheno)**	**BisOPP-A**	$C_{27}H_{24}O_2$		380.49	10.8-10.9[a]	118	>300[a]	$<1\times10^{-8}$ [a]	0.011[a]	$<1\times10^{-8}$ [a]	7.2[a]
1571-75-1	**4,4'-(1-Phenylethylidene)bisphenol**	**Bisphenol AP**	$C_{20}H_{18}O_2$		290.36	9.91-10.1	189	>300[a]	$<1\times10^{-8}$ [a]	1.1[a]	$<1\times10^{-8}$ [a]	4.9[a]
PROPRIETARY	**PROPRIETARY**	**Substituted phenolic compound #1**				4.7, 10[a]	171-172	>300[a]	$<1\times10^{-8}$ [a]	180[a]	$<1\times10^{-8}$ [a]	3.4[a]
PROPRIETARY	**PROPRIETARY**	**Substituted phenolic compound #2**				10[a]	135-139	>300[a]	$<1\times10^{-8}$ [a]	0.12[a]	$<1\times10^{-8}$ [a]	6.3[a]
94-18-8	**Benzyl 4-hydroxybenzoate**	**PHBB**	$C_{14}H_{12}O_3$		228.25	7.8[a]	111-112	>300[a]	3.8×10-6	60	2.9×10^{-10} [a]	3.56
80-09-1	**4-Hydroxyphenyl sulfone**	**Bisphenol S**	$C_{12}H_{10}O_4S$		250.27	8	240.5	>300[a]	$<1\times10^{-8}$ [a]	1.1×10^{-3}	$<1\times10^{-8}$ [a]	1.2
5397-34-2	**2,4'-Bis(hydroxyphenyl)sulfone**	**2,4-BPS**	$C_{12}H_{10}O_4S$		250.3	7.6, 8.2[a]	184	>300[a]	$<1\times10^{-8}$ [a]	1.7×10^{3}[a]	$<1\times10^{-8}$ [a]	1.7[a]

CASRN	Chemical Name	Common Name	Molecular Formula	Structure	MW	pK_a	MP (°C)	BP (°C)	VP (mmHg @ 25 °C)	H_2O_{sol} (g/L)	Henry's Law ($atm \cdot m^3/mole$)	Log K_{ow}
41481-66-7	**bis-(3-allyl-4-hydroxyphenyl) sulfone**	**TGSA**	$C_{18}H_{18}O_4S$		330.40	8.3-8.5[a]	151-155	dec	9.2×10^{-10}	4.79	8×10^{-8a}	3.22
97042-18-7	**Phenol,4-[[4-(2-propen-1-yloxy)phenyl]sulfonyl]-**	**BPS-MAE**	$C_{15}H_{14}O_4S$		290.34	8.20[a]	172	>300[a]	$<1\times10^{-8}$ [a]	83[a]	$<1\times10^{-8}$ [a]	3.1
63134-33-8	**4-Hydroxy-4'-benzyloxydiphenylsulfone**	**BPS-MPE**	$C_{19}H_{16}O_4S$		340.40	8.2	170[c]	>300[a]	$<1\times10^{-8}$ [a]	10[a]	$<1\times10^{-8}$ [a]	3.9
95235-30-6	**4-hydroxyphenyl 4-isoprooxyphenylsulfone**	**D-8**	$C_{15}H_{16}O_4S$		292.35	8.2[a]	129	>300[a]	$<1\times10^{-8}$ [a]	21	$<1\times10^{-8}$ [a]	3.36
191680-83-8	**4-[4'-[(1'-methylethyloxy) phenyl]sulfonyl]phenol**	**D-90**	$C_{28}H_{26}O_9S_2$ (n = 1); $C_{44}H_{42}O_{14}S_3$ (n = 2)		570.6; 891.00	6.9-7.5[a]	ND	>300[a]	$<1\times10^{-8}$ [a]	0.54 [a]; $<1\times10^{-3}$ [a]	$<1\times10^{-8}$ [a]	3.8[a]; 5.9[a]
93589-69-6	**1,7-bis(4-Hydroxyphenylthio)-3,5-dioxaheptane**	**DD-70**	$C_{17}H_{20}O_4S_2$		352.5	9.6[a]	108	>300[a]	$<1\times10^{-8}$ [a]	130[a]	$<1\times10^{-8}$ [a]	3.4[a]
232938-43-1	**N-(p-Toluenesulfonyl)-N'-(3-p-toluenesulfonyloxyphenyl)urea**	**Pergafast 201**	$C_{21}H_{20}N_2O_6S_2$		460.5	12.5; 5.3; -3.8; -13.6[a]	157.7	250 (dec)	$<1\times10^{-8}$ [a]	35	$<1\times10^{-8}$ [a]	2.6
151882-81-4	**4,4'-bis(*N*-carbamoyl-4-methylbenzenesulfonamide)diphenylmethane**	**BTUM**	$C_{29}H_{28}N_4O_6S_2$		592.70	4.8-5.4[a]	154-156	>300[a]	$<1\times10^{-8}$ [a]	0.77	$<1\times10^{-8}$ [a]	2.61
321860-75-7	**Urea Urethane Compound**	**UU**	$C_{42}H_{36}N_6O_8S$		784.9[d]	10.3	ND	>300[a]	$<1\times10^{-8}$ [a]	$<1\times10^{-3}$	$<1\times10^{-8}$ [a]	6.5[a]

