



FOREVER CHEMICALS

The Health and Environmental
Risks of Bisphenol A
and its Analogues

The Precautionary Principle

'When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically'.

Executive Summary

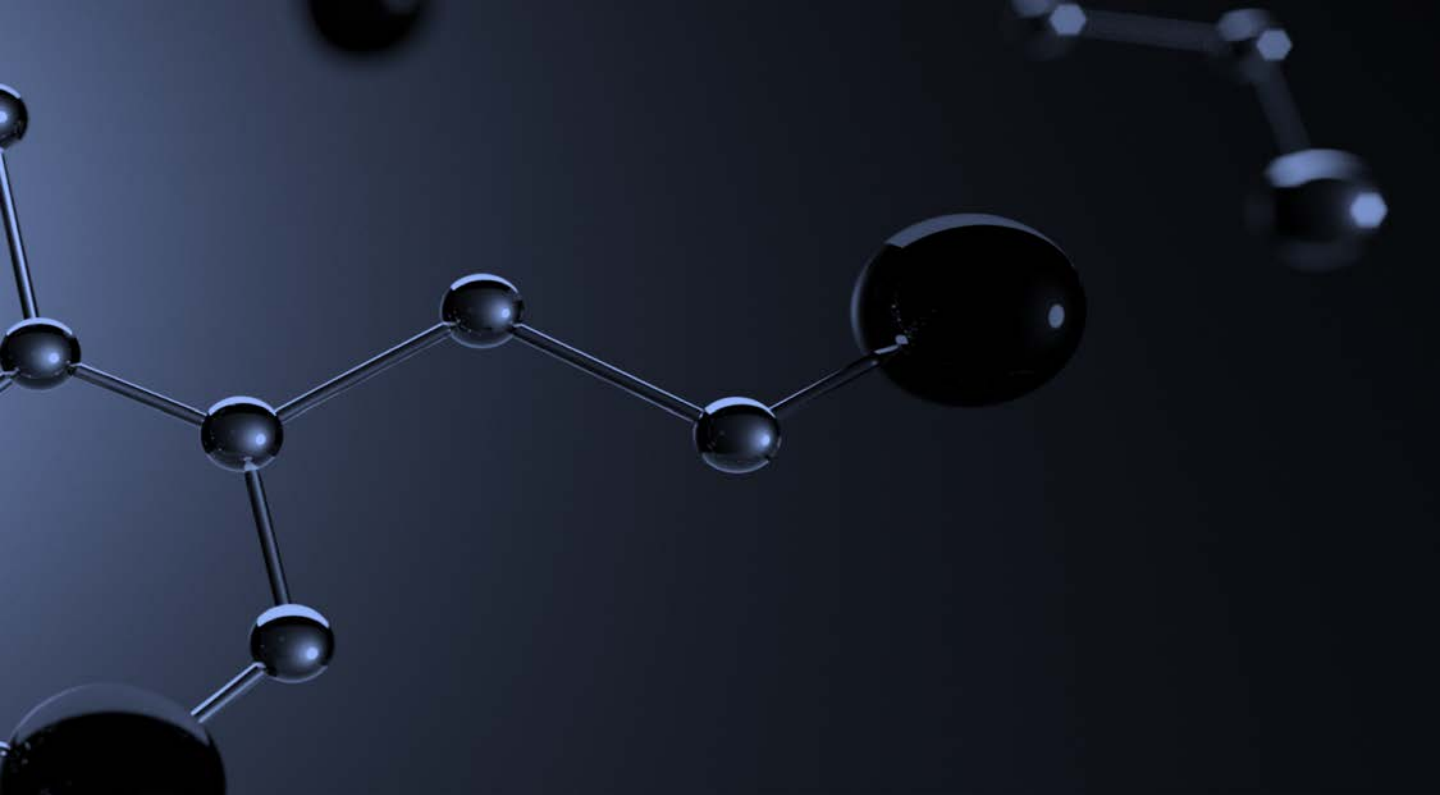
Bisphenol A (BPA) is an industrial chemical widely used in a range of products we use in everyday life and is developing a reputation as a chemical that should be avoided. BPA is cheap and easily accessible and is therefore produced on mass for use worldwide. The chemical itself is used in the production of many common plastics, resins and paper products.

