Bisphenol A Alternatives in Thermal Paper

Chapter 6

Considerations for Selecting Thermal Paper Developers

FINAL REPORT

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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

6. Considerations for Selecting Thermal Paper Developers

Selecting an appropriate developer for use in the manufacture of thermal paper involves consideration of a range of factors. Design for the Environment (DfE) Alternatives Assessments provide information on chemical hazards and discuss other factors relevant to substitution decisions, such as use information, exposure considerations, cost and performance. Decision-makers will likely supplement the human health and environmental information in this report with these other factors.

This chapter begins by describing five general attributes evaluated in this assessment that can inform decision-making about chemical hazards: human health hazard, ecotoxicity, persistence, bioaccumulation, and exposure potential. It provides a discussion of data gaps in the full characterization of chemicals included in this assessment. Performance, economic, and social considerations are also briefly addressed. This chapter concludes by discussing interim risk management measures that may be relevant for instances in which alternatives are associated with trade-offs, and by providing additional resources related to state, federal, and international regulations, and available life-cycle assessment information.

6.1 Human Health and Environmental Considerations

This section identifies a set of attributes for consideration when formulating or selecting alternative thermal paper developers. In general, a safer chemical has low human health hazard, low exposure potential, low ecotoxicity, rapid degradability, and low potential for bioaccumulation.

6.1.1 Human Health Hazard

The DfE Alternatives Assessment criteria address a consistent and comprehensive list of hazard endpoints (U.S. EPA 2011). Chemical hazards to human health include acute lethality, carcinogenicity, genotoxicity, reproductive and developmental toxicity, neurotoxicity, repeated dose toxicity, skin and respiratory sensitization, irritation/corrosivity, and endocrine activity. DfE criteria for most of these endpoints involve thresholds establishing levels of concern. Where data for certain endpoints were not available, hazard values were assigned using structure-activity modeling and professional judgment.

Several of the chemicals evaluated in this assessment are structurally similar to either bisphenol A (BPA) or bisphenol S, resulting in similar human health hazard profiles. Some general trends based on the information provided in Chapter 4 include: all chemicals exhibit low concern for acute toxicity; and most chemicals exhibit low to moderate concern for carcinogenicity, genotoxicity, repeated dose toxicity, irritation, and sensitization; however an important caveat is that most hazard designations are based on modeled data and expert judgment. There are some opportunities for distinction based on reproductive and developmental toxicity. With lower absorption, systemic effects are not as likely.

6.1.2 Ecotoxicity

Ecotoxicity includes adverse effects observed in wildlife, discussed in detail in Section 4.5.1. Aquatic organisms have historically been the focus of this endpoint.[1] Industry and government chemical reviews have traditionally focused on fish, aquatic invertebrates, and algae. Both acute and chronic aquatic toxicity should be considered in choosing a developer for use in thermal paper. Where data or expert knowledge is available, ecotoxic effects on other classes of animals and plants should be included in the hazard evaluation. Data from standard laboratory animals presented in respect to human health attributes can also be relevant to wildlife. To prevent concerns for higher trophic level organisms, bioaccumulation potential (Section 6.1.4) is an important consideration for substitution decisions.

For the thermal paper developers evaluated in this report, acute and chronic aquatic toxicity are variable, and thus may present an opportunity for distinction among the alternatives.

6.1.3 Persistence

Persistence describes the tendency of a chemical to resist degradation and removal from environmental media, such as air, water, soil, and sediment. This is an important characteristic for chemicals used in thermal paper, as the paper may be recycled with potential releases to the environment. Chemical degradation in the environment either occurs through chemical reactivity with its surroundings or through biodegradation by microorganisms. Chemical reactivity is most commonly a result of hydrolysis (reactions with water) and photolysis (reactions with sunlight). Oxidative gas-phase processes may also play a role. In the absence of rapid chemical reactivity, biodegradation is the primary process that causes degradation. The destruction of a chemical by biodegradation is accomplished by the action of a living organism. Depending on the organism and chemical substrate combination, chemicals may degrade into other chemical substances (primary degradation) or may be completely mineralized into carbon dioxide and water (ultimate degradation).

The rate of degradation is important, but equally important are the byproducts formed through the degradation process. In some cases, the products of biodegradation might be more toxic and persistent than the parent compound.