5.2 Potential Sources of Exposure in the Life-cycle of Thermal Paper

This section addresses potential releases and exposures throughout the life-cycle of thermal paper. Exposure pathways can be extremely complex. For example, the release of a chemical to the environment during manufacture and use could potentially lead to environmental contamination. The entry of chemicals into the environment may then lead to exposure of the general population to substances through the consumption of contaminated drinking water, contact with contaminated environmental media (e.g., soil, house dust, sediment, water), and/or the consumption of contaminated food. This section is not intended to be a comprehensive exposure assessment but instead is designed to offer readers a general overview of potential sources of exposure throughout the life-cycle of thermal paper. It is important to note that the sources of BPA and other developers are numerous, and it is often not known to what degree thermal paper is contributing to releases.

5.2.1 Manufacture of Developers

This section addresses potential exposure scenarios associated with the manufacture of BPA and alternative developers. Unit operations, operating conditions, transfer procedures, and packaging operations vary with the manufacture of different developers. Potential releases and occupational exposures will depend on each of these parameters. While it is outside the scope of this report to identify and quantify the releases and exposures associated with individual chemicals, this section presents a general description of typical chemical manufacturing processes and identifies potential releases.

Throughout the chemical manufacturing process, there are several release points that may pose an exposure risk to workers including packaging operations, leaks from pumps and tanks, fugitive emissions from equipment, cleaning of process equipment, and product sampling activities. Additionally, crude or finished products are often stored on site in drums, day-tanks, or more permanent storage vessels until the chemical is packaged and shipped to next user. Transfer and packaging operations, any routine and unplanned maintenance activities, and spills or accidents may result in releases of chemicals to environmental media, leading to general population exposures.

Potential release points from manufacturing and formulating can include:

- Transfer and packaging operations involving handling a chemical product;
- Routine and unplanned maintenance activities;
- Leaks from pumps and pipelines;
- Fugitive emissions from equipment;
- Product sampling;
- Transport and cleaning or equipment and storage vessels; and
- Accidental releases.

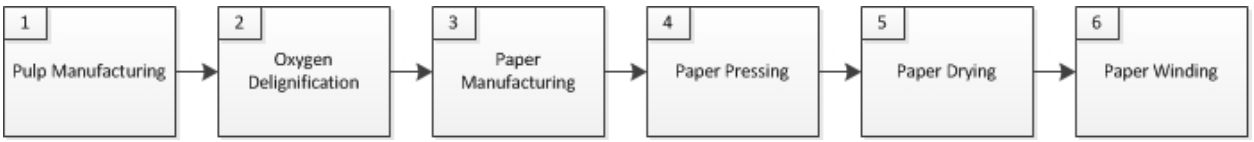
BPA is present in the environment as a result of direct releases from a variety of manufacturing or processing facilities (U.S. EPA 2010). BPA may also be present in the environment as a result of fugitive emissions during processing and handling, or a release of unreacted monomer from products (NTP-CERHR 2008). Workers may be exposed to BPA by inhalation or skin contact during the manufacture of BPA and BPA-containing products. A worst-case potential inhalation exposure to BPA during manufacturing is estimated at 100 μg/kg body weight/day (NTP-

CERHR 2008). The general population may be exposed to BPA through the contamination of drinking water or contact with contaminated environmental media. Alternative chemicals with similar physical/chemical properties are likely to result in similar exposure and release pathways.

5.2.2 Manufacture of Thermal Paper

A general manufacturing process for paper, in six major steps, is depicted in Figure 5-2 below (Evergreen Packaging 2011).

