Bisphenol A Alternatives in Thermal Paper

Chapter 3

Background on Thermal Printing Technology

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

3. Background on Thermal Printing Technology

Thermal printing is a rapid and inexpensive printing technology widely used in commercial applications such as point-of-sale (POS) receipts, luggage tags, faxes, and labels (Mendum, Stoler et al. 2011). Direct thermal printing produces an image when specific chemicals within the coating of thermal paper are heated.[1] Thermal printing technology was first developed in the late 1960s, and its popularity grew in the 1980s and 1990s as it became more cost-effective and versatile. This chapter describes the components of the thermal paper system, its associated equipment, process, and applications, as well as the alternative chemicals analyzed and considered in the alternatives assessment.

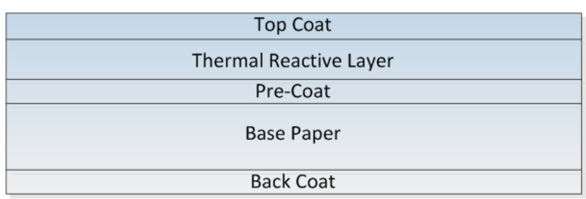
3.1 Components of Thermal Paper

Thermal paper is a highly engineered product, in which paper is coated with a thermal sensitive layer that reacts in the presence of heat to create the printed image. The following sections describe the key components of thermal paper development, including chemistry and manufacture. This information was useful in evaluating potential alternatives in this application.

3.1.1 Paper

Thermal paper is a standard paper grade that has been coated with a thermal sensitive layer, also known as a thermal reactive layer (see Figure 3-1). A pre-coat, or base coat, is applied to the base paper and allows for high resolution by preventing the heat transfer through all of the paper's layers, and for smoothness. Applied to the pre-coat is a thermal layer that contains the necessary reactive components (see Section 3.1.2). Additionally, thermal paper may contain a protective top coat and/or back coat. Top coats may be used for some applications to protect thermal paper from mechanical stress or chemical reactions. Similarly, back coats may be used to provide additional protection during lamination, printing, or other mechanical processes (Koehler Thermal Papers n.d.). Thermal paper used for receipts typically lacks the top and back coats.

Figure 3-1: Cross-Section of Thermal Paper



Thermal paper manufacturers produce the thermal paper in "jumbo rolls," which is considered a semi-finished product. Paper converters print the paper, cut the product to the appropriate size for use, rewind the paper onto a specific core (called "slit rolls"), and package the paper for sale to distributors. There are three major categories of thermal paper depending on basis weight, or density (typically g/m^2 or pounds per ream): (1) fax and POS grades, with an average basis weight of 58 grams, (2) label and ticket grades, with an average basis weight of 80 grams, and (3) heavy ticket grades, with an average basis weight of 120 grams (USITC 2007). Thermal paper is generally not made from recycled material, as post-consumer content can lack the

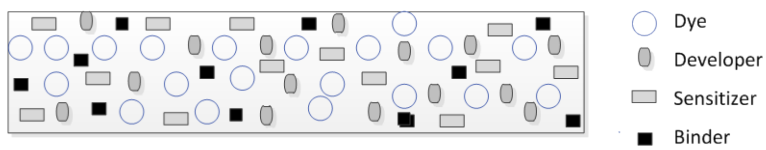
[1] Note: Other types of thermal printing include thermal transfer printing or dye sublimation. Direct thermal printing is the focus of the DfE Alternatives Assessment, and thus of this report.

consistency required for this highly engineered product. Limited quantities of recycled thermal paper are available, often including up to 50 percent post-consumer content. Thermal paper can be printed in both single-sided and double-sided formats.

3.1.2 Printing Chemistry

The thermal layer includes three key compounds (see Figure 3-2): a dye (also referred to as a colorformer), a developer (also referred to as a coreactant), and in some systems, a sensitizer (also referred to as a modifier). A binder, such as polyvinyl alcohol or latex, helps these coatings adhere to the paper. The materials are slurried and applied as an aqueous emulsion to the paper. The combination of these materials and their properties determines the image color, scanning characteristics and durability.

