Australian Government
Department of Health
Australian Industrial Chemicals Introduction Scheme

Phenol, 4,4’-sulfonylbis- (BPS)

Evaluation statement

30 June 2022

Table of contents

Contents

AICIS evaluation statement

Subject of the evaluation

Phenol, 4,4’-sulfonylbis- (BPS)

Chemical in this evaluation

Name	CAS registry number
Phenol, 4,4’-sulfonylbis-	80-09-1

Reason for the evaluation

Evaluation Selection Analysis indicated a potential environmental risk.

Parameters of evaluation

This evaluation considers the environmental risks associated with the industrial uses of BPS (CAS RN 80-09-1). This chemical has been assessed for:

- Default Australian introduction volume of 100 tonnes per annum
- Industrial uses listed in the ‘Summary of Use’ section
- Expected emission into sewage treatment plants (STPs) due to consumer and commercial use.

Summary of evaluation

Summary of introduction, use and end use

The chemical BPS is used as a developer in thermal paper, as an intermediate in polymer reactions to prepare epoxy resins and polyether sulfone (PES) materials, in internal coatings of food and drink cans, and as a dye fixer and flame retardant in polymeric textile clothing.

Available information indicates that BPS is used in high volumes worldwide, although introduction volumes of BPS, either as a chemical or as part of articles, in Australia are unknown.

Environment

Summary of environmental hazard characteristics

According to domestic environmental hazard thresholds and based on the available data the chemical is:

- Not persistent (not P)
- Not bioaccumulative (not B)

- Toxic (T).

Environmental hazard classification

Bisphenol S satisfies the criteria for classification according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) for environmental hazards (UN 2017). The following classification of acute and chronic aquatic hazards posed by this chemical is based on the measured ecotoxicity data presented in this assessment. This evaluation does not consider classification of physical hazards and health hazards.

Environmental Hazard	Hazard Category	Hazard Statement
Acute Aquatic	Acute aq. – Cat. 3	H402: Harmful to aquatic life
Chronic	Chronic aq. – Cat. 1	H410: Very toxic to aquatic life with long lasting effects

Summary of environmental risk

The chemical BPS is released to the environment through diffuse emissions that result from its use in various commercial products. The main source of emissions to the aquatic environment are expected to be:

- Paper, textiles, PES plastics and metal can wastes discarded directly into surface waters or that enter water via runoff.
- Leaching from landfill wastes.
- Effluent discharges from STPs.

The risk to the aquatic environment from uses of BPS was evaluated based on measured levels of the chemical in influents from Australian STPs (PEC) and the predicted no-effect concentration (PNEC) determined in this assessment. As the Risk Quotient (RQ) obtained is <1.0, the chemical is unlikely to pose a significant risk to the environment.

The chemical BPS can cause adverse effects in aquatic vertebrates through an endocrine-mediated mode of action, in particular by impairing the reproductive success in fish. According to currently available data, BPS has similar or marginally lower aquatic toxicity than bisphenol A (BPA), and its endocrine activity is lower or similar than that of BPA. While BPS is not persistent, it does appear to be more recalcitrant to aquatic biodegradation than BPA. Though current concentrations of BPS in Australian waters are below the range of recorded endpoints for endocrine effects, environmental concentrations of BPS may increase in the future if this chemical continues to replace BPA in some products.

Conclusions

The conclusions of this evaluation are based on the information described in this Evaluation Statement.

The Executive Director is satisfied that the identified environment risks can be managed within existing risk management frameworks. This is provided that all requirements are met under environmental, workplace health and safety and poisons legislation as adopted by the relevant state or territory.

Note: Obligations to report additional information about hazards under *Section 100 of the Industrial Chemicals Act 2019* apply.

Supporting information

Rationale

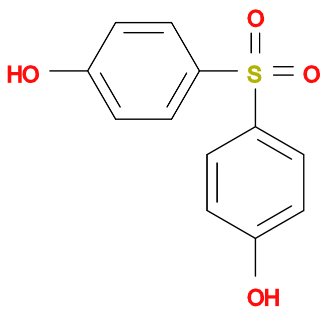
This evaluation considers the environmental risks associated with the industrial uses of phenol, 4,4'-sulfonylbis-, commonly known as bisphenol S or BPS.

Bisphenol S is currently used as a replacement for phenol, 4,4'-(1-methylethylidene)bis-, commonly known as BPA in thermal paper, epoxy resins and some plastic products. BPA is undergoing international restrictions and voluntary withdrawl from use due to its endocrine active properties. As a result, the use of BPS is expected to increase in the future.

The evaluation selection analysis (ESA) for this chemical indicated a need to investigate the environmental release of BPS in Australia and to determine whether this chemical exerts endocrine-mediated adverse effects comparable to those of BPA. BPS and BPA are structurally similar, comprising two phenol groups joined by a bridge. In BPS the bridge is a sulfone (SO_2) group whereas in BPA the bridge is a quaternary carbon with two methyl groups.

This evaluation will focus on the risks associated with exposure to BPS at environmentally relevant concentrations in Australia.

Chemical identity

Chemical name	Phenol, 4,4’-sulfonylbis-
CAS No.	80-09-1
Synonyms	bisphenol S bis(4-hydroxyphenyl) sulfone BPS 4,4'-sulfonyldiphenol
Structural formula	
Molecular formula	$C_{12}H_{10}O_4S$

Molecular weight (g/mol)	250.27
SMILES	C1=CC(=CC=C1O)S(=O)(=O)C2=CC=C(C=C2)O
Chemical description	-

Relevant physical and chemical properties

Measured physical and chemical property data for BPS was retrieved from the registration dossiers for BPS under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation in the European Union (EU) (REACH 2021). The vapour pressure was calculated using standard quantitative structure property relationships (QSPR), and the Henry’s Law constant was calculated from the measured value for water solubility and calculated value for vapour pressure using EPISuite (US EPA 2017).

Physical form	Solid
Melting point	245 - 248 °C (exp.)
Boiling point	315°C (decomposition, exp.)
Vapour pressure	4.94×10^{-5} Pa (calc.)
Water solubility	715 mg/L at 20°C (exp.)
Henry’s law constant	2.73×10^{-10} Pa·m^3/mol (calc.)
Ionisable in the environment?	Yes
pKa	8 at 20°C (exp.)
log K_{ow}	1.2 at 23°C (pH 6.2, exp.)

Introduction and use

Australia

No specific Australian introduction data have been identified for BPS. Based on information reported to the former National Industrial Chemicals Notification and Assessment Scheme (NICNAS) under previous mandatory and/or voluntary calls for information, BPS has reported domestic uses as a flame retardant and fire preventing agent (NICNAS 2015).

A significant additional source of BPS introduction is likely to be through import of thermal paper and PES plastics.

International

Available information indicates that BPS is used in high volumes worldwide. The chemical is mainly used as a drop-in replacement for BPA (CAS RN 80-05-7) in thermal paper and as a synthetic monomer used to produce epoxy resins and PES plastics.

The chemical BPS is used in the EU in the range of 10,000–100,000 tonnes/ (REACH 2021). In the United States of America (USA) BPS is listed as a high production volume chemical with an annual use volume of 453–4530 tonnes in 2012 (US EPA 2021). BPS was manufactured and/or imported to Japan in quantities of 8,000–9,000 tonnes in 2019 (NITE 2020).

The quantity of BPS used is increasing worldwide, and this has been attributed to the phase out of BPA, following increasing global concern about its endocrine disrupting properties and tightened regulations (Frankowski et al. 2020a; Usman and Ahmad 2016). In 2011, the USA's largest thermal paper manufacture announced that it had discontinued the use of BPA in favour of a new alternative – BPS (Appleton Ideas 2011). However, in recent years, major retailers in Canada and the USA such as Loblaw Companies Ltd., CVS Health and Target Corporation have committed to phasing out all phenol-containing (including BPS) thermal paper for receipts by 2021 (CVS Health 2020; Loblaw 2020; Target 2020). In Japan, BPS has replaced BPA in all thermal paper (Frankowski et al. 2020a).