For the thermal paper developers evaluated in this report, persistence is variable and may be an opportunity for distinction among the alternatives (see Chapter 4).

6.1.4 Bioaccumulation Potential

The ability of a chemical to accumulate in living organisms is described by the bioconcentration, bioaccumulation, biomagnification, and/or trophic magnification factors. Most of the alternatives assessed in this report have been assessed as having Low to Moderate potential for bioaccumulation, but nearly all of the assessments are based on computer models. Based on structure activity relationships (SARs), the potential for a molecule to be absorbed by an organism tends to be lower when the molecule is larger than 1,000 daltons. None of the chemicals in this assessment meet this threshold. Note that care should be taken not to consider

[1] Aquatic organisms became the focus of ecotoxicology assessments for several reasons: releases to water were a prominent concern, data were more abundant, and hence computer models were developed based on aquatic organisms.

the 1,000 daltons size to be an absolute threshold for absorption – biological systems are dynamic and even relatively large chemicals may be absorbed under certain conditions.

The test guidelines available to predict potential for bioaccumulation have some limitations. Bioconcentration tests tend to be limited for chemicals that have low water solubility (hydrophobic). Even if performed properly, a bioconcentration test may not adequately measure bioaccumulation potential because bioaccumulation is a measure of all uptake, while most bioconcentration tests do not currently measure dietary uptake (i.e., uptake by fish via food versus via their gills, respectively). Under review in the Organisation for Economic Cooperation and Development (OECD) program and close to finalization is a major upgrade to the fish bioconcentration test, in which dietary uptake is included for the first time. Dietary uptake is of critical importance and is probably the dominant route of exposure for hydrophobic chemicals.

For the thermal paper developers evaluated in this report, bioaccumulation concerns generally fall within the Low to Moderate range (see Chapter 4).

6.1.5 Exposure Considerations

For humans, chemical exposures may occur at different points throughout the chemical and product life-cycle through skin contact, by inhalation, and by ingestion, and exposures are affected by multiple physicochemical factors, as discussed in Chapter 5. The DfE Alternatives Assessment begins with the assumption that exposure scenarios for chemicals and their alternatives within a functional use class are roughly equivalent. The assessment also recognizes that in some instances, chemical properties or use patterns may affect exposure scenarios. For example, some BPA alternatives may require different amounts to achieve the same technical specifications. Stakeholders should evaluate whether manufacturing changes, life-cycle considerations, and physicochemical properties will result in different patterns of exposure as a result of informed chemical substitution. In general, the chemicals included in this assessment have similar physicochemical parameters, and their use as developers is roughly equivalent. Therefore, exposure patterns are expected to be similar.

6.2 Considerations for Poorly or Incompletely Characterized Chemicals and Variable Amounts of Data

For most industrial chemicals, experimental data for hazard characterization are limited. For chemicals in this report without full data sets, analogs, SAR modeling, and expert judgment were used. More information on predicted hazard levels can be found in Chapter 4. Estimated values in the report can be used to prioritize testing needs.

Several chemicals included in this analysis appear to have more preferable profiles, with Low human health and ecotoxicity endpoints (see Chapter 4). However, because no chemical-specific empirical data were available, their hazard evaluations were entirely predicted based on SARs, analogs, and expert judgment. Empirical data will allow for a more robust assessment that will support expert judgments and we therefore strongly encourage additional studies to fill these data gaps.

In the absence of measured data, users of this alternatives assessment should be cautious in the interpretation of hazard profiles. For chemicals without data, developing data would prevent unexpected consequences if a prediction did not hold true. If chemicals are used at higher volumes, or are likely to be used at higher volumes in the future, this fact should also be given weight when considering data needs. Decision-makers should proceed with caution and are advised to read the full hazard assessments for each chemical (see Chapter 4) which may inform whether additional testing is needed.

Where hazard characterizations are based on measured data, there are often cases where the amount of test data supporting the hazard rating varies considerably between alternative chemicals. In Table 4-4, the hazard characterizations based on SAR or expert judgment are listed in ***black italics***, while those with hazard characterizations based on measured test data are listed in **bold** **color**. The amount of measured test data available to inform the evaluation of endpoints can vary from only one study to many studies in many species with different routes of exposure and exposure duration. In some instances, testing may go beyond basic guideline studies, and it can be difficult to compare data for such chemicals against those with only a single guideline study, even though hazard designations for both chemicals are "based on empirical data" and thus come with a higher level of confidence.