Figure 3-2: Elements of the Thermal Reactive Layer



Dye

The colorant typically used in thermal paper is a leuco dye, which is colorless at room temperature (Biedermann, Tschudin et al. 2010). Leuco dyes used in thermal paper undergo a structural change when protonated in the presence of heat and a proton donor (i.e., developer). The structural change results in the production of color. During printing, the thermal head of the printing unit pulses heat to the paper, which causes the components to melt, triggering the transfer of the proton from the developer to the dye, causing the leuco dye molecule to change structure to form a visible color (Biedermann, Tschudin et al. 2010). When used, the sensitizer has a lower melting point, thus acting as a solvent, promoting the interaction of the developer with the dye.

The dyes are often spirolactone compounds, with Black 305 and ODB2 among the most common. Some dyes extend the wavelength resulting in direct transfer systems that can scan in the near infrared (NIR) and infrared (IR) wavelengths (ETAC and NIR Black 78, respectively). Based on discussions with stakeholders, Design for the Environment (DfE) compiled a list that illustrates a variety of dyes that can be used in direct thermal printing (see Table 3-1). Each of these dyes shares the property that they are colorless until developed following heat activation.

Table 3-1: Example of Dyes Used in Thermal Paper

Chemical Names and Synonyms	CASRN	Color
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one, 6'-(dibutylamino)-3'-methyl-2'-(phenylamino)-; 2-Anilino-6-dibutylamino-3-methylfluoran; ODB-2, Black 400	89331-94-2	black
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one, 6'-(dipentylamino)-3'-methyl-2'-(phenylamino)-; Black 305	129473-78-5	black
Furo[3,4-b]pyridin-5(7H)-one, 7,7-bis[4-(diethylamino)-2-ethoxyphenyl]-; 3,3-Bis (4-diethylamino-2-ethoxyphenyl)-4-azaphthalide GN-2	132467-74-4	green
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one, 6'-(diethylamino)-3'-methyl-2'-(phenylamino)-; N-102 (ODB)	29512-49-0	black
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one,6'-[ethyl(4-methylphenyl)amino]-3'-methyl-2'-(phenylamino)-; ODB-250, ETAC	59129-79-2	black
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one,6'-(diethylamino)-3'-methyl-2'-[(3-methylphenyl)amino]-; ODB-7	151019-95-3	black
Spiro[12H-benzo[a]xanthene-12,1'(3'H)-isobenzofuran]-3'-one,9-[ethyl(3-methylbutyl)amino]-; Red 500	115392-27-3	red
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one,6'-[ethyl(4-methylphenyl)amino]-2'-methyl-; Red 520	42228-32-0	red
1(3H)-Isobenzofuranone,6-(dimethylamino)-3,3-bis[4-(dimethylamino)phenyl]-; Crystal violet lactone; CVL	1552-42-7	blue
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one,6'-[ethyl(3-methylbutyl)amino]-3'-methyl-2'-(phenylamino)-; S-205	70516-41-5	black
1(3H)-Isobenzofuranone, 4,5,6,7-tetrachloro-3,3-bis[2-[4-(dimethylamino)phenyl]-2-(4-methoxyphenyl)ethenyl]-; NIR Black 78	113915-68-7	black

Chemical Names and Synonyms	CASRN	Color
3-(4-Diethylamino-2-methylphenyl)-3-(1-ethyl-2-methyl-1H-indol-3-yl)-4-azaphthalide; Blue 220	114090-18-5	blue
7-[4-(diethylamino)-2-hexoxyphenyl]-7-(1-ethyl-2-methylindol-3-yl)furo[3,4-b]pyridin-5-one; Blue 203	98660-18-5	blue
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one,6'-[ethyl(4-methylphenyl)amino]-2'-(methylphenylamino)-; ATP	42530-35-8	green
Spiro[isobenzofuran-1(3H),9'-[9H]xanthen]-3-one,6'-[(3-ethoxypropyl)ethylamino]-3'-methyl-2'-(phenylamino)-(93071-94-4); Black 500	93071-94-4	black

Developer

The purpose of the developer, also referred to as a coreactant, which is weakly acidic, is to transfer protons to the dye, triggering color formation. In selecting a developer, its solubility, pKa, melting point, color, odor, purity, and vapor pressure are key properties. Performance characteristics of effective developers include:

- 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 permanence for the application,
- Appropriate performance vs. cost balance, and
- Feasible in large-scale production.