The chemical BPS is mainly used as a colour developer in thermal paper (dye fixative) used for receipts, boarding passes, transport tickets and aeroplane luggage tags, where it is applied as a powdery film that is chemically unbound (Liao et al. 2012b). It has been detected in concentrations up to 26.2 mg/g in retail store receipts (Liao et al. 2012b; Molina-Molina et al. 2019; Pivnenko et al. 2015; Russo et al. 2017; Thayer et al. 2016). Paper products made from recycled paper and cardboard, such as mailing envelopes, flyers, corrugated cardboard boxes and office paper can contain BPS as a result of thermal receipts entering the recycling paper stream (Liao et al. 2012b; Pivnenko et al. 2015).

Another use of BPS is as an intermediate in polymer reactions, to prepare epoxy resins and polyether sulfone materials. Polymers containing the BPS subunit have commercial uses in pigment, dye and printing inks; the manufacture of textile products and finishes; surface treatments and fixing agents (NICNAS 2019). PES plastics have been used to replace BPA containing polycarbonate plastics in infant bottles and storage containers (WSDE 2021), and have technical applications in high temperature and flame retardant electrical components, automotive parts and medical equipment (SpecialChem 2021). Epoxy resins are also used to internally protect metal cans for drink and food storage. BPS has been identified in the liquid supernatant of canned food in concentrations up to 175 ng/mL (Viñas et al. 2010), presumably from leaching out from the lining resin, although there is no clear evidence that BPS may leach from PES and epoxy resins (Gallart-Ayala et al. 2011). The structurally and functionally analogous chemical BPA is known to leach from related materials during consumer use (Chang et al. 2005; Viñas et al. 2012).

The chemical BPS has been detected in textile clothing, including nylon stockings and infant clothing, in concentrations up to 2.19 mg/g (Li AJ and Kannan 2018; Sait et al. 2021; Xue et al. 2017). Its source is thought to be the polymeric textile finishing chemicals used (e.g. dye fixers, flame retardants) or the recycling of PES plastics into synthetic textiles (Li AJ and Kannan 2018; Papaspyrides et al. 2009).

The chemical BPS has also been detected in personal care products in concentrations up to 15.2 ng/g. The source of the chemical in these products was not elucidated (Liao and Kannan 2014).

Existing Australian regulatory controls

Environment

The industrial use of BPS is not subject to any specific national environmental regulations.

International regulatory status

United Nations

The chemical BPS is not currently identified as a Persistent Organic Pollutant (POP) (UNEP 2001), ozone depleting substance (UNEP 1987), or hazardous substance for the purpose of international trade (UNEP & FAO 1998).

OECD

A Screening Information Dataset (SIDS) initial assessment profile on BPS was agreed upon in 2013 at the Organisation for Economic Co-operation and Development (OECD) Cooperative Chemicals Assessment Meeting (CoCAM) 4 (OECD 2013). The summary conclusion of the SIDS Initial Assessment Report was that the chemical possesses properties indicating a hazard for the environment (acute aquatic toxicity endpoints between 10 and 100 mg/L), is not readily biodegradable, and has a low bioaccumulation potential.

Canada

Under the Chemicals Management Plan 34 bisphenols, including BPS, were identified in the 2017–2018 Identification of Risk Assessment Priorities review. This is the first step towards developing a problem formulation for structural analogues and functional alternatives to BPA in Canada, with the ultimate aim of making regulatory decisions on chemicals that may exert adverse effects. These chemicals were scheduled for mandatory information gathering from industry between October and December 2020 (Government of Canada 2021).

European Union

Belgium initiated a substance evaluation of BPS through the Community Rolling Action Plan (CoRAP) under the REACH legislation for its human health and environmental risk profile (ECHA 2021b). The evaluation is currently unresolved due to an outstanding information request on an extended fish one generation reproduction test. Once resolved, it would determine if BPS is eligible for categorisation of the substance as SVHC (an environmental endocrine disruptor) and its possible inclusion in Annex XIV (Authorisation List) of the REACH regulation (ECHA 2016).

BPS is authorised to be used as a monomer in the manufacture of plastic food contact materials and articles with a specific migration limit of 0.05 mg/kg (Annex I of Commission regulation (EU) No 10/2011) (EC 2011).

United States of America

The chemical BPS is targeted in several of the following state level regulations:

- on the Chemicals of High Concern to Children reporting list in Washington, which forces manufacturers to report annually on the presence and use of these chemicals in children's products offered for sale in Washington (DOE 2021)
- is listed as a chemical of high concern to children in Oregon, requiring manufacturers of children's product in the state to report, and ultimately remove, these chemicals from certain products (OHA 2021)
- was added to Vermont's list of chemicals of high concern to children in 2019, which requires manufacturers to report the presence of these chemicals in children's products available in the state (Health Vermont 2021).

Asia

The chemical BPS is classified in Japan as a general chemical substance that is not highly bioaccumulative (NITE 2020).

Other

In June 2019, Switzerland banned BPS from being used in thermal paper in a concentration of 0.02% or higher by weight (Fedlex 2019).

Environmental exposure

The chemical BPS is released to the environment through diffuse emissions that result from its use in various commercial products. The main source of emissions to the aquatic environment are as follows:

- Paper, textiles, PES plastics and metal can wastes discarded directly into surface waters or that enter water via runoff.
- Leaching from landfill wastes.
- Effluent discharges from STPs.

Major emission sources are the paper and textiles industries (Lee Sunggyu et al. 2015; Sait et al. 2021), including the recycling of products that contain thermal paper and PES plastics (Xue et al. 2017). BPS can be released from thermal paper in the form of dust particles, and this is a common source of emissions in urban environments (Liao et al. 2012a) that contaminates the surrounding soil and surface waters.

Biosolids obtained from STPs contain residues of BPS and other bisphenols (Karthikraj and Kannan 2017; Pan et al. 2021; Yu et al. 2015), since the removal of these compounds in waste treatment facilities is incomplete (Česen et al. 2018; Wang H et al. 2019).

It is unclear whether the BPS residues found in marine plastic debris result from leaching out of the plastic matrix or have been adsorbed directly from waters contaminated with this chemical (Chen Q et al. 2019; Schmidt et al. 2020). In any case, plastic wastes constitute a route of transport for BPS and other bisphenols in the environment (Schmidt et al. 2019).

Environmental fate

Dissolution, speciation and partitioning

Based on a calculated vapour pressure of 4.93 x 10^{-5} Pa, BPS is not a volatile chemical and is not expected to be found in the air phase. The estimated log K_{OA} is 14.1 (US EPA 2017), indicating negligible diffusion into the gaseous phase.

A measured value of log K_{OW} of 1.2 indicates low partitioning to organic matter. The estimated partitioning to organic carbon (log K_{OC}) is 3.26 (US EPA 2017), which indicates moderate adsorption to soil matrices. A similar value (log K_{OC} 3.5) was estimated in sediments of a lake in China (Jin and Zhu 2016). Sorption is highest under acidic soil conditions and higher organic content (Choi and Lee 2017a), whereas in alkaline soils BPS is more mobile than other bisphenol compounds (Shi et al. 2019).

BPS is soluble in water (715 mg/L), where it dissociates readily under alkaline conditions (pKa 8.0) due to its two phenolic hydroxyl groups. Based on an estimated Henry's Law constant of 2.74 x 10^{-10} Pa·m^3/mol (US EPA 2017), the chemical is not expected to volatilise from surface waters. In river waters, BPS is found mostly dissolved in the aqueous phase (89.9%) with a small proportion in colloidal matter (9.6%) and very little (0.5%) bound to suspended particles (Zheng et al. 2019).

Fugacity modelling suggests a distribution of 16% to water, 83% to soil and 0.9% to sediment under a typical scenario of equal emissions to air, soil and water and steady state conditions (US EPA 2017). With release solely to the water compartment, modelling suggests a distribution of 94% to water and 6% to sediment, with negligible amounts to air.

Degradation

The chemical BPS biodegrades slowly in waters, but rapidly in soils and sediment compartments. The chemical undergoes rapid aqueous photolysis and will eventually mineralise in natural surface waters.

In the atmosphere, BPS is likely to react with hydroxyl radicals, with an estimated half-life of 8.83 hours (US EPA 2017). However, as BPS is not a volatile chemical, this is unlikely to be a significant dissipation pathway in the environment.

Like other phenolic compounds, BPS is stable to hydrolysis at normal temperatures. A laboratory study showed no hydrolysis of BPS in water at pH 4, 7 and 9 at 50 ^{o}C after 5 days (OECD 2013), and another showed >90% of the chemical remained in water after 48 hours (Kovačič et al. 2019a). No degradation of BPS was observed in sterile water from a lake after 49 days (Zhou et al. 2020) nor in natural river water and seawater after 60 days, (Danzl et al. 2009; ECHA 2021a; Ike et al. 2006).