Figure 5-2: The Overall Paper Production Process

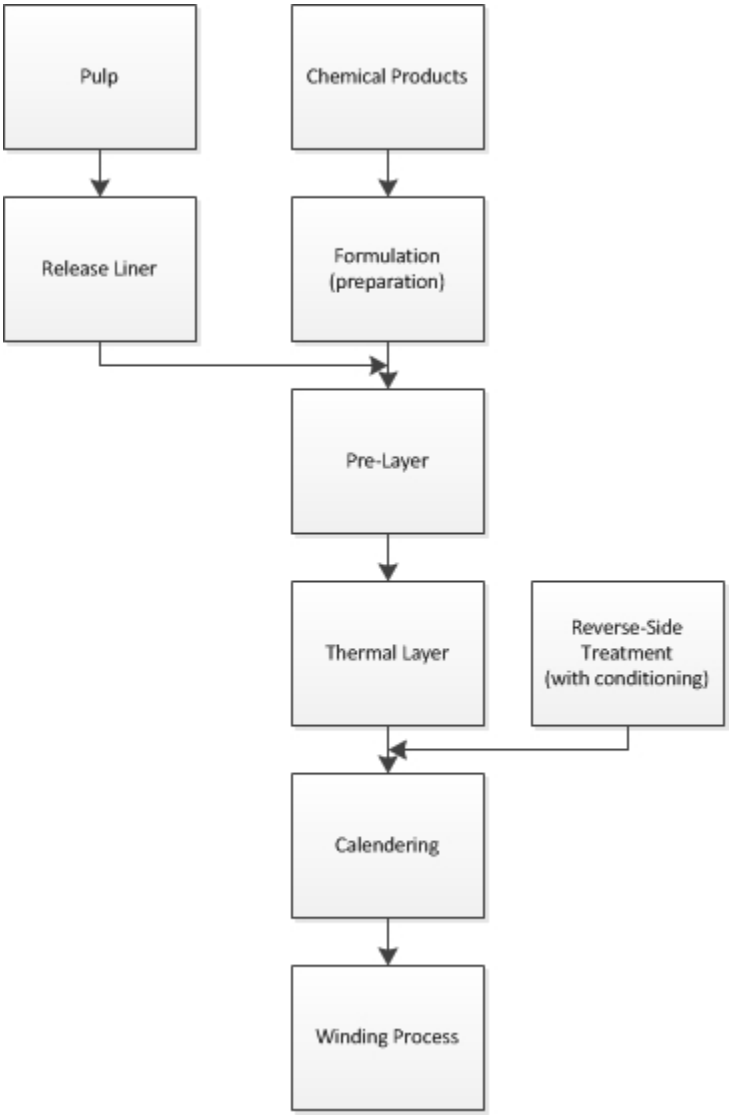


- The first step of the paper manufacturing process involves the generation of pulp. To accomplish this, wood chips and cooking liquor are mixed in a digester and heated. The wood chips are then expelled through the high-pressure digester, which breaks them up into individual fibers, or pulp.
- The oxygen delignification step next removes 40 to 50 percent of the lignin that remains in the pulp. The pulp is washed and bleached, which aids in the removal of the pulp's raw brown color.
- A large volume of water is then added in order to manufacture the paper. A slurry is created, with a pulp to water ratio of about 1 to 99. The slurry is moved on a moving wire mesh to form a uniform sheet. As the wet sheet travels along the wire, water drains through the wire mesh.
- This wet sheet is then moved onto a moving belt of felt where the sheet is pressed and squeezed in sections to compact the fibers.
- Once the fibers have been pressed, the sheet is moved onto dryer felts that pass over a series of heating rollers. Nine-five percent of the water is removed, leaving a small percentage of moisture to prevent cracking.
- Lastly, in the paper winding process, the paper is wound onto large reels, which are then cut into smaller rolls for convenient shipping and packaging.

The manufacture of thermal paper follows the same general manufacturing process as for non-specialty paper, with a few extra steps to incorporate additives in the formulation. The manufacturing process for thermal paper is shown below in Figure 5-3.

A release liner is added to the pulp prior to the coalescing of the thermal paper's multiple layers. This liner contains a release agent that provides a release effect against any type of sticky material. The various formulated layers (see Section 3.1), which contain the key additives in thermal paper (see Section 3.1.2), are pressed or calendered together between metal cylinders called calendars; this renders the paper's surface smooth. This step also defines the paper's texture: matte or glossy. The paper is then wound, bound, and shipped to product stores (see Section 5.2.3 for further details on the conversion process) (Torraspapel 2008).

Figure 5-3: The Production Process for Thermal Paper



Reference: (Torraspapel 2008)

Potential release points from paper manufacturing can include:

- Addition and handling of chemicals,
- Fugitive emissions from equipment, and
- Wastewater discharges.

The amount of thermal paper manufactured in Europe in 2005-2006 was approximately 370 million pounds of paper or an area of approximately 2.9 billion square yards (JRC-IHCP 2010). This value accounts for 4.2 million pounds of BPA. Similar statistics are not available for manufacture of thermal paper in the United States, or for the amounts of alternatives used in thermal paper.

Very little information exists regarding releases of BPA, or alternative developers, by paper manufacturers in the United States. BPA is listed under section 313 of the Emergency Planning

and Community Right-to-Know Act (EPCRA) of 1986. Under EPCRA, facilities with more than 10 employees, subject to Toxics Release Inventory (TRI) reporting requirements, that are manufacturing or processing more than 25,000 pounds of a listed chemical within a calendar year, or are using more than 10,000 pounds of a listed chemical within a calendar year, must report releases and transfers to the U.S. Environmental Protection Agency (EPA). None of the alternatives are TRI-listed chemicals. A review of TRI reporting for 2009 for BPA by paper companies (North American Industry Classification System (NAICS) Code 322) indicates two companies reporting: one that reported releases of 60 pounds for fugitive emissions, and another that reported total off-site transfers of 14,796 pounds (4,829 pounds transferred to treatment; 9,967 pounds transferred to a wastewater treatment facility) (U.S. EPA 2011b). Note that the TRI reporting for BPA in the paper industry is not specific to thermal paper, although it is likely that this is the dominant use in paper manufacturing.