See Section 3.4 for a list of alternative developers considered in this alternatives assessment.

Sensitizer

Sensitizers, also referred to as modifiers, can facilitate the dye coloration process by lowering the melting point of the dye/developer, and/or by acting as a type of solvent in which a dye and developer dissolve below their melting point. Sensitizers typically have a melting point between 45-65ºC (Mendum, Stoler et al. 2011). The sensitizer helps to provide the optimal conditions for the developer to transfer protons upon heating, which enables color formation and can increase printing speed, or make a product suitable for low-energy printers. A variety of sensitizers are used in direct thermal printing (see Table 3-2).

Table 3-2: Examples of Sensitizers Used in Thermal Printing

Chemical Names and Synonyms	CASRN
Ethanedioic acid,1,2-bis[(4-chlorophenyl)methyl] ester; Di-(P-Chlorobenzyl) oxalate	19829-42-6
Ethanedioic acid,1,2-bis[(4-methylphenyl)methyl] ester; Di-(P-Menthylbenzyl) oxalate	18241-31-1
Ethanedioic acid,1,2-bis(phenylmethyl) ester; Dibenzyl oxalate	7579-36-4
Naphthalene, 2-(phenylmethoxyl)-; 2-Benzyloxynapthalene	613-62-7
1,4-diphenylbutane-1,4-dione; 1,4-Diphenoxybutanes	495-71-6
1-phenyl-4-(phenylmethyl)benzene; 4-Benzylbiphenyl	613-42-3
1,4-Benzenedicarboxylicacid,1,4-dimethylester; Dimethyl terephthalate	120-61-6
Benzene, 1,1’-[1,2-ethanediylbis(oxy)]bis-; (2-Phenoxyethoxy)benzene; 1,2-Diphenoxyethane	104-66-5
Benzene,1,1'-[1,2-ethanediylbis(oxy)]bis[3-methyl-; 1,2-Bis(3-methoxyphenoxy) ethane	54914-85-1
1,1'-Sulfonylbisbenzene; Diphenyl sulfone	127-63-9
Octadecanamide; Stearamide (waxy)	124-26-5
Hexanedioic acid, polymer with 1,4-butanediol and 1,2-ethanediol; Oligoethylene butylene glycol adipate, Hexanedioic acid; Kemamide S (waxy)	26570-73-0
Octadecanamide,N,N'-1,2-ethylenebis-; Ethylene bis stearamide	110-30-5
Octadecanamide, N-phenyl; N-phenylstearamide;	637-54-7
N-(2-methylphenyl)-3-oxobutanamide; o-Acetoacetotoluidide	93-68-5

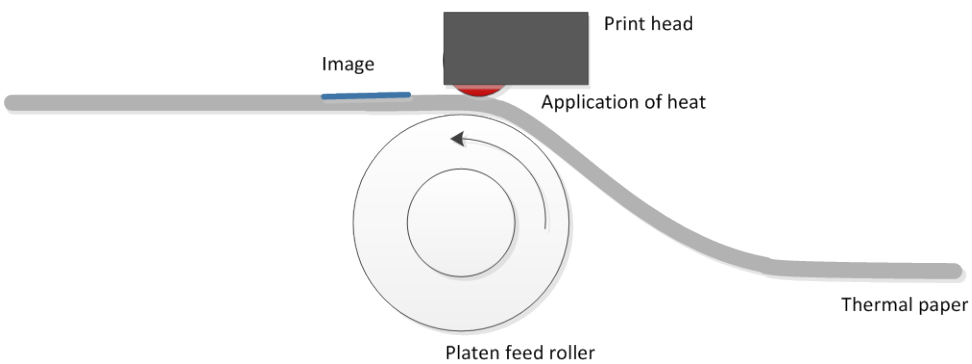
3.2 Thermal Printing Equipment and Process