The chemical BPS undergoes rapid photolysis under ultraviolet (UV) radiation in aqueous solutions, with 99% degraded in 4 hours (ECHA 2021a; Kovačič et al. 2019a). Photolytic rates in alkaline solutions were faster than those in acidic and neutral waters because of the ionisation of BPS; an average half life of 43 minutes was determined in pure water at different concentrations (Cao G et al. 2012). Degradation by UV radiation can be complete in 20 minutes using a Fenton treatment (Frankowski et al. 2021; Kovačič et al. 2019b).

The chemical BPS has shown low mineralisation in standard ready biodegradability screening tests. In a study conducted according to OECD test guideline (TG) 301C, 0% mineralisation of BPS at 100 mg/L was measured after 28 days incubation (OECD 2013). In a study conducted according to OECD TG 301B and extended to 59 days total duration, a biodegradation lag phase was observed. No mineralisation was observed for the first 27 days of the test, followed by 32% mineralisation over the remaining 32 days. For both tests, the inoculum was sludge sampled from an STP receiving primarily municipal sewage (ECHA 2021b).

Non-standard biodegradation studies in water have also been conducted. In a die away study using both river water and STP sludge inocula, 40–50% primary degradation of BPS spiked at 10 mg/L was observed over 52 days (Frankowski et al. 2020b). In a laboratory culture study with the freshwater green algae *Chlorella vulgaris*, removal of BPS from the liquid culture strongly depended on the concentrations tested, with 34% removal at 10 and 5 mg/L and 94% removal at 0.5 mg/L over 6 days (Ding et al. 2020). Some bacteria are also capable of degrading bisphenols by phenolic ring hydroxylation followed by cleavage of the resulting 3,4-dihydroxyphenyl ring (Ogata et al. 2013).

The chemical BPS can be readily degraded by aerobic micro-organisms present in soil. A laboratory study found that 53.6% of the chemical was mineralised in 28 days with an estimated half life of 2.8 days, while the remainder was transformed to several metabolites. Lack of degradation in sterilised soil demonstrates that the process is carried out by micro-organisms (Cao S et al. 2020). Another study determined half-lives between 0.66 and 1.1 days in farm and forest soils, respectively (Choi and Lee 2017b).

The chemical BPS is expected to degrade in sediments. In a mixed sediment/water study under anaerobic conditions, a 60 day lag period was observed before 60% disappearance of the BPS test substance from day 60 to day 80 (REACH 2021). At environmental relevant concentrations BPS can be partially degraded by micro-organisms in anaerobic sediment systems, with 60% degraded in 60 days in laboratory microcosms (Ike et al. 2006) and up to 99% degraded in 10 days by a bacteria consortium from river sediments (Wang X et al. 2019).

Removal of BPS in STPs has been reported as one to 24% in North America (Xue and Kannan 2019), 69–97% in India (Karthikraj and Kannan 2017), between 81% and >95% in China (Qian et al. 2021; Sun et al. 2017; Wang H et al. 2019) and 88–99% in Europe (Česen et al. 2018). Half lives of BPS in activated sludge from STPs have been estimated between 4.3 and 17.3 days (Kovačič et al. 2021).

Bioaccumulation

The available experimental data indicates that BPS is not bioaccumulative.

Calculated bioconcentration and bioaccumulations factors (BCF and BAF) of 2.88 and 1.8 L/kg, respectively (US EPA 2017) are below the domestic categorisation threshold for bioaccumulation (BCF or BAF ≥ 2000 L/kg) (EPHC 2009), and indicate little potential for bioaccumulation in organisms.

A bioconcentration study according to OECD TG 305C concluded that the BCF of BPS in carp (*Cyprinus carpio*) is <2.2 L/kg wet weight (ww) over test concentrations of 50 and 500 µg/L (NITE). Measured bioaccumulation factors (log BAF) in marine organisms exposed to contamination in the Pearl River (China) were 2.99 in molluscs, 1.58 in fish and 1.07 in crustaceans (Zhao et al. 2019). Another field study proved there was no biomagnification of BPS in an aquatic food web of Lake Taihu (China), as the calculated trophic magnification factor (TMF) was <1 (Wang et al. 2017).

Residues of BPS in aquatic organisms are rare (one to 3% detection rates) and are present at low levels that range from 0.88 ng/g ww in fish to 22.7 ng/g ww in molluscs (Liao and Kannan 2019; Wong et al. 2017; Zhao et al. 2019). However, predatory cetaceans such as dolphins have higher residues of BPS in their muscles (8.3–142 ng/g ww) (Montoto-Martínez et al. 2021).

Environmental transport

The chemical BPS is moderately soluble in water (715 mg/L at 20°C), has an octanol/water partition coefficient (log K_{OW}) of just 1.2 and the Henry’s Law constant indicates low potential to volatilise from aqueous systems or moist soil. Consequently, transport of BPS in the environment is mainly in the aqueous compartment. Numerous monitoring studies report the presence of low levels of BPS, together with other bisphenols, in river waters (Česen et al. 2019; Chiriac et al. 2020; Wilkinson et al. 2017; Yamazaki et al. 2015), lakes (Jin and Zhu 2016; Yan et al. 2017), effluents from wastewater treatment facilities (Caban and Stepnowski 2020; Huang et al. 2021; Lee Sunggyu et al. 2015), estuaries (Zhao et al. 2019) and even open ocean waters (Schmidt et al. 2019).

The chemical BPS has been detected in indoor dust of North American and Asian countries at average concentrations of 0.13 to 0.82 ng/g dry weight (Liao et al. 2012a), but transport by dust is likely to be limited due to wet deposition on surfaces.

Predicted environmental concentration (PEC)

Average concentrations of BPS in surface waters internationally are typically in the range 20–150 ng/L with the highest recorded at 2174 ng/L in rivers from India (Yamazaki et al. 2015). Such levels are usually one order of magnitude lower (9–44 ng/L) in effluents from water treatment facilities (Česen et al. 2018; Wang H et al. 2019).

The only identified Australian monitoring study found a median concentration of 1.1 µg/L BPS in raw STP influent wastewaters. This was a median value of 108 samples from 3 STPs, with samples taken every year from 2012–2017 (Tang et al. 2020).

Average concentrations of BPS in seawater range 1.1 to 17 ng/L. In sediments, BPS residues are in the range 2 to 32 ng/g dw (Huang et al. 2020; Liao et al. 2012c; Nejumal et al. 2017), similar to those found in sludge from STPs (10–35 ng/g dw).

The median BPS levels found in influent wastewaters from Queensland (1.1 µg/L) is taken conservatively as the PEC for evaluation of this chemical in the Australian environment.

Environmental effects

Effects on Aquatic Life

Acute toxicity

The chemical BPS has low acute toxicity to model aquatic organisms.

The following measured median lethal concentration (LC50) and median effective concentration (EC50) values for model organisms across three trophic levels exposed to BPS were retrieved from the scientific literature (Chen M-Y et al. 2002; Moreman et al. 2017;

Park et al. 2019) or the registration dossier for BPS under EU REACH legislation (Chen M-Y et al. 2002; REACH 2021):

Taxon	Endpoint	Method
Fish	96 h LC50 = 199 mg/L	*Danio rerio* (zebrafish) Semi-static, measured OECD TG 236
Invertebrate	48 h EC50 = 20.1 mg/L	*Moina macrocopa* (waterflea) Semi-static, measured OECD TG 202
Algae	72 h EC50 = 106 mg/L	*Desmodesmus subspicatus* (green algae) Static, growth OECD TG 201

Chronic toxicity

The following measured no observed effect concentrations (NOEC) in model organisms across three trophic levels were retrieved from the registration dossier for BPS under EU REACH legislation (REACH 2021) and from the literature (Naderi et al. 2014):

Taxon	**Endpoint**	**Method**
Fish	75 d NOEC = 0.01 mg/L 75 d LOEC = 0.1 mg/L	*Danio rerio* (zebrafish) Semi-static, nominal Growth and mortality
Invertebrates	21 d NOEC = 2.7 mg/L	*Daphnia magna* (water flea) Reproduction OECD TG 211
Algae	72 h NOEC = 10.2 mg/L	*Desmodesmus subspicatus* (green algae) Static, growth OECD TG 201

There are some conflicting data on the toxicity of BPS to fish. A study (not presented in the table above) that followed OECD TG 210 found no effects on zebrafish survival at 10 mg/L after 34 days exposure (REACH 2021). However, other authors have reported relevant endpoints for survival and growth of fish at much lower concentrations.