5.2.3 Conversion of Thermal Paper

Once thermal paper is manufactured, it is then sent to a facility where it is converted into a specific paper application. During this conversion process, thermal paper is wound onto large rolls. If the paper is to be used for label applications, such as shipping labels or labels for deli food packaging, adhesives may be applied to the paper. (See Section 2.2 for additional applications of thermal paper.) The thermal paper is then cut into smaller rolls, packaged, and sent to product stores (Torraspapel 2008).

Potential release points from converting thermal paper can include:

- Addition or handling of chemicals, such as adhesives applied to labels,
- Cutting and packaging operations, and
- Fugitive emissions from equipment.

Up to 10 percent of thermal paper from European manufacturers, which manufacture an estimated three millions pounds of thermal paper annually (JRC-IHCP 2010), is removed during manufacturing as trimmings. This waste material, known as “broke,” is immediately sent to a recycling facility. Similar statistics are not available for U.S. thermal paper conversion industry.

5.2.4 Use of Thermal Paper

Thermal paper is used in a variety of applications. Most commonly this includes point-of-sale (POS) receipts, but it may also include tickets, labels, and medical applications. In its finished form, thermal paper may release chemicals, including developers such as BPA, via dermal contact. While thermal paper does not account for a large percentage of the production volume of BPA, unlike most applications, BPA in thermal paper is a free monomer and is not chemically bound; thus, it is expected that the free BPA in this use would be more readily available to humans and the environment (Zalko, Jacques et al. 2011). Studies show that BPA is transferred from thermal receipt paper to currency when they come in contact, suggesting thermal receipt paper is an important source of BPA in paper currency (Schreder 2010; Liao and Kannan 2011a). Braun, Kalkbrenner et al. (2011) found that, by occupation, cashiers had the highest relative BPA concentrations in their blood.

5.2.5 End-of-Life

After use, thermal paper has several end-of-life possibilities, including recycling, landfilling, and incineration, as well as abandonment. Limited information is available on the fate of BPA in thermal paper during end-of-life processes. No information is available on the other thermal paper developers. The European Union (EU) Risk Assessment Report for BPA included an analysis of thermal paper recycling and disposal practices that estimated that approximately 4 million pounds of BPA was used to produce thermal paper in 2005-2006, with 1.5 million pounds of BPA reaching paper recycling sites each year (JRC-IHCP 2010). In the EU, about 10 percent of thermal paper is sent for recycling when trimmed, with an additional 30 percent from commercial uses and consumer uses eventually ending up in the paper recycling stream (JRC-IHCP 2010). According to the EU report, BPA releases from paper recycling plants can vary greatly based on capacity and process differences, such as the de-inking and pulping processes, and the level of wastewater treatment. There is also some evidence from Europe that BPA is entering recycled paper streams, including consumer paper products such as towels and tissue paper (Vinggaard, Körner et al. 2000). It is expected that disposal practices in the EU differ from the United States because recycling and incineration are much more common in the EU. Information on U.S. practices is not available, but it is likely that recycled paper in the U.S. also contains BPA.

The concentration of BPA in paper processing wastewater effluent depends on the recycled paper treated. The concentration of BPA in the final effluent of 20 recycling facilities in Japan ranged from 0.2 to 370 μg/L (average of 59 μg/L) (Fukazawa, Watanabe et al. 2002). Effluents from facilities where only pulp was processed contained lower BPA concentrations.

Chlorinated BPA byproducts may be formed in secondary paper mills that use recycled paper feedstock containing thermal paper with BPA. BPA contaminants from recycled thermal paper can react with low concentrations of chlorine and sodium hypochlorite, which is added as a bleaching agent, yielding polychlorinated derivatives of BPA (Fukazawa, Watanabe et al. 2002). Chlorinated derivatives of BPA were detected at concentrations ranging from trace to 2.0 μg/L. Estrogenic activities of chlorinated derivatives of BPA were found to be relatively more potent than BPA, based on the yeast two-hybrid system assay (Fukazawa, Watanabe et al. 2002).

Post-use thermal paper that is sent to a landfill can contribute to leachate (i.e., the mixture of rainwater and contaminants within the waste). This leachate has the potential to seep into the ground or drain into nearby surface water, transporting chemicals to places where humans and wildlife might be exposed to them. For example, there is concern that free monomeric BPA can leach out of thermal paper and contaminate landfill leachate. Gehring et al. (2004) concluded that continuous emissions of BPA from leachate from landfills receiving significant amounts of wastepaper can occur under anaerobic conditions. Although no data are available, the same concern would exist for alternatives to BPA, depending on their suitability to anaerobic degradation and transport processes.