Food storage containers, baby bottles, plastic drink bottles, tinned food cans, paper receipts and concert tickets are a few everyday items that may contain BPA. Studies have found that unbonded BPA molecules in plastic products and the linings inside food cans can leach out into the food and water that they are in contact with and consequentially enter the human body. The degree to which BPA leaches out of these products increases with the age of the product itself and with the temperature it is exposed to. Furthermore, a number of studies have provided evidence that BPA can enter the body through dermal contact with thermal paper products. BPA is a problem because it is both highly mobile and fairly stable in the environment.

The ability of BPA to enter the human body from contact with these everyday items means that exposure to it is widespread among the general public. This is particularly concerning given that BPA is known to be an Endocrine Disrupting Chemical (EDC). The endocrine system is a network of glands and organs located throughout the body. It's similar to the nervous system in that it plays a vital role in controlling and regulating many of the body's functions. However, while the nervous system uses nerve impulses and neurotransmitters for communication, the endocrine system uses chemical messengers called hormones. Endocrine disrupting chemicals can interfere with the messages of the endocrine system and impact human health in a variety of ways.

Some of the detrimental impacts associated with endocrine disruption are reduced fertility in men and women, increased risk of breast and prostate cancers, childhood behavioural issues and impaired neurodevelopment, obesity and Type 2 Diabetes, among others.

Risk assessment of BPA and its structurally similar alternatives (analogues) presents a challenge to human health and medical research.



Unlike many other toxic chemicals, the effects do not follow typical dose-response toxicological patterns, making recommendations around safe exposure levels difficult.

BPA has also been detected in the environment and is likely to be impacting the health of wildlife, particularly aquatic organisms. Studies on fish have found negative health impacts in both exposed individuals and in the offspring of these individuals, showing that the health impacts of BPA can be carried across generations.

Guided by the precautionary principle Planet Ark is interested in supporting initiatives that limit exposure to potentially harmful chemicals. There is still ongoing debate as to whether the amount of BPA we are exposed to in our everyday lives is enough to cause any adverse human health effects. In Europe, Japan and some US states, regulations have been put in place to ban or restrict the use of products containing BPA. The issue with this transition is that in many cases, BPA is replaced with analogues such as Bisphenol S (BPS), Bisphenol F (BPF) or Bisphenol B (BPB). This group of chemicals is often referred to as Phenols. BPS is an organic compound with a very similar composition to that of BPA and likely produces the same effects on human and environmental health. BPF and BPB also have similar structures and endocrine disrupting properties to BPS and BPA and are not considered sound replacements.

For this reason, Planet Ark supports a transition to safer alternatives to Phenols (BPA and its analogues). The aim of this report is to promote awareness of the health and environmental risks of Phenols and support a transition to the use of lower-risk chemicals. The thermal paper industry has begun to invest in the use of phenol-free chemicals in their cash register receipts. Planet Ark supports this proactive move and the shift to safer paper products, specifically till/receipt rolls, that consumers are exposed to frequently.

Planet Ark also supports the conclusions of organisations such as Project TENDR. This is a collaboration of leading scientists, health professionals and children's and environmental advocates based in the USA. They have concluded that manufacturers of any new chemicals must prove they are safe, instead of the current process which assumes chemicals to be safe until harm is proven e.g. BPA use in products. This change in public policy would stop potentially unsafe chemicals being used for decades, causing substantial health harm before being pulled from the market. This would result in industrial chemicals being held to the same approval process standard as pharmaceuticals.

Although there are examples of positive product changes being made, until these safer options are widespread and readily available for consumers, we recommend individuals limit exposure to products containing BPA and its analogues where possible.

What is BPA?

For over 50 years BPA has been used in the production of epoxy resins and polycarbonate plastics, so millions of tonnes of it are produced each year¹. Resins and plastics are polymers composed of molecular chains (like bead necklaces) made up of repeating monomers (the beads) bonded together. If the chains are stacked tightly next to each other the resulting plastic is hard and crystalline, and not very flexible, because the chains cannot slide easily past each other.