The above chronic NOEC and lowest observed effect concentration (LOEC) values for fish are taken from the open literature (Naderi et al. 2014). This study is considered reliable with limitations as the test concentrations were not validated and the spacing between concentrations was large (10x). To account for this, a maximum allowable toxicant concentration (MATC) of 0.032 mg/L was derived as the geometric mean of the reported NOEC and LOEC above: MATC = (NOEC x LOEC)$^{1/2}$ (EPHC 2009). This procedure is justified when there is a large difference between reported NOEC and LOEC values, which is primarily due to the study design and wide spacing of concentration intervals. The actual NOEC is expected to be somewhere in between the two concentrations.

Effects on terrestrial Life

The chemical BPS is not toxic to earthworms in both acute and chronic exposures, with estimated 56 d reproduction NOEC >1000 mg/kg dry soil and acute 48 h LC50 of 2 mg/ml in a contact test for *Eisenia fetida* (Marcos et al. 2021).

Effects on sediment dwelling life

As for other aquatic organisms, BPS can be considered slightly toxic to sediment dwelling invertebrates, even though relevant concentrations of the chemical at 0.5 mg/L did not affect survival of midge larvae (*Chironomus riparius*) in an acute test after 48 hours (Herrero et al. 2018).

Endocrine effects

Like BPA and other bisphenol analogues, BPS exhibits weak oestrogenic activity that is derived from having two hydroxyphenyl functionalities in its structure (Chen M-Y et al. 2002). The oestrogenic potency of BPS in zebrafish assays is 3×10^5 times lower than that of 17β-estradiol (E2), having estimated EC50 values between 0.25 mg/L for the oestrogen-β1 receptor and 1.0 mg/L for the oestrogen-α receptor (Le Fol et al. 2017).

Experimental in vivo and in vitro studies with zebrafish (*Danio rerio*) demonstrate that BPS increases levels of E2 in both male and female fish, while reducing the testosterone levels in males and the fecundity of females (Ji et al. 2013; Naderi et al. 2014). These effects occur after chronic exposures to low concentrations (5–100 µg/L), and have the potential to reduce the fish populations in the environment. Also, BPS induces the production of vitellogenin in both sexes and alters the hatching time of fish embryos (Le Fol et al. 2017; Moreman et al. 2017; Naderi et al. 2014; Qiu et al. 2016). The latter effect is due to BPS inducing transcriptional changes in the genes related to thyroid development, thyroid hormone transport and metabolism (Lee Sangwoo et al. 2019). It has been reported that egg and sperm production decreased in zebrafish after long exposure (75 days) to 10 and 100 µg/L of BPS (Naderi et al. 2014). The chemical also impaired fecundity in *Daphnia* sp., with a reported EC50 of 14 mg/L in a study conducted according to OECD TG 211 (US EPA 2015).

Like other bisphenols, BPS can interact with the thyroid hormone signalling pathway by binding to the thyroxine receptors TRα and TRβ and competing with the natural hormone T3. Binding of BPS to the TRβ receptors in orders of magnitude weaker than to the oestrogen receptors, with half-maximal inhibitory concentration (IC50) of 574 mg/L and a relative potency 8×10^6 times lower than that of T3 (Zhang Y-F et al. 2018). In addition, BPS induces up-regulation of deiodinase enzyme genes (Lee Sangwoo et al. 2019; Zhang D-h et al. 2017), which result in decreased levels of T4 and increased levels of T3 in fish plasma, and expression of genes in the hypothalamic-pituitary-thyroid axis is also altered, thus affecting embryonic development and hatching (Wei et al. 2018; Zhang D-h et al. 2017).

Abnormal behaviour in fish exposed to relevant environmental levels of BPS has been observed, including impaired memory (Naderi et al. 2020), reduced swimming performance (Wu and Seebacher 2021) and increased anxiety due to a surge in cortisol levels (Wei et al. 2020). Oxidative stress leading to inflammation and increased lipid peroxidation has also been reported in fish (Qiu et al. 2019a), as well as increased triglyceride production that results in fat accumulation and obesity (Wang W et al. 2019; Xiao et al. 2021)

The chemical BPS is as genotoxic as BPA (Lee Sangwoo et al. 2013) but it is not mutagenic and is less cytotoxic than other bisphenols (Michałowicz et al. 2015; Usman and Ahmad 2016).

Predicted no-effect concentration (PNEC)

The 75 day MATC of 0.032 mg/L for mortality and growth of zebrafish is selected as the pivotal endpoint in this evaluation. Given that chronic data are available for three trophic levels, the PNEC is 0.0032 mg/L (3.2 µg/L) after applying an assessment factor of 10.

This PNEC is considered protective but reasonable, as BPS shows endocrine activity that could impact on populations of fish at levels between 0.005 and 0.1 mg/L.

Categorisation of environmental hazard

The categorisation of the environmental hazards of the assessed chemical according to domestic environmental hazard thresholds is presented below:

Persistence

Not Persistent (Not P). Based on measured half lives in soil and in sludge <180 days, and evidence of ultimate biodegradation and degradation by photolysis in the water compartment, BPS is categorised as Not Persistent.

Bioaccumulation

Not Bioaccumulative (Not B). Based on measured BCF in fish of 2.88 L/kg, a log K_{OW} value of 1.2 and evidence of biotransformation, BPS is categorised as Not Bioaccumulative.

Toxicity

Toxic (T). Based on available ecotoxicity values below 1 mg/L, evidence of chronic toxicity and endocrine properties, BPS is categorised as Toxic.

Environmental risk characterisation

Main emissions of BPS to the aquatic environment are through domestic discharges to the sewage system and storm water runoff. Discharges into the sewage system can be managed, as STPs can remove > 95% of BPS through biodegradation in activated sludge (Česen et al. 2018; Wang H et al. 2019). Direct discharges into water runoff are expected to be removed to a lesser extent by natural photolysis and biodegradation processes.

Since no Australian introduction volumes are available for BPS, and as BPS levels in wastewater are also affected by imported articles, the risk to the aquatic environment was evaluated based on the PEC and PNEC values determined above. Concentrations of BPS in effluents from STPs are expected to be lower than the median levels found in influents from Queensland (Tang et al. 2020), and the PEC is therefore conservative.

The following Risk Quotient (RQ = PEC ÷ PNEC) has been calculated for release of BPS directly into surface waters:

Compartment	PEC	PNEC	RQ
Surface waters	1.1 µg/L	3.2 µg/L	0.35

Given that the RQ value is below 1.0, it is concluded that BPS is unlikely to pose a significant risk to the aquatic environment.

The chemical BPS can cause adverse effects in aquatic vertebrates through an endocrine-mediated mode of action. However, many of the specific endocrine-related effects occur at concentrations well in excess of what has been detected in the Australian environment. Expected concentrations of BPS in Australian waters are below the range of recorded endpoints for endocrine effects (5 to 100 µg/L), although environmental concentrations could increase in the future as this chemical is expected to continue to replace BPA in some products. Such effects are nonetheless of concern as, affecting in particular the reproductive success in aquatic organisms at very low levels (Ji et al. 2013; Naderi et al. 2014), they could potentially reduce population levels of these organisms in the aquatic environment. However, the specific effects of BPS in the Australian environment are difficult to distinguish from effects caused by other known oestrogenic chemicals in STP effluent and surface waters, including natural and synthetic oestrogens.

According to currently available data, BPS has similar or marginally lower aquatic toxicity than BPA (Chen M-Y et al. 2002), and its endocrine activity is lower than or similar to that of BPA (Qiu et al. 2019b; Zhang Y-F et al. 2018). While BPS is not persistent, it does appear to be more recalcitrant to aquatic biodegradation than BPA.

Uncertainty

This evaluation was conducted based on a set of information that may be incomplete or limited in scope. Some relatively common data limitations can be addressed through use of conservative assumptions (OECD 2019) or quantitative adjustments such as assessment factors (OECD 1995). Others must be addressed qualitatively, or on a case by case basis (OECD 2019).