5.2.6 Manufacture of Recycled Paper Products

Several researchers have analyzed the BPA content in recycled paper products. Gehring et al. examined various sources of recycled paper collected in the city of Dresden, Germany (2004). Samples included toilet paper, imported cellulose, and various types of post-use paper stock including brown/grey corrugated board, advertising supplements, magazines, catalogues,

newspapers, free advertising papers, and chromo board. Of the types of recycled products analyzed, Gehring et al. found the most significant levels of BPA in toilet paper. The amount of BPA in toilet paper derived from recycled paper varied greatly, ranging from 3.2 to 41.1 mg/kg dry matter (2004). Gehring et al. also demonstrated that BPA in toilet paper also results in significant emission of the chemical into domestic wastewater, contributing about 36,000 pounds of BPA to wastewater annually (2004).

Other sources of BPA in recycled paper products include paper and paperboard commonly used for food packaging. These products are often adapted to directly contact foodstuff. According to a study conducted by Ozaki et al. (2004), 67 percent of the recycled paper analyzed contained BPA (0.19-26 μg/g) (2004). BPA was also detected in virgin paper products; however, its concentrations were ten-fold higher in recycled paper products (Ozaki, Yamaguchi et al. 2004). Similarly, Vinggaard et al. (2000) analyzed BPA levels in 20 different brands of paper towels sold in retail shops in Denmark. Results indicated that paper towels manufactured from recycled paper contained 0.6 to 24 mg/kg of BPA whereas extracts from virgin paper contained negligible levels. Although no data are available, it is likely that alternatives to BPA would also be present in recycled paper products.

5.3 Available Data on Occupational, Consumer, and Environmental Exposures to BPA, Thermal Paper Life-cycle

A quantitative exposure assessment is outside the scope of this project and not necessary for comparative hazard assessment. However, this section presents information on the levels of human and environmental exposures to developers in thermal paper that have already been published in the literature. Most published studies pertain to BPA, but chemicals with similar physical/chemical and environmental properties can be expected to behave similarly.

5.3.1 BPA in Receipts

As discussed in Chapter 2, BPA is widely used as a developer in thermal paper, including receipts. Several studies evaluated the presence of BPA in thermal paper, noting that alternatives to BPA are currently on the market. In one study, BPA was detected at levels up to 2.2 percent of the total weight in 11 of the 22 POS receipts sampled, but half of the receipts were BPA-free (Biedermann, Tschudin et al. 2010). Mendum et al. (2011) likewise found BPA in 8 of 10 receipts tested with levels ranging from 0.3-1.54 percent of the total weight.

The Environmental Working Group (EWG) conducted a similar study to determine BPA levels in cash register receipts. Of the 36 receipts tested, 16 contained BPA in levels from 0.8 percent to 2.8 percent (Lunder, Andrews et al. 2010). The Washington Toxics Coalition found BPA in 11 of the 22 receipts it tested (Schreder 2010). The study also found BPA in 21 of the 22 dollar bills it tested, concluding that BPA travels from receipts to other objects.

Liao and Kannan studied levels of BPA in paper currency from 21 countries (2011a). BPA was found in all paper currencies analyzed at concentrations ranging from 0.001 to 82.7 μg/g (equal to 0.000001 to 0.0827 mg/g). They also found that concentrations of BPA increased after 24 hours of contact with thermal paper, which suggests that thermal paper is a major source of BPA in paper currency bills. Liao and Kannan conducted a similar study that found BPA in 94 percent of receipts tested at a geometric mean level of 0.211 mg/g (Liao and Kannan 2011b). Other paper products tested, such as napkins and toilet paper made from recycled paper, contained BPA at

microgram-per-gram concentrations, and the authors concluded that contamination during the paper recycling process is a source of BPA in paper products.

5.3.2 Bisphenol S (BPS) in Receipts

Liao, Liu et al. (2012b) also evaluated levels of BPS in 16 types of paper and paper products and paper currency from 21 countries. BPS was found in all thermal receipt paper samples at concentrations ranging from 0.0000138 to 22.0 mg/g. BPS was detected in 14 other types of paper products, such as napkins and toilet paper, at concentrations ranging from the level of quantitation to 0.00838 mg/g. BPS was found in 87 percent of paper currencies analyzed at concentrations ranging from the limit of quantitation to 0.00626 mg/g.

5.3.3 BPA Transfer to Skin and Potential for Dermal Absorption

Releases of free BPA monomers in thermal paper can occur upon contact with the paper and can be subsequently absorbed into the skin, leading to exposure during handling and use. Several studies have analyzed such releases of BPA, particularly in POS receipts. Biedermann et al. (2010) demonstrated that BPA can be extracted from the receipts and has the potential to be absorbed in the skin upon contact. The researchers founds that two hours after contact, about 0.17 µg (equal to 0.00017 mg) BPA migrated into the skin, such that it could not be recovered by washing with water.

Zalko, Jacques et al. (2011) demonstrated that BPA can penetrate the skin under experimental conditions. Applying BPA to pig and human explants demonstrated that only two percent of the BPA remained on the skin surface; nearly half of the chemical passed completely through the skin and the rest persisted in the skin after 72 hours. There is also evidence that enzymes located in the skin glucuronidate BPA (Zalko, Jacques et al. 2011), a mechanism that facilitates elimination.