Comparisons between a chemical with only one study and a second chemical with many studies are complex and merit careful consideration. For hazard screening assessments, such as the DfE approach, a single adequate study can be sufficient to provide a hazard rating. Therefore, some ratings reflect assessment based on one study, while others reflect assessment based on multiple studies of different design. The hazard rating does not convey these differences – the full hazard profile should be consulted to understand the limitations of the available data.

6.3 Performance Considerations

This section identifies general performance attributes that companies can consider when formulating or selecting alternative chemicals. These attributes are critical to the overall function and marketability of the chemicals and can be considered jointly with economic considerations and the human health and environmental attributes described above.

Known thermal paper developers are typically organic or organometallic compounds that have the following physical properties: low water solubility, substantially colorless, odorless, and chemically inert towards water and oxygen over a pH range from 6 to 10 (D. Keller, personal communication, December 1, 2011).

As discussed in Chapter 3, performance characteristics of effective developers in thermal paper include:

- Appropriate acidity, such that it produces no background imaging;
- Ability to fully react with the colorformer when heated;
- Reaction at the temperature of the specific printer;
- Stable at end use temperatures;
- Appropriate level of permanence for the application;
- Appropriate performance vs. cost balance; and
- Feasibility for large-scale production.

In considering alternative formulations or chemical substitutions, decision-makers will need to consider the pH, temperature, and water solubility of the developer, as well as the stability and durability of the resulting image. The following conditions may limit the durability of thermal images: exposure to temperatures greater than 40˚C, wet environments, direct sunlight, and certain chemicals such as alcohol, fuels, and oils (Koehler Thermal Papers 2011). However, depending on the grade, thermal papers can retain their image integrity even in conditions of bright lights, moisture, scuffing, and high temperatures up to 180˚F (Appleton 2003).

In addition to considering the hazard information provided in Chapter 4 and the performance characteristics described above, other considerations include:

- **Printer Compatibility:** Modifications to thermal paper manufacture, either to developers or more broadly to other chemistry or process, should require consideration of how these changes may affect compatibility with existing thermal printers or what changes to printer technology or re-design may be required as a result.
- **Compatibility with End Use:** Specific developers and types of thermal paper are used for specific applications, depending on performance, design, and economic considerations. Direct thermal paper can be used in a wide range of applications, including amusement park tickets, produce labels, retail hang tags, ski lift tickets, baggage tags, mass transit tickets, parking receipts, and lottery tickets (Appleton 2011). Modifications to thermal paper design would require consideration of appropriateness for specific end uses.
- **Appropriate Image Quality:** Alternatives should ensure appropriate image quality at the time of printing and stability for the required time period. Thermal images have sufficient resolutions for printing of text, graphics, and barcodes. Depending on grade, image integrity can last up to 10 years (Appleton 2003; Koehler Thermal Papers 2011).

6.4 Economic Considerations

This section identifies economic attributes that companies can consider when formulating or selecting alternative chemicals. A comprehensive consideration of economic factors is often more fully addressed by decision-makers within the context of their companies or organizations. Accurate cost estimations are company-specific, and the impact of substituting chemicals on complex product formulations can only be analyzed using in-house data that is likely to be business confidential. A company should determine for itself how changes will impact market share or other business factors. Cost considerations may be relevant across the chemical and/or product life-cycle. These attributes are critical to the overall function and marketability of alternatives and can be considered jointly with performance attributes and human health and environmental attributes.

To ensure economic viability, alternatives should be easy to process and cost-effective to integrate into products. The most desirable alternatives are compatible with existing process equipment and can be integrated in existing products. If this compatibility is not available, manufacturers will need to modify their processes and potentially purchase new equipment. From an economic standpoint, the ideal alternative would be a drop-in replacement that has similar physical and chemical properties such that existing storage and transfer equipment as well as manufacturing technologies could be used without significant modification. However, chemicals with similar physical and chemical properties may have similar hazard and exposure profiles.

Substituting chemicals can involve significant costs, as industries may need to adapt their production processes and have products re-tested for all required performance and product standards. Decision-makers are advised to see informed chemical substitution decisions as long-term investments and to replace the use of BPA with a chemical they anticipate using for many years to come. This includes attention to potential future regulatory actions as well as market trends.