Direct thermal printing produces an image by selectively heating specific areas of thermal paper (Mendum, Stoler et al. 2011). At room temperature, the dye is in its neutral, unprotenated state, which is colorless. When the dye/developer/ sensitizer system is heated above the melting point of the sensitizer, the developer (commonly bisphenol A (BPA)) donates a proton. In the case of the CVL dye (Table 3-1), this causes the lactone ring to open and increases the conjugation of the system, resulting in color formation (Mendum, Stoler et al. 2011). The chemicals then solidify to create a relatively stable image.

As Figure 3-3 illustrates, a thermal printing system consists of three basic components: a printer head, thermal paper, and a platen (i.e., backing roll). The printer head contains miniature heating units along the length of the printer head that electronically transfers the required amount of heat to the paper. As the thermal paper is driven by the platen, it is heated by the unit’s thermal head causing the dye and the developer in the coating of the paper to melt and react, which subsequently produces an image on the paper (Koehler Thermal Papers n.d.).

Figure 3-3: Overview of Thermal Printing Process

(based on Koehler Thermal Paper n.d. and Charters Paper Pty Ltd 2006)



To ensure optimal printing results, it is important to consider the characteristics of the type of thermal paper and printer used. Different grades of thermal paper have certain characteristics that render them more applicable to certain uses. One important characteristic is dynamic sensitivity, which pertains to the length of time the paper is exposed to heat. The faster a printer operates, the less time the paper is exposed to the unit's heating element. Thermal paper with a higher dynamic sensitivity is most appropriate for higher-speed or lower-energy printing. If thermal paper with low dynamic sensitivity is used instead, insufficient heat will be applied to the paper resulting in a reduced long-term stability of the finished product (Koehler Thermal Papers n.d.).

Static sensitivity is another important characteristic of thermal paper. Static sensitivity defines the temperature at which the dye and the developer begin to melt. The static sensitivity value is important for thermally-sensitive applications, such as for parking tickets or environments with high temperatures (e.g., pizza boxes, coffee cup labels) (Koehler Thermal Papers n.d.). Different grades of thermal paper exhibiting varying degrees of thicknesses and sensitivities affect the lifespan of the print job. If the appropriate paper and printer combination is used, and proper storage conditions are met, an image printed on thermal paper typically lasts between five to ten years (Koehler Thermal Papers 2011).

3.3 Advantages and Disadvantages of Thermal Printing Technology

Direct thermal printing offers several advantages in commercial environments, including not requiring any additional inks or chemicals to form the printer image. The only consumable item needed for direct thermal paper printing is the paper. Unlike thermal transfer printing, the direct thermal paper technology obviates the need for ink or ribbon maintenance and replacement.[2] Thermal printing systems also have few moving parts, making them reliable and relatively durable. In addition, direct thermal printing systems are quiet, have appropriate edge definition (up to 400 dpi, or dots per inch), can be manufactured to be small and lightweight, and can print quickly (up to 406 mm per second) (Charters Paper Pty Ltd 2006). Such advantages make direct

[2] The use of ribbons, which contain a mirror image of anything printed, raise privacy and security concerns; ribbons used in the printing of medical information must be destroyed in accordance with the Health Insurance Portability and Accountability Act of 1996 (HIPAA).

thermal printing systems a useful tool for market segments like retailers, laboratories with recorders, transportation, and hospitality, which tend to value an economical and fast printing system. Stakeholders noted that direct transfer print systems can be made portable, which is a highly valued attribute.