The most consequential areas of uncertainty for this evaluation are:

- There are no specific introduction volume data nor Australian environmental monitoring data for BPS. The risk profile of BPS may change should additional information become available to indicate that BPS may be present in the Australian environment above the levels of concern.
- There are insufficient data to fully characterise the risks to the environment from the endocrine effects of these chemicals. Further evaluation may be required should additional reliable effects or exposure data become available. For example the extended fish one generation reproduction test requested by European Chemicals Agency (ECHA) may become available in the future.

References

Appleton Ideas (2011) *Appleton statement on the discontinued use of BPA and replacement with BPS,* Appleton, accessed July 2021.

Caban M and Stepnowski P (2020) 'The quantification of bisphenols and their analogues in wastewaters and surface water by an improved solid-phase extraction gas chromatography/mass spectrometry method', *Environmental Science and Pollution Research,* **27**(23), pp 28829–28839, doi:doi.org/10.1007/s11356-020-09123-2.

Cao G, Lu J and Wang G (2012) 'Photolysis kinetics and influencing factors of bisphenol S in aqueous solutions', *Journal of Environmental Sciences,* **24**(5), pp 846–851, doi:doi.org/10.1016/S1001-0742(11)60809-7.

Cao S, Wang S, Zhao Y, Wang L, Ma Y, Schäffer A and Ji R (2020) 'Fate of bisphenol S (BPS) and characterization of non-extractable residues in soil: Insights into persistence of BPS', *Environment International,* **143**, pp 105908, doi:doi.org/10.1016/j.envint.2020.105908.

Česen M, Heath D, Krivec M, Košmrlj J, Kosjek T and Heath E (2018) 'Seasonal and spatial variations in the occurrence, mass loadings and removal of compounds of emerging concern in the Slovene aqueous environment and environmental risk assessment', *Environmental Pollution,* **242**, pp 143–154, doi:doi.org/10.1016/j.envpol.2018.06.052.

Česen M, Ahel M, Terzić S, Heath DJ and Heath E (2019) 'The occurrence of contaminants of emerging concern in Slovenian and Croatian wastewaters and receiving Sava river', *Science of The Total Environment,* **650**, pp 2446–2453, doi:doi.org/10.1016/j.scitotenv.2018.09.238.

Chang C-M, Chou C-C and Lee M-R (2005) 'Determining leaching of bisphenol A from plastic containers by solid-phase microextraction and gas chromatography–mass spectrometry', *Analytica Chimica Acta,* **539**(1), pp 41–47, doi:doi.org/10.1016/j.aca.2005.03.051.

Chen M-Y, Ike M and Fujita M (2002) 'Acute toxicity, mutagenicity, and estrogenicity of bisphenol-A and other bisphenols', *Environmental Toxicology,* **17**(1), pp 80–86, doi:doi.org/10.1002/tox.10035.

Chen Q, Allgeier A, Yin D and Hollert H (2019) 'Leaching of endocrine disrupting chemicals from marine microplastics and mesoplastics under common life stress conditions', *Environment International,* **130**, pp 104938, doi:doi.org/10.1016/j.envint.2019.104938.

Chiriac FL, Paun I, Iancu V, Florinela P, Niculescu M and Galaon T (2020) 'Occurrence of phenolic endocrine disruptors in Danube Delta, Romania', *Revista de Chimie,* **71**(7), pp 316–324, doi:doi.org/10.37358/RC.20.7.8250.

Choi YJ and Lee LS (2017a) 'Partitioning behavior of bisphenol alternatives BPS and BPAF compared to BPA', *Environmental Science & Technology,* **51**(7), pp 3725–3732, doi:doi.org/10.1021/acs.est.6b05902.

Choi YJ and Lee LS (2017b) 'Aerobic soil biodegradation of bisphenol (BPA) alternatives bisphenol S and bisphenol AF compared to BPA', *Environmental Science & Technology,* **51**(23), pp 13698–13704, doi:doi.org/10.1021/acs.est.7b03889.

CVS Health (2020) *2020 Corporate Social Responsibility Report,* CVS Health, accessed July 2021.

Danzl E, Sei K, Soda S, Ike M and Fujita M (2009) 'Biodegradation of bisphenol A, bisphenol F and bisphenol S in seawater', *International Journal of Environmental Research and Public Health,* **6**(4), doi:doi.org/10.3390/ijerph6041472.

Ding T, Li W, Yang M, Yang B and Li J (2020) 'Toxicity and biotransformation of bisphenol S in freshwater green alga Chlorella vulgaris', *Science of The Total Environment,* **747**, pp 141144, doi:doi.org/10.1016/j.scitotenv.2020.141144.

DOE (Department of Ecology) (2021) *Chemicals of high concernt to children reporting list,* accessed July 2021.

EC (European Commission) (2011) *Commission Regulation (EC) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food,* accessed July 2021.

ECHA (European Chemicals Agency) (2016) *Authorisation List,* European Chemicals Agency (ECHA), accessed December 2021.

ECHA (European Chemicals Agency) (2021a) *4,4'-sulphonyldiphenol - Brief profile,* European Chemicals Agency (ECHA), accessed October 2021.

ECHA (European Chemicals Agency) (2021b) *Substance evaluation - CoRAP: 4,4'-sulfonyldiphenol,* accessed July 2021.

EPHC (Environment Protection and Heritage Council) (2009) *Environmental Risk Assessment Guidance Manual for Industrial Chemicals*, Commonwealth of Australia, accessed July 2021.

Fedlex (The Federal Council for Federal Law) (2019) *SR 814.81 Ordinance of 18 May 2005 on the Reduction of Risks relating to the Use of Certain Particularly Dangerous Substances, Preparations and Articles (Chemical Risk Reduction Ordinance, ORRChem),* accessed July 2021.

Frankowski R, Zgoła-Grześkowiak A, Grześkowiak T and Sójka K (2020a) 'The presence of bisphenol A in the thermal paper in the face of changing European regulations – A comparative global research', *Environmental Pollution,* **265**, pp 114879, doi:doi.org/10.1016/j.envpol.2020.114879.

Frankowski R, Zgoła-Grześkowiak A, Smułek W and Grześkowiak T (2020b) 'Removal of bisphenol A and its potential substitutes by biodegradation', *Applied Biochemistry and Biotechnology,* **191**(3), pp 1100–1110, doi:doi.org/10.1007/s12010-020-03247-4.

Frankowski R, Płatkiewicz J, Stanisz E, Grześkowiak T and Zgoła-Grześkowiak A (2021) 'Biodegradation and photo-Fenton degradation of bisphenol A, bisphenol S and fluconazole in water', *Environmental Pollution,* **289**, pp 117947, doi:doi.org/10.1016/j.envpol.2021.117947.

Gallart-Ayala H, Moyano E and Galceran MT (2011) 'Analysis of bisphenols in soft drinks by on-line solid phase extraction fast liquid chromatography–tandem mass spectrometry', *Analytica Chimica Acta,* **683**(2), pp 227–233, doi:doi.org/10.1016/j.aca.2010.10.034.

Government of Canada (2021) *Information gathering plan (2020 - 2021),* accessed July 2021.

Health Vermont (2021) *2019 Additions to Vermont's List of Chemical's of High Concern to Children* accessed July 2021.

Herrero Ó, Aquilino M, Sánchez-Argüello P and Planelló R (2018) 'The BPA-substitute bisphenol S alters the transcription of genes related to endocrine, stress response and biotransformation pathways in the aquatic midge *Chironomus riparius* (Diptera, Chironomidae)', *PLOS ONE,* **13**(2), pp e0193387, doi:doi.org/10.1371/journal.pone.0193387.

Huang Z, Zhao J-L, Yang Y-Y, Jia Y-W, Zhang Q-Q, Chen C-E, Liu Y-S, Yang B, Xie L and Ying G-G (2020) 'Occurrence, mass loads and risks of bisphenol analogues in the Pearl River Delta region, South China: Urban rainfall runoff as a potential source for receiving rivers', *Environmental Pollution,* **263**, pp 114361, doi:doi.org/10.1016/j.envpol.2020.114361.

Huang Z, Zhao J-L, Zhang C-Y, Rao W-L, Liang G-H, Zhang H, Liu Y-H, Guan Y-F, Zhang H-Y and Ying G-G (2021) 'Profile and removal of bisphenol analogues in hospital wastewater, landfill leachate, and municipal wastewater in South China', *Science of The Total Environment,* **790**, pp 148269, doi:doi.org/10.1016/j.scitotenv.2021.148269.