Polycarbonates are strong, tough materials, and some grades are optically transparent. They are easily worked, moulded and thermoformed. Because of these properties, polycarbonates find many applications. This polymer is ideal for drink bottles and food containers. Additionally, polycarbonate plastics are used in the everyday lives of most people in such items as baby bottles, eyeglass lenses and medical equipment among many others¹.

Example of a BPA plastic

Polycarbonate plastic is composed of polymer chains stacked together. Each chain is composed of BPA monomers connected by carbonate links

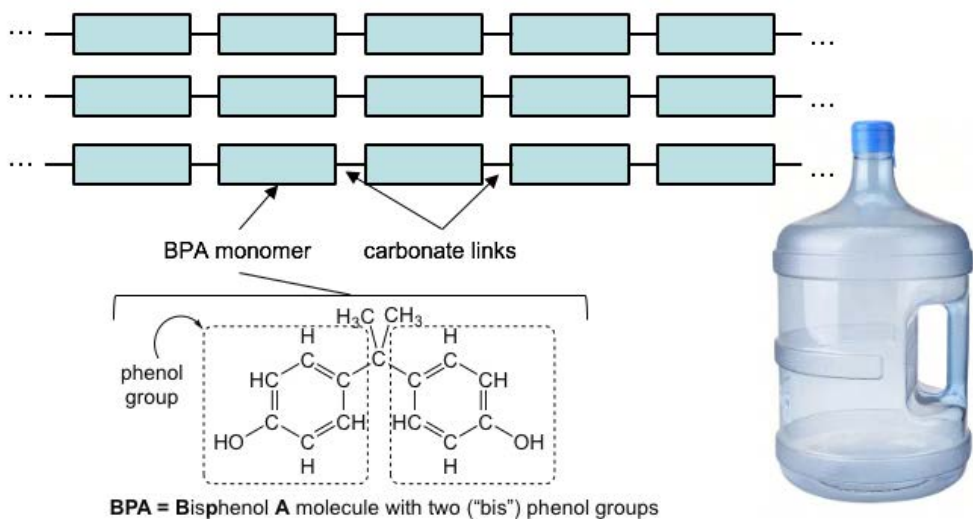


Figure 1. Bisphenol A monomers are bonded together in polycarbonate plastics and epoxy resins

If additional chemicals are added in the production process, the molecular chains cross-link to each other making the polymer suitable as an epoxy resin for use in lining cans. When these plastics and resins are heated or decomposed by light, unbonded BPA is released, and dissolves into the food or beverage to be consumed. These materials may also contain traces of unreacted, unbonded BPA that has not been polymerised

Additionally, BPA is present in thermal papers such as till receipts, aeroplane tickets and self-adhesive labels. In these products it is used as an unbonded colour developer that is activated during the printing process². Since it is all unbonded, the BPA in thermal paper can leach out and be easily absorbed through the skin³.

Analogues of BPA

There are more than 24 compounds used as alternatives to BPA and relatively little is known about potential toxicity of these compounds⁴. BPS is the most common replacement and predicted to increase in use as more restrictions and bans are placed on the use of BPA. This is concerning as BPS has a very similar chemical structure to BPA and is likely to present very similar risks to those posed by BPA⁵. A study by Moon (2019), found that as the structures of BPS and BPA are so alike, BPS has similar metabolism, potency and action as BPA in animal studies. Furthermore, because of these similarities, it is likely to have similar health effects on both humans and wildlife⁵. Other common commercially available analogues of BPA are Bisphenol F (BPF) and Bisphenol B (BPB). The structures of all these compounds are similar to estradiol, the major female sex hormone, as shown in Figure 2.