Alternatives that are either more expensive per pound or require more chemical per unit area to be functional will increase costs. In this situation, the cost of a chemical that must be used at a higher application rate may be passed on to customers, who will subsequently pass the cost on to consumers. In some cases, the price premium may diminish over the different stages of the value chain.

Some of the alternative chemicals assessed in this report are currently manufactured in high volume. Others are not currently available in quantities that would allow for immediate widespread use. Prices and availability are likely to change with an increase in demand.

Handling, disposal, and treatment costs may be important considerations when evaluating alternatives. Inherently high hazard chemicals may require special engineering controls and worker protections that are not required of less hazardous alternatives. Disposal costs for high hazard chemicals may also be greater than for low hazard alternatives. High hazard chemicals may be more likely to result in unanticipated cleanup requirements should risk management protections fail or unanticipated exposures or spills occur. Additionally, some chemicals may require specific treatment technologies prior to discharge through wastewater treatment systems. These costs can be balanced against the up-front costs for the purchase of the alternative chemical, new equipment, etc. Finally, initial chemical substitution expenses may reduce future costs of mitigating consumer concerns and perceptions related to hazardous chemicals.

6.5 Social Considerations

Decision-makers should be mindful of a number of social considerations when choosing alternative chemicals. This section highlights occupational, consumer, and environmental justice considerations. Stakeholders may identify additional social considerationsfor application to their own decision-making processes.

Awareness of social considerations related to informed substitutions includes attention to participation in decision-making processes, the impacts of human behaviors on the implementation or on outcomes of interventions, and the distributions of impacts across populations. Social considerations are one of the three pillars of sustainability (National Academy of Sciences 2011) and a focus on sustainability recognizes that human and environmental systems are coupled and interdependent (Clark 2007). Decisions should be made to maximize social, environmental, and economic benefits and to minimize the adverse effects of conflicts between these areas. According to the National Academy of Sciences report on “Sustainability and the U.S. EPA” (2011), the U.S. Environmental Protection Agency (EPA) would benefit from working with stakeholders to develop robust indicators for these attributes.

Occupational considerations: Some stakeholders have raised concerns for differential exposure to BPA based on occupation. In particular, some partners noted that cashier jobs are often held by young women of childbearing age, who may experience greater exposures to BPA due to frequent handling of thermal paper receipts. Existing research reinforces these concerns (see Section 5.3.4). Braun et al. (2011) found that prenatal urinary BPA exposures were highest among cashiers, although this finding was attenuated after adjustment for socioeconomic factors. Prenatal exposures are of particular concern due to the increased susceptibility of early life stages, discussed in Section 5.3.4. Liao and Kannan (2011) compared occupational exposure, based on handling 150 pieces of thermal paper/day to exposure in the general population, based on handling two pieces of thermal paper/day. They estimated occupational exposure to thermal paper at 1,303 ng/day of BPA, compared to BPA exposure in the general population of only 17.5 ng/day.

Consumer considerations: Consumers are potentially exposed to any chemicals found on thermal paper. As detailed in Section 5.3.5, exposure research has found that Americans carry body burdens of BPA (Calafat, Ye et al. 2008), although thermal paper is not considered to be the primary source of exposure (Rudel, Gray et al. 2011). Nonetheless, consumer reactions to exposure concerns can impact markets by creating pressure for substitution. DfE Alternatives Assessments can assist companies navigating these substitution pressures. There is greater emphasis on "green" products, and some consumers and non-governmental organizations (NGOs) advocate for informed substitution of chemicals, moving away from certain classes of chemicals entirely, with product re-design.

In addition to substituting in alternative chemicals, some organizations advocate for moving away from certain classes of chemicals entirely, with product re-design, to avoid future substitutions altogether. Product manufacturers should be mindful of the role of these organizations in creating market pressure for alternative chemicals and strategies, and should choose replacement chemicals – or re-designs – that meet the demands of their customers.

Environmental justice considerations: At EPA, environmental justice concerns refer to the disproportionate impacts on minority, low-income, or indigenous populations that exist prior to or that may be created by the proposed action. These disproportionate impacts arise because these population groups experience higher exposures, are more susceptible in response to exposure, or experience both conditions. Factors that are likely to influence resilience/ability to withstand harm from a toxic insult can vary with sociodemographics (e.g., co-morbidities, diet, metabolic enzyme polymorphisms) and are therefore important considerations. Adverse outcomes associated with exposure to chemicals may be disproportionately borne by minority and low income populations. Insights into EPA's environmental justice policy can be accessed at: www.epa.gov/compliance/ej/resources/policy/considering-ej-in-rulemaking-guide-07-2010.pdf.