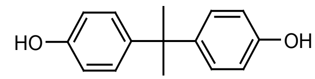
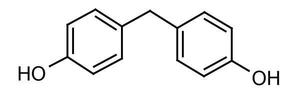
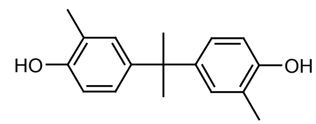
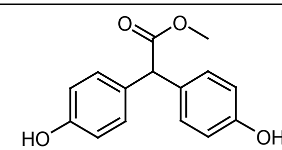
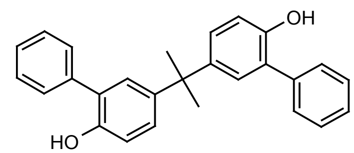
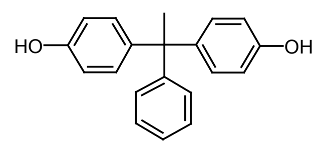
Thermal paper rolls exposed to heat may turn black, necessitating appropriate storage conditions. POS thermal paper is generally very thin and may be damaged by prolonged exposure to sunlight, water, or chemicals (e.g., solvents, plasticizers) and to friction. In general, POS thermal printing is best suited for short-term printing needs more so than longer term data storage. However, some thermal printing is estimated to last five to 12 years (Koehler Thermal Papers n.d.).

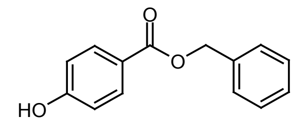
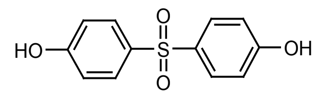
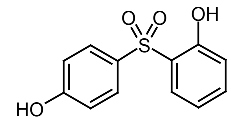
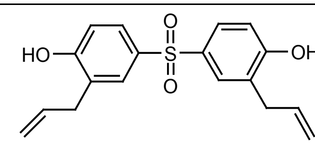
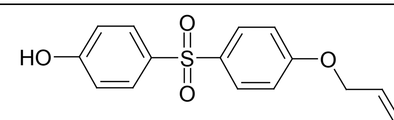
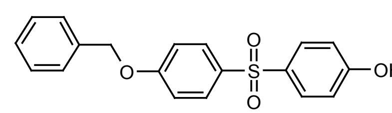
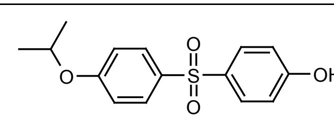
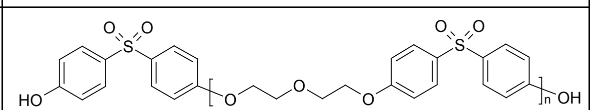
3.4 Alternatives Included in this Assessment

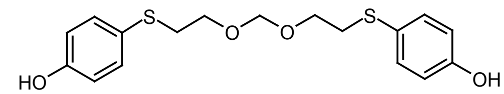
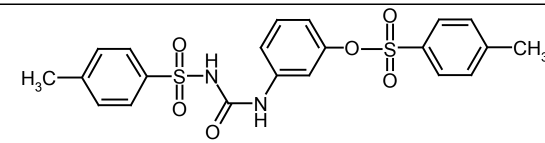
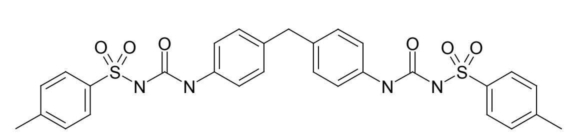
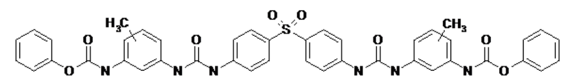
Potential alternatives to BPA for use in thermal paper were initially identified through internet searches, and focused on chemicals of similar structure and physical/chemical properties. Stakeholders also suggested specific chemicals for inclusion. With the assistance of stakeholders, the U.S. Environmental Protection Agency (EPA) identified 19 alternatives to BPA in thermal paper (see Table 3-3 below). These alternatives were selected because they have the potential to be functional substitutes to BPA based on their physical and chemical properties and/or because they are already in commercial use. Current commercial use was not a requirement for inclusion. A hazard assessment was conducted on BPA and these 19 alternatives; the findings are discussed in Chapter 4.