5.3.4 Occupational Exposure

Occupational exposures may occur during the manufacture of developers, the manufacture of thermal paper, or the handling of thermal paper. There is limited information on worker exposures to BPA during chemical manufacture. A series of studies conducted by Li and colleagues suggests a relationship between exposure to BPA and reproductive and developmental effects in Chinese workers in the BPA and epoxy manufacturing industry (Li, Zhou et al. 2010; Li, Zhou et al. 2011; Miao, Yuan et al. 2011); however, similar studies are not available for U.S. manufacturers of BPA. To our knowledge, there are no studies examining BPA exposures in thermal paper manufacturing.

Occupational exposure to BPA may come from handling receipts. Biedermann et al. (2010) estimated that repeated handling of thermal paper containing BPA could result in transfer of up to 71 µg/day (equal to 0.071 mg/day), which is well below 3,000 µg/day (equal to 3 mg/day), a value derived by Biederman et al. from the present total daily intake (TDI)[1] of 0.050 mg/kg bw/day, assuming 60 kg body weight. Liao and Kannan estimated that mean daily intake (MDI)

[1] TDI is a protective estimate of the amount of a chemical substance humans can be exposed to daily basis over the course of a lifetime without experiencing significant health risk. The TDI value set by the European Food Safety Authority (EFSA) for BPA is 0.05 mg/kg bw. More information about EFSA and BPA can be found at: http://www.efsa.europa.eu/en/topics/topic/bisphenol.htm.

of BPA through dermal absorption in adults handling thermal paper was 921 ng/day (equal to 0.000921 mg/day) for occupationally exposed individuals (2011b), significantly lower than the estimates of Biederman et al. The cumulative occupational exposure from handling a variety of thermal paper products was estimated to be 1,303 ng/day (equal to 0.001303 mg/day) (Liao and Kannan 2011b). Liao and Kannan (2011a) also estimated that the MDI of BPA from handling U.S. paper currency to be 1.02 ng/day (equal to 0.00000102 mg/day) for occupationally exposed individuals in the United States.

In one U.S. study, pregnant women who worked as cashiers, who presumably had frequent contact with thermal paper used in cash register receipts, had the highest urinary BPA concentrations at 2.8 µg/g (equal to 0.0028 mg/g) compared with pregnant women in other occupations, including 1.8 µg/g (equal to 0.0018 mg/g) in teachers and 1.2 µg/g (equal to 0.0012 mg/g) in industrial workers (Braun, Kalkbrenner et al. 2011).

To date, one study has estimated the MDI of BPS from handling paper products and currency. Liao, Liu et al. (2012b) estimated that MDI of BPS through dermal absorption in adults handling paper products and paper currency was 789 ng/day (equal to 0.000789 mg/day) for occupationally exposed individuals.

5.3.5 Consumer and General Population Exposure

Several studies have estimated consumer and/or general population exposures. This section provides an overview of this research. Based on BPA concentrations in thermal paper, the Washington Toxics Coalition estimated that an average shopper would transfer approximately 30 µg (equal to 0.030 mg) of BPA to the skin by rubbing a receipt (five times between two fingers and a thumb) (Schreder 2010). Liao and Kannan (2011b) estimated that the MDI of BPA, via handling of thermal paper to be 12.3 ng/day (equal to 0.0000123 mg/day) for the general population (2011b). Liao and Kannan (2011a) also estimated that the MDI of BPA from handling paper currency to be 0.102 ng/day (equal to 0.000000102 mg/day) for the general population in the United States.

Although BPA exposure from dietary sources is estimated to be much greater, thermal paper accounted for more than 98 percent of the exposure from paper products, mainly because thermal receipt papers contain relatively high concentrations of BPA (Liao and Kannan 2011b). BPA is also used in numerous other applications with which consumers and the general public come into contact on a regular basis, contributing to exposure. Measured levels of urinary BPA reflect these complex exposure patterns.

The Centers for Disease Control (CDC) reported that 95 percent of a sample size of 294 Americans had detectable levels of BPA in their urine (Calafat, Ye et al. 2008). The median concentration of BPA in urine across all ages was found to be 2.7 ng/mL (equal to 0.0000027 mg/mL) (uncorrected for creatinine) (Calafat, Ye et al. 2008). Based on currently available exposure data, BPA exposures appear to be higher in infants and children (NTP-CERHR 2008). Two studies evaluating exposure in children based on the National Health and Nutrition Examination Survey indicate that children ages 6-11 have higher exposures relative to adults (LaKind and Naiman 2008; LaKind and Naiman 2011).