Some populations have higher exposures to certain chemicals in comparison to the general population. Minority and low-income populations are over-represented in the manufacturing sector, increasing their occupational exposure to chemicals (Bureau of Labor Statistics 2012). Higher exposures to environmental chemicals may also be attributable to atypical product use patterns and exposure pathways. This may be due to a myriad of factors such as cultural practices, language and communication barriers, and economic conditions. The higher exposures may also be a result of the proximity of these populations to sources that emit the environmental chemical (e.g., manufacturing industries, industries that use the chemical as production input, hazardous waste sites), access to and use of consumer products that may result in additional exposures to the chemical, or higher employment of these groups in occupations associated with exposure to the chemical.

Considering environmental justice in the assessment of an alternative chemical may include exploring product use patterns, pathways and other sources of exposure to the substitute, recognizing how upstream factors such as socio-economic position, linguistic and communication barriers may alter typical exposure considerations. One tool available to these populations is the Toxics Release Inventory (TRI), which was established under the Emergency Planning and Community Right-to-Know Act (EPCRA) to provide information about the presence, releases, and waste management of toxic chemicals. Communities can use information reported to TRI to learn about facilities in their area that release toxic chemicals and to enter into constructive dialogue with those facilities. This information can empower impacted populations by providing an understanding about chemical releases and the associated environmental impacts in their community. Biomonitoring data for an alternative chemical, if available, can also signal the potential for disproportionate exposure among populations with environmental justice issues.

6.6 Trade-offs and Interim Risk Mitigation

In the absence of clearly-preferable low hazard functional alternatives, risk mitigation may be necessary in the interim. The hazard evaluations in Chapter 4 of this alternatives assessment include an analysis of the intrinsic properties that influence exposure, fate, and transport. Further information on exposure pathways and life-cycle considerations is presented in Chapter 5. A chemical alternative that poses a significantly greater opportunity for exposure should be further evaluated, and decision-makers should supplement the comparative chemical hazard assessment described in this report with other assessments, such as risk assessments, for potentially preferable alternatives.

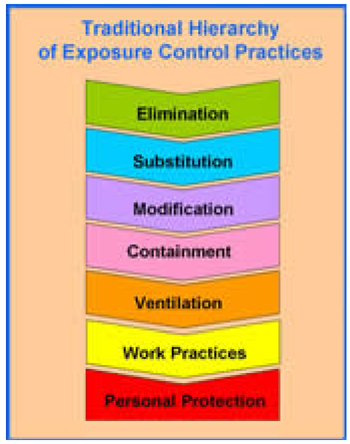
In many instances, it is apparent that alternative chemicals come with trade-offs. For any chemical identified as a potential alternative, some endpoints may appear preferable, while others indicate increased concern relative to the original chemical. For example, a chemical may have a lower concern for human health but a higher concern for aquatic toxicity or persistence.

These types of trade-offs can be difficult to evaluate, and such decisions should take into account relevant information about the chemical's hazard profile, expected product use, the potential for worker and consumer exposure, and the opportunity for the chemical to enter various waste streams, among other life-cycle and mitigation considerations. For example, chemicals expected to have high levels of developmental or reproductive toxicity should not be used in products intended for use by children or women of child-bearing age. Chemicals with high aquatic toxicity concerns should not be used if releases to water cannot be mitigated in the manufacturing, use, and disposal process.

Risk mitigation actions provide the opportunity to limit human health and environmental exposure. These actions provide immediate opportunities to address exposure concerns and may be considered alone or in conjunction with selection of an alternative, if appropriate. Examples of actions that may be appropriate are presented below.

The traditional hierarchy of exposure control practices begins with elimination and substitution (NIOSH 2011). When chemicals cannot be eliminated or substituted with safer alternatives, there are a variety of modifications and engineering controls that should be considered. For example, in the manufacture and use of chemicals in industrial processes, exposure can be limited through innovative engineering controls such as containment, improvements to local ventilation, and the use of negative-pressure systems for feeding materials (He, Miao et al. 2009). Personal protective equipment can also be used and is considered to be the last line of protection in the exposure control hierarchy.