Table 3-3: The Alternatives Selected for Analysis in the Hazard Assessment

The chemicals included in this assessment are identified based on information provided to us by stakeholders, supplemented with publicly available information obtained through internet information searches.

CASRN	Chemical Name(s)	Common Name(s)	Molecular Formula	Structure
80-05-7	Phenol, 4,4'-(methylethylidene)bis- ; 2,2-bis(p-hydroxyphenyl)propane	Bisphenol A, BPA	$C_{15}H_{16}O_2$	
620-92-8	Phenol, 4,4'-methylenebis-; Bis(4-hydroxyphenyl)methane	Bisphenol F, BPF	$C_{13}H_{12}O_2$	
79-97-0	Phenol, 4,4'-(1-methylethylidene)bis[2-methyl; ,2'-Bis(4-hydroxy-3-methylphenyl)propane	Bisphenol C, BPC	$C_{17}H_{20}O_2$	
5129-00-0	Benzeneacetic acid, 4-hydroxy-.alpha.-(4-hydroxyphenyl)-, methyl ester; Methyl bis(4-hydroxyphenyl)acetate	MBHA	$C_{15}H_{14}O_4$	
24038-68-4	[1,1'-Biphenyl]-2-ol, 5,5''-(1-methylethylidene)bis-; 4,4'-Isopropyllidenebis(2-phenylpheno)	BisOPP-A	$C_{27}H_{24}O_2$	
1571-75-1	4,4'-(1-Phenylethylidene)bisphenol	Bisphenol AP, BPAP	$C_{20}H_{18}O_2$	
PROPRIETARY		Substituted phenolic compound #1	N/A	N/A

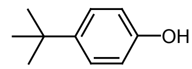
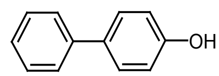
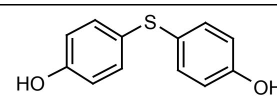
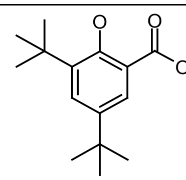
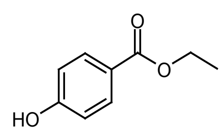
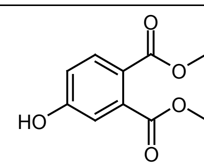
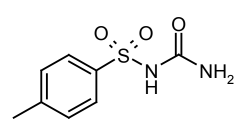
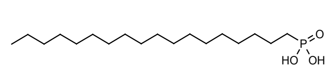
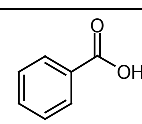
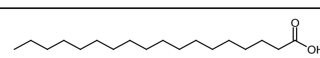
CASRN	Chemical Name(s)	Common Name(s)	Molecular Formula	Structure
PROPRIETARY		Substituted phenolic compound #2	N/A	N/A
94-18-8	Benzoic acid, 4-hydroxy-, phenylmethyl ester; Benzyl 4-hydroxybenzoate	PHBB	$C_{14}H_{12}O_3$	
80-09-1	Phenol, 4,4'-sulfonylbis-; 4-Hydroxyphenyl sulfone	Bisphenol S	$C_{12}H_{10}O_4S$	
5397-34-2	Phenol, 2-[(4-hydroxyphenyl)sulfonyl]-; 2,4'-Bis(hydroxyphenyl)sulfone	2,4-BPS	$C_{12}H_{10}O_4S$	
41481-66-7	Phenol, 4,4'-sulfonylbis[2-(2-propen-1-yl)-; bis-(3-allyl-4-hydroxyphenyl) sulfone	TGSA	$C_{18}H_{18}O_4S$	
97042-18-7	Phenol,4-[[4-(2-propen-1-yloxy)phenyl]sulfonyl]-	BPS-MAE	$C_{15}H_{14}O_4S$	
63134-33-8	Phenol, 4-[[4-(phenylmethoxy)phenyl]sulfonyl]-; 4-Hydroxy-4'-benzyloxydiphenylsulfone	BPS-MPE	$C_{19}H_{16}O_4S$	
95235-30-6	Phenol, 4-[[4-(1-methylethoxy)phenyl]sulfonyl]-; 4-hydroxyphenyl 4-isoprooxyphenylsulfone	D-8	$C_{15}H_{16}O_4S$	
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)	