Subsequent studies have sought to clarify sources of BPA exposures in children. In one recent study, Morgan, Jones et al. (2011) quantified urinary total BPA in 81 Ohio preschool children

ages 23-64 months over 48-hours. This study found the BPA intake through diet correlated with urinary excretion, suggesting that diet is the predominant source. The study authors estimated mean intake of 156.5 ng/kg/day (equal to 0.0001565 mg/kg/day) through dietary ingestion, and 0.11 ng/kg/day (equal to 0.00000011 mg/kg/day) through non-dietary ingestion. The data were in agreement with an earlier study in which dietary ingestion through the consumption of both solid and liquid foods was shown to be the major route of exposure for 257 preschool children to BPA at their homes and daycare centers in North Carolina and Ohio (Wilson, Chuang et al. 2007).

BPA is also found in breast milk; in a study of 23 healthy women, all breast milk samples registered positive for BPA (Sun, Irie et al. 2004). Additionally, the presence of BPA has been documented in human amniotic fluid (Ikezuki, Tsutsumi et al. 2002), although there is controversy regarding the ability of the fetus to metabolize BPA (Nishikawa, Iwano et al. 2010; Doerge, Twaddle et al. 2011), which would influence the concentration of free and glucuronidated BPA in this compartment.

To date, one study has estimated the MDI of BPS from handling paper products and currency. Liao, Liu et al. (2012b) estimated that MDI of BPS through dermal absorption in adults handling paper products and paper currency was 12.0 ng/day (equal to 0.000012 mg/day) for the general population. The results of this study suggest that other alternatives with similar physical/chemical properties and behavior would also transfer from the surface of thermal paper at least to the surface of skin, and potentially be absorbed through the skin or ingested.

Another study reported exposure to bisphenol S based on urinary measurements (Liao, Liu et al. 2012a). BPS was detected in 81% of the urine samples collected from 315 individuals in eight countries. The mean value in the U.S. was reported as 0.299 ng/ml (equal to 0.000000299 mg/ml). Using a pharmokinetic model, the authors estimated that the median estimated daily intake of BPS associated with these urinary values is 0.316 µg/person (equal to 0.000316 mg/person).

5.3.6 Environmental Exposure

As noted above, there are releases and transfers of BPA from the paper sector that are reportable to TRI. The relationship between these releases and transfers and environmental concentrations is not known. There are several studies on concentrations of BPA in the environment (Klecka, Staples et al. 2009). BPA is present in the environment as a result of direct releases and fugitive emissions from a variety of manufacturing or processing facilities (U.S. EPA 2011a). In addition, based on information from European and Japanese studies, the use of monomeric BPA in thermal paper also may contribute to environmental releases of BPA from paper manufacturing and recycling plants and to the presence of BPA in the stream of recycled paper used in toilet paper, paper tableware, and other products, and may contribute to the presence of BPA in landfills because paper products are a major contributor to the U.S. solid waste stream (JRC-IHCP 2010; Vinggaard, Körner et al. 2000; Fukazawa, Hoshino et al. 2001; Gehring, Vogel et al. 2004; Ozaki, Yamaguchi et al. 2004; Terasaki, Shiraishi et al. 2007). Liao and Kannan estimated that between 33.5 tons (based on the median concentration of BPA in thermal paper) and 1,040 tons (based on the 95th percentile) are released into the environment per year in the United States and Canada through the disposal of thermal receipt papers (2011b). The following paragraphs provide a brief overview of some of the available studies of BPA in environmental media.

Surface Water: Most environmental monitoring results show that the concentrations of BPA in surface water bodies are lower than 1 µg/L (ppb), mainly due to its partitioning and biodegradability (Tsai 2006). Current predicted no effect concentrations (PNEC) for ecological organisms are 1.5 µg/L (EU), 1.6 µg/L (Japan), and 0.175 µg/L (Canada) (U.S. EPA 2010). BPA was detected at a median concentration of 0.14 µg/L (ppb) and a maximum concentration of 12 µg/L (ppb) in 41.2 percent of 85 samples collected from U.S. streams in 1999 and 2000, although the authors suggest that the maximum concentration of 12 µg/L (ppb) may be an outlier as it was much higher than any of the other samples (Kolpin, Furlong et al. 2002). A recent review of BPA monitoring studies found that out of 26 studies in North America (2 in Canada and 24 in the United States), 80 percent (852 of 1,068) of surface water samples reported BPA concentrations below the detection limit. The median concentration reported was 0.081 µg/L (ppb) and the 95th percentile concentration was 0.47 µg/L (ppb) (Klecka, Staples et al. 2009).

Wastewater: Two studies have addressed individual WWTPs; BPA was not detected above the detection limit of 0.0001 µg/L (ppb) in Louisiana in effluent from a WWTP, in samples collected from surface waters in Louisiana, or in drinking water at various stages of treatment at plants in Louisiana (Boyd, Reemtsma et al. 2003). A California study detected BPA in two of three treated wastewater samples at 0.38 and 0.31 µg/L (ppb) (limit of detection = 0.25 µg/L (ppb)) (Jackson and Sutton 2008). It also reported detecting BPA in wastewater generated by a pharmaceutical manufacturer (0.295 µg/L (ppb)), an industrial laundry (21.5 µg/L (ppb)), and a paper products manufacturer (0.753 µg/L (ppb)).