Ike M, Chen MY, Danzl E, Sei K and Fujita M (2006) 'Biodegradation of a variety of bisphenols under aerobic and anaerobic conditions', *Water Science and Technology,* **53**(6), pp 153–159, doi:doi.org/10.2166/wst.2006.189.

Ji K, Hong S, Kho Y and Choi K (2013) 'Effects of bisphenol S exposure on endocrine functions and reproduction of zebrafish', *Environmental Science & Technology,* **47**(15), pp 8793-8800, doi:doi.org/10.1021/es400329t.

Jin H and Zhu L (2016) 'Occurrence and partitioning of bisphenol analogues in water and sediment from Liaohe River Basin and Taihu Lake, China', *Water Research,* **103**, pp 343–351, doi:doi.org/10.1016/j.watres.2016.07.059.

Karthikraj R and Kannan K (2017) 'Mass loading and removal of benzotriazoles, benzothiazoles, benzophenones, and bisphenols in Indian sewage treatment plants', *Chemosphere,* **181**, pp 216–223, doi:doi.org/10.1016/j.chemosphere.2017.04.075.

Kovačič A, Česen M, Laimou-Geraniou M, Lambropoulou D, Kosjek T, Heath D and Heath E (2019a) 'Stability, biological treatment and UV photolysis of 18 bisphenols under laboratory conditions', *Environmental Research,* **179**, pp 108738, doi:doi.org/10.1016/j.envres.2019.108738.

Kovačič A, Gys C, Kosjek T, Covaci A and Heath E (2019b) 'Photochemical degradation of BPF, BPS and BPZ in aqueous solution: Identification of transformation products and degradation kinetics', *Science of The Total Environment,* **664**, pp 595–604, doi:doi.org/10.1016/j.scitotenv.2019.02.064.

Kovačič A, Gys C, Gulin MR, Gornik T, Kosjek T, Heath D, Covaci A and Heath E (2021) 'Kinetics and biotransformation products of bisphenol F and S during aerobic degradation with activated sludge', *Journal of Hazardous Materials,* **404**, pp 124079, doi:doi.org/10.1016/j.jhazmat.2020.124079.

Le Fol V, Aït-Aïssa S, Sonavane M, Porcher J-M, Balaguer P, Cravedi J-P, Zalko D and Brion F (2017) 'In vitro and in vivo estrogenic activity of BPA, BPF and BPS in zebrafish-specific assays', *Ecotoxicology and Environmental Safety,* **142**, pp 150–156, doi:doi.org/10.1016/j.ecoenv.2017.04.009.

Lee S, Liu X, Takeda S and Choi K (2013) 'Genotoxic potentials and related mechanisms of bisphenol A and other bisphenol compounds: A comparison study employing chicken DT40 cells', *Chemosphere,* **93**(2), pp 434–440, doi:doi.org/10.1016/j.chemosphere.2013.05.029.

Lee S, Liao C, Song G-J, Ra K, Kannan K and Moon H-B (2015) 'Emission of bisphenol analogues including bisphenol A and bisphenol F from wastewater treatment plants in Korea', *Chemosphere,* **119**, pp 1000–1006, doi:doi.org/10.1016/j.chemosphere.2014.09.011.

Lee S, Kim C, Shin H, Kho Y and Choi K (2019) 'Comparison of thyroid hormone disruption potentials by bisphenols A, S, F, and Z in embryo-larval zebrafish', *Chemosphere,* **221**, pp 115–123, doi:doi.org/10.1016/j.chemosphere.2019.01.019.

Li AJ and Kannan K (2018) 'Elevated concentrations of bisphenols, benzophenones, and antimicrobials in pantyhose collected from six countries', *Environmental Science & Technology,* **52**(18), pp 10812–10819, doi:doi.org/10.1021/acs.est.8b03129.

Liao C, Liu F, Guo Y, Moon H-B, Nakata H, Wu Q and Kannan K (2012a) 'Occurrence of eight bisphenol analogues in indoor dust from the United States and several Asian countries: Implications for human exposure', *Environmental Science & Technology,* **46**(16), pp 9138–9145, doi:doi.org/10.1021/es302004w.

Liao C, Liu F and Kannan K (2012b) 'Bisphenol S, a new bisphenol analogue, in paper products and currency bills and its association with bisphenol A residues', *Environmental Science & Technology,* **46**(12), pp 6515–6522, doi:doi.org/10.1021/es300876n.

Liao C, Liu F, Moon H-B, Yamashita N, Yun S and Kannan K (2012c) 'Bisphenol analogues in sediments from industrialized areas in the United States, Japan, and Korea: Spatial and temporal distributions', *Environmental Science & Technology,* **46**(21), pp 11558–11565, doi:doi.org/10.1021/es303191g.

Liao C and Kannan K (2014) 'A survey of alkylphenols, bisphenols, and triclosan in personal care products from China and the United States', *Archives of Environmental Contamination and Toxicology,* **67**(1), pp 50–59, doi:doi.org/10.1007/s00244-014-0016-8.

Liao C and Kannan K (2019) 'Species-specific accumulation and temporal trends of bisphenols and benzophenones in mollusks from the Chinese Bohai Sea during 2006–2015', *Science of The Total Environment,* **653**, pp 168–175, doi:doi.org/10.1016/j.scitotenv.2018.10.271.

Loblaw (2020) *Corporate Social Responsibility 2020,* Loblaw Companies Limited, accessed July 2021.

Marcos A, Trigo D, Muñiz-González AB, Tilikj N, Martínez-Guitarte JL and Novo M (2021) 'Effects of bisphenol S on the life cycle of earthworms and its assessment in the context of climate change', *Science of The Total Environment,* **781**, pp 146689, doi:doi.org/10.1016/j.scitotenv.2021.146689.

Michałowicz J, Mokra K and Bąk A (2015) 'Bisphenol A and its analogs induce morphological and biochemical alterations in human peripheral blood mononuclear cells (in vitro study)', *Toxicology in Vitro,* **29**(7), pp 1464–1472, doi:doi.org/10.1016/j.tiv.2015.05.012.

Molina-Molina JM, Jiménez-Díaz I, Fernández MF, Rodriguez-Carrillo A, Peinado FM, Mustieles V, Barouki R, Piccoli C, Olea N and Freire C (2019) 'Determination of bisphenol A and bisphenol S concentrations and assessment of estrogen- and anti-androgen-like activities in thermal paper receipts from Brazil, France, and Spain', *Environmental Research,* **170**, pp 406–415, doi:doi.org/10.1016/j.envres.2018.12.046.

Montoto-Martínez T, De la Fuente J, Puig-Lozano R, Marques N, Arbelo M, Hernández-Brito JJ, Fernández A and Gelado-Caballero MD (2021) 'Microplastics, bisphenols, phthalates and pesticides in odontocete species in the Macaronesian Region (Eastern North Atlantic)', *Marine Pollution Bulletin,* **173**, pp 113105, doi:doi.org/10.1016/j.marpolbul.2021.113105.

Moreman J, Lee O, Trznadel M, David A, Kudoh T and Tyler CR (2017) 'Acute toxicity, teratogenic, and estrogenic effects of bisphenol A and its alternative replacements bisphenol S, bisphenol F, and bisphenol AF in zebrafish embryo-larvae', *Environmental Science & Technology,* **51**(21), pp 12796–12805, doi:doi.org/10.1021/acs.est.7b03283.

Naderi M, Wong MYL and Gholami F (2014) 'Developmental exposure of zebrafish (Danio rerio) to bisphenol-S impairs subsequent reproduction potential and hormonal balance in adults', *Aquatic Toxicology,* **148**, pp 195–203, doi:doi.org/10.1016/j.aquatox.2014.01.009.

Naderi M, Salahinejad A, Attaran A, Chivers DP and Niyogi S (2020) 'Chronic exposure to environmentally relevant concentrations of bisphenol S differentially affects cognitive behaviors in adult female zebrafish', *Environmental Pollution,* **261**, pp 114060, doi:doi.org/10.1016/j.envpol.2020.114060.

Nejumal KK, Dineep D, Mohan M, Krishnan KP, Aravind UK and Aravindakumar CT (2017) 'Presence of bisphenol S and surfactants in the sediments of Kongsfjorden: a negative impact of human activities in Arctic?', *Environmental Monitoring and Assessment,* **190**(1), pp 22, doi:doi.org/10.1007/s10661-017-6383-7.