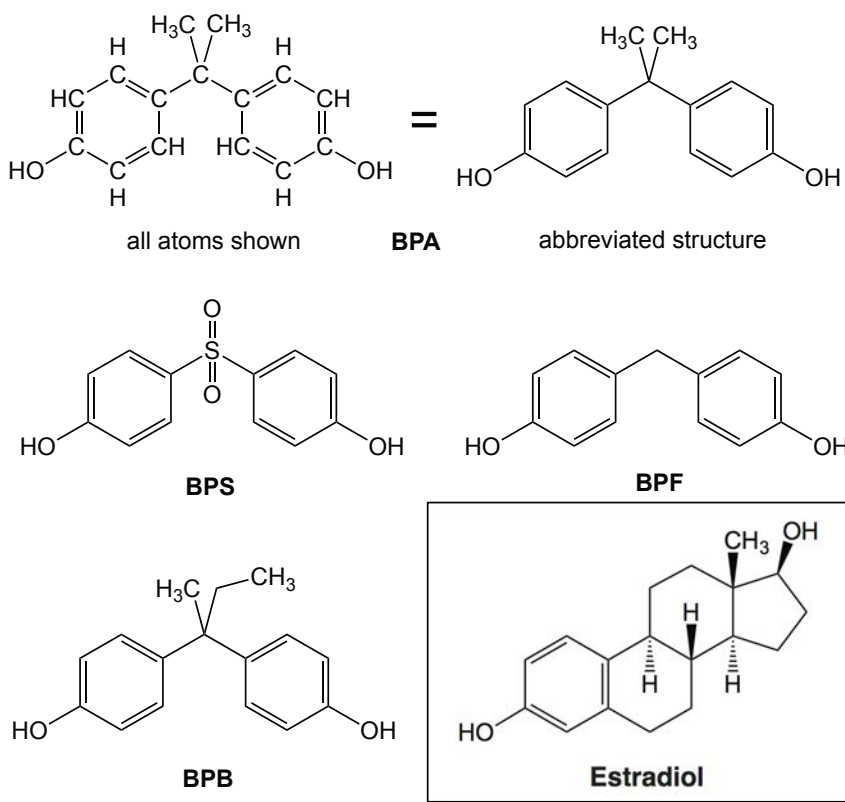


Figure 2. The molecular structures and shapes of BPA and its analogues – BPS, BPF and BPB – are similar to each other, and to the shape of the female sex hormone, estradiol when it folds up.



The risks associated with BPA

1. Human Health



2. Dosage



3. Environment





1. Human Health



Studies on BPA in humans have shown that most people tested (adult men and women, pregnant women and children) have BPA present in both tissue and body fluids¹.

Hormonal disturbance

The structural and shape similarity of BPA and its analogues to estradiol shown in Figure 2 explains why they can interfere with the hormone endocrine system in animals. Most hormone molecules act like 'keys' that bind to receptor molecule 'locks' to trigger a specific response in cells (Figure 3 below). BPA and its analogues can mimic hormone receptor-binding behaviour, acting as potential endocrine disruptor chemicals (EDCs) in humans, depending on the dose⁶. Our constant interaction with products containing BPA means that we are exposed to potential disruption of our endocrine systems on a daily basis. We are also frequently exposed to other EDCs in commonly used products such as cosmetics, detergents, pharmaceuticals, pesticides, toys and food additives⁷. Most importantly, there are no toxicological studies of the combined (synergistic) health effects due to these multiple exposures to EDCs.

BPS has the potential to interact with the endocrine system in a similar way. Rochester and Bolden (2015) undertook a literature review of the hormonal effects of BPS, including 25 in vitro (laboratory), and seven in vivo (live organism) studies.

The majority of these studies found the potency of BPS to be of a similar order of magnitude and of similar action to BPA.

BPS also showed effects including altered organ weight, reproductive endpoints and enzyme activity, both in vitro and in vivo⁸.

Exposure to BPA and its analogues

Exposure to BPA can occur through many routes – including ingesting contaminated food/drink, absorption through skin and inhalation of particles⁹. Studies on BPA in humans have shown that most people tested (adult men and women, pregnant women and children) have BPA present in both tissue and body fluids¹. As more research is conducted into BPA and alternatives such as BPS, the risks associated with exposure are becoming clearer. BPA exposure can affect a range of human health endpoints, primarily through exposure from regularly used items such as drink bottles, canned food, plastic storage containers and thermal paper till receipts^{10,11}.

Figure 4 highlights some of the detrimental health endpoints associated with BPA exposure⁹.