Figure 6-1: Traditional Hierarchy of Exposure Control Practices



Source: (NIOSH 2011)

In consumer and occupational settings, risk mitigation measures may help reduce or avoid exposure to BPA in thermal paper. For example, after handling receipts, consumers and retail workers can limit their exposure to BPA by washing their hands prior to preparing or eating food, storing receipts separately in a wallet or purse, and avoiding the use of alcohol-based hand cleaners, which have the potential to increase dermal BPA absorption (Lunder, Andrews et al. 2010).

Risk mitigation measures may also limit human and environmental exposures to BPA and other chemicals during recycling or disposal. For example, recycling of thermal paper can lead to release of BPA into the environment through sludge and wastewater (JRC-IHCP 2010) and BPA contamination of recycled paper products, which are often used to store food (Ozaki, Yamaguchi et al. 2004). As an alternative to recycling, thermal paper can be disposed of in a landfill. While the anaerobic conditions associated with many landfills do not favor the degradation of BPA (Ying and Kookana 2005), the collection and treatment of landfill leachate can decrease the likelihood of BPA entering the environment.

A recent study suggests that the burning of plastics in waste disposal is a significant source of atmospheric BPA, but further research is needed to confirm the results and determine if prolonged exposure to low level atmospheric BPA could be associated with negative health effects (Fu and Kawamura 2010). Incineration produces negligible waste to soil and aquatic environments (JRC-IHCP 2010).

6.7 Innovation and Design Challenges

A DfE Alternatives Assessment can suggest directions for innovation and product development, especially when clearly preferable alternatives are not available. This can spur innovation by identifying design challenges and by highlighting the hazard endpoints and measures of exposure potential that delineate safer chemicals.

Green chemistry tools and expertise are growing. The DfE approach can enable identification of safer substitutes that emphasize greener chemistry, and it points the way to innovation in safer chemical design, where hazard becomes a part of a performance evaluation. EPA encourages collaboration to identify safer solutions to complex chemical hazards. For more information on green chemistry, please refer to the EPA Green Chemistry Program (http://www.epa.gov/greenchemistry/) or the American Chemical Society Green Chemistry Institute (www.acs.org/greenchmistry).

Innovation options that could be considered include the development of new chemicals that have a preferable hazard profile, while still meeting the performance considerations required by particular applications. Another option would be to re-design thermal paper, and could include using recycled materials and low concern chemicals as developers, colorformers, and sensitizers. Other approaches could include conducting additional research to determine if the application of a top coat (currently an optional design characteristic depending on a particular application) helps to limit exposure to consumers or workers. It is important to note that these approaches are not mutually exclusive; a combination of techniques may be appropriate.

In addition to reconfiguring thermal printing systems, decision-makers may wish to consider alternative printing systems. These systems should be evaluated and compared to thermal printing to better understand relative performance, cost, and hazard. To make an informed substitution, chemicals used in alternative printing systems must not be assumed to be low hazard. Thermal transfer printing, impact printing, and laser printing are all alternatives to direct thermal printing (Seiko Instruments U.S.A. Inc. n.d.). However, thermal paper printers are unique because they require no ribbons, inks, or toner cartridges. Thermal paper printers typically have fewer moving parts and low maintenance costs compared to similar technology (Appleton 2003).

A significant use of thermal paper is for point-of-sale (POS) receipts. Every year, an estimated 9.6 million trees are cut down in the United States for receipts (Clifford 2011), although many companies strive for sustainability through stewardship and management programs and studies show paper product industries are not a significant cause of deforestation (Behreandt 2012). Electronic receipts (e-receipts) are becoming increasingly common in the retail industry, being offered by Apple, Nordstrom, Whole Foods, and other major retailers. They are either emailed directly to consumers or uploaded to a password-protected website. While e-receipts may generate certain benefits, such as reducing manufacture, transport, storage, and disposal of thermal paper and its associated chemicals, they also require the establishment of additional data storage devices and electronic products and peripherals. A full examination of the relative merits and trade-offs of thermal paper versus e-receipts requires the consideration of life-cycle attributes, which is beyond the scope of this project.