NICNAS (2015) *Phenol, 4,4'-sulfonylbis-: Human health tier II assessment* National Industrial Chemicals Notification and Assessment Scheme, accessed July 2021.

NICNAS (2019) *Polymers including formaldehyde and Bisphenol S (BPS): Human health tier II assessment* National Industrial Chemicals Notification and Assessment Scheme, accessed July 2021.

NITE (2020) *4,4'-Sulfonyldiphenol*, National Institute of Technology and Evaluation, accessed October 2021.

OECD (Organisation for Economic Co-operation and Development) (1995) *Guidance document for aquatic effects assessment*, Organisation for Economic Co-operation and Development, Paris.

OECD (Organisation for Economic Cooperation and Development) (2013) *SIDS Initial Assessment Profile: 4,4'-sulfonyldiphenol (CAS RN 80-09-1),* accessed July 2021.

OECD (Organisation for Economic Cooperation and Development) (2019) *Guiding Principles and Key Elements for Establishing a Weight of Evidence for Chemical Assessment*, Environment, Health and Safety Division, Environment Directorate accessed July 2021.

Ogata Y, Goda S, Toyama T, Sei K and Ike M (2013) 'The 4-tert-butylphenol-utilizing bacterium *Sphingobium fuliginis* OMI can degrade bisphenols via phenolic ring hydroxylation and meta-cleavage pathway', *Environmental Science & Technology,* **47**(2), pp 1017–1023, doi:doi.org/10.1021/es303726h.

OHA (Oregon Health Authority) (2021) *Toxic Substances, Environmental Public Health, Toxic-Free Kids Program,* accessed July 2021.

Pan Y, Shen M, Du B, Luo D, Chen H, Zhu C and Zeng L (2021) 'Occurrence and nationwide distribution of multiple novel bisphenol S analogues in municipal sewage sludge across China', *Environmental Science & Technology Letters,* **8**(9), pp 766–772, doi:doi.org/10.1021/acs.estlett.1c00545.

Papaspyrides CD, Pavlidou S and Vouyiouka SN (2009) 'Development of advanced textile materials: Natural fibre composites, anti-microbial, and flame-retardant fabrics', *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications,* **223**(2), pp 91-102, doi:doi.org/10.1243/14644207JMDA200.

Park S, Hong Y, Lee J, Kho Y and Ji K (2019) 'Chronic effects of bisphenol S and bisphenol SIP on freshwater waterflea and ecological risk assessment', *Ecotoxicology and Environmental Safety,* **185**, pp 109694, doi:doi.org/10.1016/j.ecoenv.2019.109694.

Pivnenko K, Pedersen GA, Eriksson E and Astrup TF (2015) 'Bisphenol A and its structural analogues in household waste paper', *Waste Management,* **44**, pp 39–47, doi:doi.org/10.1016/j.wasman.2015.07.017.

Qian Y, Jia X, Ding T, Yang M, Yang B and Li J (2021) 'Occurrence and removal of bisphenol analogues in wastewater treatment plants and activated sludge bioreactor', *Science of The Total Environment,* **758**, pp 143606, doi:doi.org/10.1016/j.scitotenv.2020.143606.

Qiu W, Zhao Y, Yang M, Farajzadeh M, Pan C and Wayne NL (2016) 'Actions of bisphenol A and bisphenol S on the reproductive neuroendocrine system during early development in zebrafish', *Endocrinology,* **157**(2), pp 636–647, doi:doi.org/10.1210/en.2015-1785.

Qiu W, Yang M, Liu J, Xu H, Luo S, Wong M and Zheng C (2019a) 'Bisphenol S-induced chronic inflammatory stress in liver via peroxisome proliferator-activated receptor γ using fish in vivo and in vitro models', *Environmental Pollution,* **246**, pp 963–971, doi:doi.org/10.1016/j.envpol.2018.11.039.

Qiu W, Zhan H, Hu J, Zhang T, Xu H, Wong M, Xu B and Zheng C (2019b) 'The occurrence, potential toxicity, and toxicity mechanism of bisphenol S, a substitute of bisphenol A: A critical review of recent progress', *Ecotoxicology and Environmental Safety,* **173**, pp 192–202, doi:doi.org/10.1016/j.ecoenv.2019.01.114.

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (2021) *REACH registration dossier for 4,4'-sulphonyldiphenol (CAS RN 80-09-1),* accessed July 2021.

Russo G, Barbato F and Grumetto L (2017) 'Monitoring of bisphenol A and bisphenol S in thermal paper receipts from the Italian market and estimated transdermal human intake: A pilot study', *Science of The Total Environment,* **599–600**, pp 68–75, doi:doi.org/10.1016/j.scitotenv.2017.04.192.

Sait STL, Sørensen L, Kubowicz S, Vike-Jonas K, Gonzalez SV, Asimakopoulos AG and Booth AM (2021) 'Microplastic fibres from synthetic textiles: Environmental degradation and additive chemical content', *Environmental Pollution,* **268**, pp 115745, doi:doi.org/10.1016/j.envpol.2020.115745.

Schmidt N, Fauvelle V, Ody A, Castro-Jiménez J, Jouanno J, Changeux T, Thibaut T and Sempéré R (2019) 'The Amazon river: A major source of organic plastic additives to the tropical North Atlantic?', *Environmental Science & Technology,* **53**(13), pp 7513–7521, doi:doi.org/10.1021/acs.est.9b01585.

Schmidt N, Castro-Jiménez J, Fauvelle V, Ourgaud M and Sempéré R (2020) 'Occurrence of organic plastic additives in surface waters of the Rhône River (France)', *Environmental Pollution,* **257**, pp 113637, doi:doi.org/10.1016/j.envpol.2019.113637.

Shi Y, Sun Y, Gao B, Xu H and Wu J (2019) 'Importance of organic matter to the retention and transport of bisphenol A and bisphenol S in saturated soils', *Water, Air, & Soil Pollution,* **230**(2), pp 43, doi:doi.org/10.1007/s11270-019-4096-y.

SpecialChem (2021) *Polyethersulfone (PES) - Complete Guide on High-temperature Engineering Polymer,* SpecialChem, accessed July 2021.

Sun Q, Wang Y, Li Y, Ashfaq M, Dai L, Xie X and Yu C-P (2017) 'Fate and mass balance of bisphenol analogues in wastewater treatment plants in Xiamen City, China', *Environmental Pollution,* **225**, pp 542–549, doi:doi.org/10.1016/j.envpol.2017.03.018.

Tang S, He C, Thai PK, Heffernan A, Vijayasarathy S, Toms L, Thompson K, Hobson P, Tscharke BJ, O'Brien JW, Thomas KV and Mueller JF (2020) 'Urinary concentrations of bisphenols in the Australian population and their association with the *per capita* mass loads in wastewater', *Environmental Science & Technology,* **54**(16), pp 10141–10148, doi:doi.org/10.1021/acs.est.0c00921.

Target (2020) *2020 Target Corporate Responsibility Report,* Target Corporation, accessed July 2021.

Thayer KA, Taylor KW, Garantziotis S, Schurman SH, Kissling GE, Hunt D, Herbert B, Church R, Jankowich R, Churchwell MI, Scheri RC, Birnbaum LS and Bucher JR (2016) 'Bisphenol A, bisphenol S, and 4-hydro xyphenyl 4-isopro oxyphenyl sulfone (BPSIP) in urine and blood of cashiers', *Environmental Health Perspectives,* **124**(4), pp 437–444, doi:doi.org/10.1289/ehp.1409427.

UN (United Nations) (2017) *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)* (Seventh revised edition ed), accessed July 2021.

UNEP (United Nations Environment Programme) (1987) *The Montreal Protocol on Substances that Deplete the Ozone Layer,* Ozone Secretariat, accessed July 2021.

UNEP (United Nations Environment Programme) (2001) *The Stockholm Convention on Persistent Organic Pollutants,* accessed July 2021.

UNEP & FAO (United Nations Environment Programme and Food and Agriculture Organization of the United Nations) (1998) *Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade,* accessed July 2021.

US EPA (United States Environmental Protection Agency) (2015) *Bisphenol A alternatives in thermal paper*, Agency USEP, accessed July 2021.

US EPA (United States Environmental Protection Agency) (2017) *Estimation Programs Interface (EPI) SuiteTM for Microsoft Windows®*, v 4.11. United States Environmental Protection Agency.