A Canadian study reported BPA concentrations ranging from 0.031 to 49.9 µg/L (ppb) in sewage influent and effluent (generally <1 µg/L (ppb) in the influent and <0.3 µg/ L (ppb) in the effluent) and from 0.104 to 36.7 µg/g (ppm) in raw and digested sewage sludge from multiple WWTPs in Canada (Lee and Peart 2000b). The same authors reported that BPA was detected in 100 percent of sewage samples from 31 WWTPs across Canada with concentrations ranging from 0.080 to 4.98 µg/L (ppb) (median 0.329 µg/L (ppb)) for the influent and from 0.010 to 1.08 µg/L (ppb)(median 0.136 µg/L (ppb)) for the effluent (Lee and Peart 2000a). Based on comparison of influent and effluent levels, they estimated that BPA in the influent was removed by the sewage treatment process with a median reduction rate of 68 percent. BPA was detected in sludge samples at concentrations ranging from 0.033 to 36.7 µg/g (ppm) on a dry weight basis. A wide range of BPA was detected in wastewater discharges from industrial facilities with concentrations ranging from 0.23 to 149.2 µg/L (ppb). Higher BPA levels in wastewater were associated with facilities producing chemicals and chemical products and packaging and paper products, and with commercial dry cleaning establishments. BPA concentrations in pulp and paper mill sludge ranged from <0.02 (below detection limit) to 3.33 µg/g (ppm), with a median value of 0.076 µg/g (ppm), on a dry weight basis (Lee and Peart 2000a; Melcer and Klecka 2011).

WWTP Biosolids: One recent study measured BPA in biosolids (treated municipal waste sewage sludge) products from WWTPs in seven states and found concentrations between 1,090 and 14,400 µg/kg (ppb) BPA (median 4,690 µg/kg (ppb)) (Kinney, Furlong et al. 2006). Another study reported BPA in treated biosolids from a single municipal U.S. WWTP at 4,600 µg/kg (ppb) and reported 81µg/ kg (ppb) in soil that received the land applied biosolids, and concentrations of 147µg/ kg (ppb) in a nearby "control" soil that did not receive treatment with biosolids (Kinney, Furlong et al. 2008). That study also detected BPA at 81 µg/kg (ppb) in earthworms living in treated soil. A separate study conducted by Staples, Friederich et al. (2010)

investigated the risk of BPA in sludge-amended soil to invertebrates and plants at the bottom of the terrestrial food chain. The risks for adverse effects to potworms, springtails, and six plant species were found to be low based on hazard quotient values that were ≤0.04 (Staples, Friederich et al. 2010)

Groundwater: The U.S. Geological Survey (USGS) collected samples from 47 ambient groundwater sites (not drinking water wells) in 18 States and analyzed them for 65 organic wastewater contaminants. BPA was detected in 29.8 percent of the sampled groundwater sites, with a mean detected concentration of 1.78 µg/L (ppb) and a range of 1.06 to 2.55 µg/L (ppb). BPA was among the top five most frequently detected organic compounds in this study (Barnes, Kolpin et al. 2008a; Barnes, Kolpin et al. 2008b). The analysis of BPA concentrations in areas that were known or suspected to have at least some human and/or animal wastewater sources in upstream or upgradient areas detected BPA in 9.5 percent of the samples at a reporting level of 1 µg/L (ppb). The maximum concentration of BPA measured in these samples was 1.9 µg/ L (ppb) (Barnes, Kolpin et al. 2008a; Focazio, Kolpin et al. 2008).

Landfill Leachate: BPA has been detected in landfill leachate with maximum concentrations of 1.7 µg/L (ppb) and 1.4 µg/L (ppb) in the receiving groundwater plume at a landfill that was known to be leaking (Rudel, Melly et al. 1998). Data for other landfill sites in the United States were not available, and this single point is not likely to be representative of the country. Landfill leachate measured in other countries contained more than 500 µg/L (ppb) of BPA (Tsai 2006). Studies conducted at Japanese landfills resulted in maximum untreated leachate concentrations of 17,200 µg/L (ppb) and treated leachate concentrations of 5.1 µg/L (ppb) (Crain, Eriksen et al. 2007).

Soil: Wilson et al. reported that BPA concentrations in soil samples taken from outdoor play areas of homes and daycare centers ranged from 4-14 ppb dry weight, with means of 6-7 ppb dry weight (2003). Klecka et al. reported a median concentration of 0.6 ppb BPA in North American freshwater sediments, including samples with measurements below the detection limit; BPA concentrations in samples from the United States ranged from 1.4 to 140 ppb dry weight (2009). Levels in U.S. marine sediments were reported to have a median of 3.5 ppb of BPA and to range from 1.5 to 5 ppb dry weight (Stuart, Capulong et al. 2005).

No data have been reported on releases to the environment for any of the alternative developers. However, it is possible that alternatives will be released to the environment during the thermal paper life-cycle. This is particularly true of alternatives with physicochemical properties that are similar to BPA.

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