6.8 Relevant Resources

In addition to the information provided in this report, there are a variety of resources that provide information on chemical regulations at the state, national, and global levels, some of which are cited in this section. Tools, including GreenScreen™ (see Section 6.6.4) are also available to assist in using the information in this report to make a substitution decision.

6.8.1 Resources for State and Local Authorities

The University of Massachusetts at Lowell created an online database that contains a collection of state and local legislative and executive branch policies from all 50 states from 1990 to the present that regulate or ban specific chemicals, provide comprehensive state policy reform, establish biomonitoring programs, or foster "green" chemistry (National Caucus of Environmental Legislators 2008):

http://www.chemicalspolicy.org/chemicalspolicy.us.state.database.php.

The Washington Department of Ecology concluded that averting toxic exposures and avoiding future health and cleanup costs is the smartest, cheapest and healthiest approach to preventing the harm associated with toxic chemicals, and created the Reducing Toxic Threats initiative to coordinate activities to achieve this goal (see: http://www.ecy.wa.gov/toxics/index.htm). Although the Department has conducted alternatives assessments as part of this effort, they are now focused on developing tools and guidance documents to allow businesses to conduct their own alternatives assessments to facilitate the movement to safer substitutes for chemicals of concern. The Department of Ecology has developed the Quick Chemical Assessment Tool, based on GreenScreen™ (see Section 6.8.4), to rapidly assess chemical options and remove from consideration those that are likely to be most toxic, so that in-depth assessments can focus on those chemicals that are likely to be safer. This is particularly important for businesses with limited resources. At the time of the writing of this report, the Department is in the process of developing an alternatives assessment guidance document.

6.8.2 Federal Agency Resources

EPA's website contains information on how the Agency develops regulations, the regulations that are in place, and information to assist companies in maintaining compliance with regulations. The website also provides information on EPA's partnership programs, such as DfE. Some EPA resources are listed below.

EPA Laws and Regulations http://www.epa.gov/lawsregs/

EPA Office of Pollution Prevention and Toxics (OPPT) http://www.epa.gov/oppt/

EPA DfE Program http://www.epa.gov/oppt/dfe/

Websites from other federal agencies that may be relevant to this alternatives assessment are provided below.

Consumer Product Safety Commission (CPSC) http://www.cpsc.gov/

U.S. Food and Drug Administration (FDA) http://www.fda.gov/

National Institute for Occupational Safety and Health (NIOSH) (part of the Centers for Disease Control and Prevention (CDC)) http://www.cdc.gov/niosh/

6.8.3 Resources for Global Regulations

The European Union (EU)'s REACH (**R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances) legislation was enacted in 2007 and aims "to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances" (European Commission 2011a). Their website contains information on legislation, publications and enforcement.

http://ec.europa.eu/environment/chemicals/reach/enforcement_en.htm

The EU's Restriction of Hazardous Substances (RoHS) legislation ensures that new electrical and electronic equipment put on the market does not contain any of the six banned substances: lead, mercury, cadmium, hexavalent chromium, poly-brominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) above specified levels (European Commission 2011b).

http://www.rohs.eu/english/index.html

6.8.4 GreenScreen™ for Safer Chemicals

The GreenScreen™ for Safer Chemicals was developed by the non-profit group Clean Production Action. It is a method for chemical hazard assessment to help move society toward the use of greener and safer chemicals. At the foundation of the GreenScreen™ method are the Principles of Green Chemistry and the work of the EPA DfE program. The GreenScreen™ addresses many of the principles of green chemistry and design for the environment through its focus on hazard reduction and informed substitution.

http://www.cleanproduction.org/Greenscreen.php

6.9 Related Assessments

In 2008, the European Commission published an environmental and human health addenda to its risk assessment of BPA.

European Union Risk Assessment Report, Human Health Addendum of April 2008, 4,4'-ISOPROPYLIDENEDIPHENOL (Bisphenol-A), Part 1 Environment

http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/15063/1/lbna24588enn.pdf

European Union Risk Assessment Report, Human Health Addendum of April 2008, 4,4'-ISOPROPYLIDENEDIPHENOL (Bisphenol-A), Part 2 Human Health

http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/15069/1/lbna24589enn.pdf

French Agency for Food, Environmental and Occupational Health & Safety, Health effects of Bisphenol A, Collective Expert Report, September 2011.

http://www.anses.fr/Documents/CHIM-Ra-BisphenolAEN.pdf

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