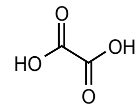
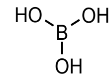
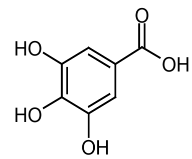
CASRN	Chemical Name(s)	Common Name(s)	Molecular Formula	Structure
93589-69-6	Phenol, 4,4'-[methylenebis(oxy-2,1-ethanediylthio)]bis-; 1,7-bis(4-Hydroxyphenylthio)-3,5-dioxaheptane	DD-70	$C_{17}H_{20}O_4S_2$	
232938-43-1	N-(p-Toluenesulfonyl)-N'-(3-p-toluenesulfonyloxyphenyl)urea	Pergafast 201	$C_{21}H_{20}N_2O_6S_2$	
151882-81-4	Benzenesulfonamide, N,N'-[methylenebis(4,1-phenyleneiminocarbonyl)]bis[4-methyl-; 4,4'-bis(*N*-carbamoyl-4-methylbenzenesulfonamide) diphenylmethane	BTUM	$C_{29}H_{28}N_4O_6S_2$	
321860-75-7		UU, Urea Urethane Compound	$C_{42}H_{36}N_6O_8S$	

3.5 Alternatives Not Included in this Assessment

The chemicals listed in this section were identified as possible alternatives to BPA, but were not included in this alternatives assessment. Chemicals were excluded based on feedback from the stakeholders, because their physical and/or chemical properties would likely render them incompatible as a functional replacement developer to BPA. Required physical properties of developers include acidity, water solubility, and melting point. A summary of the chemicals that were discussed but not included in this assessment are listed in Table 3-4.

Table 3-4: Alternatives Considered but Not Included in this DfE Alternatives Assessment

CASRN	Chemical and Common Name(s)	Molecular Formula	Structure
98-54-4	p-tert-butylphenol: Phenol, 4-(1,1-dimethylethyl)-	$C_{10}H_{14}O$	
92-69-3	p-Phenylphenol; [1,1'-Biphenyl]-4-ol	$C_{12}H_{10}O$	
2664-63-3	4,4’-Thiodiphenol; Phenol, 4,4'-thiobis-	$C_{12}H_{10}O_2S$	
19715-19-6	Benzoic acid, 3,5-bis(1,1-dimethylethyl)-2-hydroxy-; 3,5-di-tert-butylsalicylic acid	$C_{15}H_{22}O_3$	
120-47-8	Benzoic acid, 4-hydroxy-, ethyl ester; ethyl-p-hydroxybenzoate, ethyl paraben	$C_9H_{10}O_3$	
22479-95-4	Dimethyl-4-hydroxyphthalate; DMP-OH	$C_{10}H_{10}O_5$	
1694-06-0	N-(p-toluenesulphonyl)-N’-(3-p-toluenesulphonyloxyphenyl)urea	$C_8H_{10}N_2O_3S$	
4724-47-4	p-octadecylphosphonic acid; Phosphonic acid, P-octadecyl-	$C_{18}H_{39}O_3P$	
65-85-0	Benzoic acid	$C_7H_6O_2$	
57-11-4	Octadecanoic acid; stearic acid	$C_{18}H_{36}O_2$	

CASRN	Chemical and Common Name(s)	Molecular Formula	Structure
144-62-7	Ethanedioic acid; oxalic acid	$C_2H_2O_4$	
11113-50-1	Boric acid	H_3BO_3	
149-91-7	Benzoic acid, 3,4,5-trihydroxy-; gallic acid	$C_7H_6O_5$	

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