US EPA (United States Environmental Protection Agency) (2021) *High Production Volume List,* accessed July 2021.

Usman A and Ahmad M (2016) 'From BPA to its analogues: Is it a safe journey?', *Chemosphere,* **158**, pp 131–142, doi:doi.org/10.1016/j.chemosphere.2016.05.070.

Viñas P, Campillo N, Martínez-Castillo N and Hernández-Córdoba M (2010) 'Comparison of two derivatization-based methods for solid-phase microextraction–gas chromatography–mass spectrometric determination of bisphenol A, bisphenol S and biphenol migrated from food cans', *Analytical and Bioanalytical Chemistry,* **397**(1), pp 115–125, doi:doi.org/10.1007/s00216-010-3464-7.

Viñas P, López-García I, Campillo N, Rivas RE and Hernández-Córdoba M (2012) 'Ultrasound-assisted emulsification microextraction coupled with gas chromatography–mass spectrometry using the Taguchi design method for bisphenol migration studies from thermal printer paper, toys and baby utensils', *Analytical and Bioanalytical Chemistry,* **404**(3), pp 671–678, doi:doi.org/10.1007/s00216-012-5957-z.

Wang H, Liu Z-h, Zhang J, Huang R-p, Yin H, Dang Z, Wu P-x and Liu Y (2019) 'Insights into removal mechanisms of bisphenol A and its analogues in municipal wastewater treatment plants', *Science of The Total Environment,* **692**, pp 107–116, doi:doi.org/10.1016/j.scitotenv.2019.07.134.

Wang Q, Chen M, Shan G, Chen P, Cui S, Yi S and Zhu L (2017) 'Bioaccumulation and biomagnification of emerging bisphenol analogues in aquatic organisms from Taihu Lake, China', *Science of The Total Environment,* **598**, pp 814–820, doi:doi.org/10.1016/j.scitotenv.2017.04.167.

Wang W, Zhang X, Qin J, Wei P, Jia Y, Wang J and Ru S (2019) 'Long-term bisphenol S exposure induces fat accumulation in liver of adult male zebrafish (Danio rerio) and slows yolk lipid consumption in F1 offspring', *Chemosphere,* **221**, pp 500–510, doi:doi.org/10.1016/j.chemosphere.2019.01.020.

Wang X, Chen J, Ji R, Liu Y, Su Y and Guo R (2019) 'Degradation of bisphenol S by a bacterial consortium enriched from river sediments', *Bulletin of Environmental Contamination and Toxicology,* **103**(4), pp 630–635, doi:doi.org/10.1007/s00128-019-02699-7.

Wei P, Zhao F, Zhang X, Liu W, Jiang G, Wang H and Ru S (2018) 'Transgenerational thyroid endocrine disruption induced by bisphenol S affects the early development of zebrafish offspring', *Environmental Pollution,* **243**, pp 800–808, doi:doi.org/10.1016/j.envpol.2018.09.042.

Wei P, Zhao F, Zhang X and Ru S (2020) 'Long-term exposure of zebrafish to bisphenol S impairs stress function of hypothalamic-pituitary-interrenal axis and causes anxiety-like behavioral responses to novelty', *Science of The Total Environment,* **716**, pp 137092, doi:doi.org/10.1016/j.scitotenv.2020.137092.

Wilkinson JL, Hooda PS, Swinden J, Barker J and Barton S (2017) 'Spatial distribution of organic contaminants in three rivers of Southern England bound to suspended particulate material and dissolved in water', *Science of The Total Environment,* **593–594**, pp 487–497, doi:doi.org/10.1016/j.scitotenv.2017.03.167.

Wong YM, Li R, Lee CKF, Wan HT and Wong CKC (2017) 'The measurement of bisphenol A and its analogues, perfluorinated compounds in twenty species of freshwater and marine fishes, a time-trend comparison and human health based assessment', *Marine Pollution Bulletin,* **124**(2), pp 743–752, doi:doi.org/10.1016/j.marpolbul.2017.05.046.

WSDE (Washington State Department of Ecology) (2021) *Children's Safe Products Reporting Rule - Rationale for Reporting List of Chemicals of High Concern to Children 2011-2017,* accessed July 2021.

Wu NC and Seebacher F (2021) 'Bisphenols alter thermal responses and performance in zebrafish (Danio rerio)', *Conservation Physiology,* **9**(1), doi:doi.org/10.1093/conphys/coaa138.

Xiao X, Zhang X, Bai J, Li J, Zhang C, Zhao Y, Zhu Y, Zhang J and Zhou X (2021) 'Bisphenol S increases the obesogenic effects of a high-glucose diet through regulating lipid metabolism in Caenorhabditis elegans', *Food Chemistry,* **339**, pp 127813, doi:doi.org/10.1016/j.foodchem.2020.127813.

Xue J, Liu W and Kannan K (2017) 'Bisphenols, Benzophenones, and Bisphenol A Diglycidyl Ethers in Textiles and Infant Clothing', *Environmental Science & Technology,* **51**(9), pp 5279–5286, doi:doi.org/10.1021/acs.est.7b00701.

Xue J and Kannan K (2019) 'Mass flows and removal of eight bisphenol analogs, bisphenol A diglycidyl ether and its derivatives in two wastewater treatment plants in New York State, USA', *Science of The Total Environment,* **648**, pp 442–449, doi:doi.org/10.1016/j.scitotenv.2018.08.047.

Yamazaki E, Yamashita N, Taniyasu S, Lam J, Lam PKS, Moon H-B, Jeong Y, Kannan P, Achyuthan H, Munuswamy N and Kannan K (2015) 'Bisphenol A and other bisphenol analogues including BPS and BPF in surface water samples from Japan, China, Korea and India', *Ecotoxicology and Environmental Safety,* **122**, pp 565–572, doi:doi.org/10.1016/j.ecoenv.2015.09.029.

Yan Z, Liu Y, Yan K, Wu S, Han Z, Guo R, Chen M, Yang Q, Zhang S and Chen J (2017) 'Bisphenol analogues in surface water and sediment from the shallow Chinese freshwater lakes: Occurrence, distribution, source apportionment, and ecological and human health risk', *Chemosphere,* **184**, pp 318–328, doi:doi.org/10.1016/j.chemosphere.2017.06.010.

Yu X, Xue J, Yao H, Wu Q, Venkatesan AK, Halden RU and Kannan K (2015) 'Occurrence and estrogenic potency of eight bisphenol analogs in sewage sludge from the U.S. EPA targeted national sewage sludge survey', *Journal of Hazardous Materials,* **299**, pp 733–739, doi:doi.org/10.1016/j.jhazmat.2015.07.012.

Zhang D-h, Zhou E-x and Yang Z-l (2017) 'Waterborne exposure to BPS causes thyroid endocrine disruption in zebrafish larvae', *PLOS ONE,* **12**(5), pp e0176927, doi:doi.org/10.1371/journal.pone.0176927.

Zhang Y-F, Ren X-M, Li Y-Y, Yao X-F, Li C-H, Qin Z-F and Guo L-H (2018) 'Bisphenol A alternatives bisphenol S and bisphenol F interfere with thyroid hormone signaling pathway in vitro and in vivo', *Environmental Pollution,* **237**, pp 1072–1079, doi:doi.org/10.1016/j.envpol.2017.11.027.

Zhao X, Qiu W, Zheng Y, Xiong J, Gao C and Hu S (2019) 'Occurrence, distribution, bioaccumulation, and ecological risk of bisphenol analogues, parabens and their metabolites in the Pearl River Estuary, South China', *Ecotoxicology and Environmental Safety,* **180**, pp 43–52, doi:doi.org/10.1016/j.ecoenv.2019.04.083.

Zheng C, Liu J, Ren J, Shen J, Fan J, Xi R, Chen W and Chen Q (2019) 'Occurrence, distribution and ecological risk of bisphenol analogues in the surface water from a water diversion project in Nanjing, China', *International Journal of Environmental Research and Public Health,* **16**(18), doi:doi.org/10.3390/ijerph16183296.

Zhou N, Liu Y, Cao S, Guo R, Ma Y and Chen J (2020) 'Biodegradation of bisphenol compounds in the surface water of Taihu Lake and the effect of humic acids', *Science of The Total Environment,* **723**, pp 138164, doi:doi.org/10.1016/j.scitotenv.2020.138164.