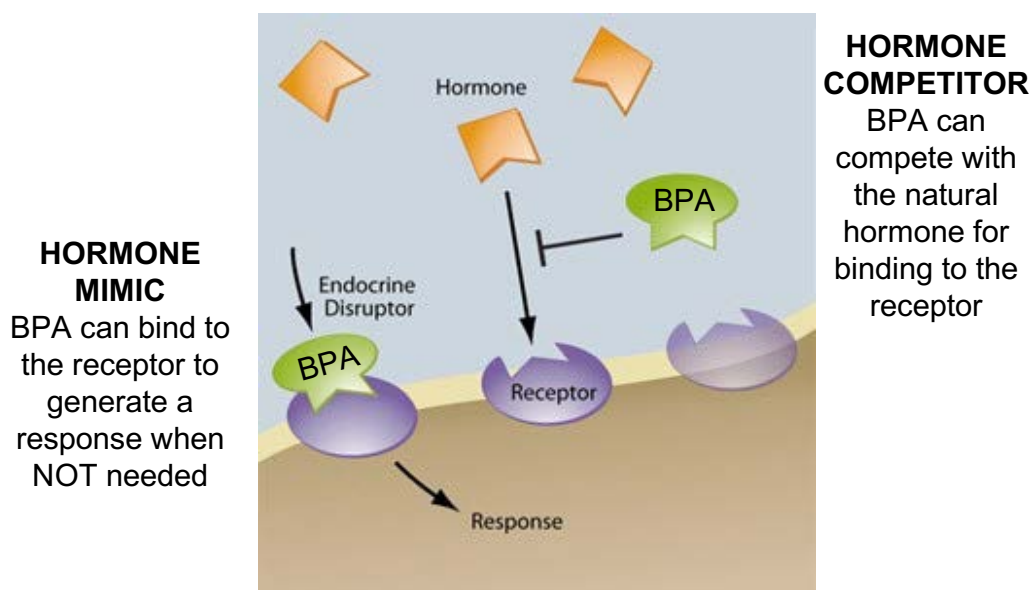


Figure 3. Graphical representation of how an endocrine disruptor chemical (EDC) can mimic, or compete with, a natural hormone as it binds to its receptor to trigger a cellular response.

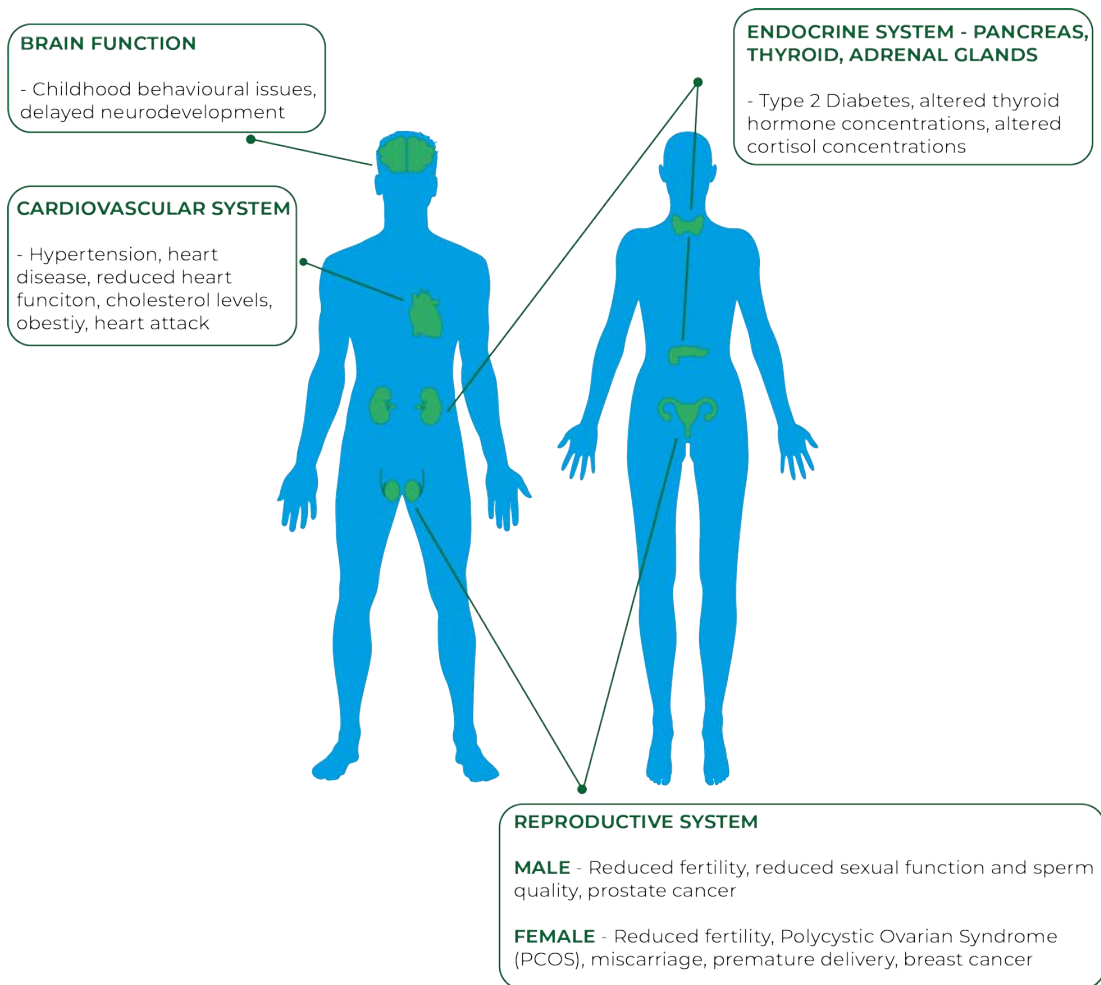


Figure 4: Diagram of the human health endpoints that BPA exposure has been linked to. As there are relatively few studies carried out on humans, these results primarily come from animal studies where the results have been extrapolated to reflect impacts on human health.

BPS

A study in 2019 exposed pigs to both BPS and BPA orally. The results showed significantly higher levels of available, circulating BPS compared to levels of BPA in the other test group. The results of this study highlight the high absorption potential and bioavailability of BPS when ingested orally, potentially making it even more of a health threat than BPA. Pigs have a very similar digestive tract to humans, so the results of this study can be extrapolated to reflect human ingestion of BPS¹².

Although there are fewer studies on the health implications of BPS, alarming results have been discovered in some animal studies. A 2019 study found that even a single dose of BPS could have severe impacts on the heart.

Mice were exposed to a dose of BPS that mimicked levels found in humans and within five minutes, were found to have reduced heart function. Furthermore, when BPA and BPS were compared, the effects of BPS on the mouse hearts were more severe than those produced by BPA exposure, but only in females. This is because BPS interfered with oestrogen receptors that are involved with heart function, causing issues with muscle contraction. These findings are concerning for human health because they show that exposure to both BPA and BPS (particularly in women) could cause potentially life-threatening heart conditions. Additionally, it provides evidence that it does not take a build up over time for this chemical to produce effects and that a single dose can pose a huge risk¹³.



2. Dosage



The dosage-response relationship of BPA in the human body is possibly the most controversial and uncertain aspect of its risk assessment to human health.

Dosage–response relationship of BPA

The dosage–response relationship of BPA in the human body is possibly the most controversial and uncertain aspect of its risk assessment to human health. In many studies and reports, particularly by regulatory authorities (FDA, EPA) in the United States, the conclusions have been that the levels of exposure we are faced with on a daily basis are not considered high enough to cause physical harm¹⁴⁻¹⁶. The Tolerable Daily Intake (TDI) of BPA has been set by the European Food Safety Authority (EFSA) as 4µg /kg bodyweight/day, recently lowered from the previous level of 50µg /kg bodyweight/day¹⁴. A number of studies on BPA concentrations in urine and blood samples after exposure have shown that contact with BPA in everyday life through products such as tinned food, plastic containers and till receipts is not enough to reach the TDI limit¹⁷.

Traditional toxicology assumes that increased dose will lead to increased effect, which is why many studies on BPA have exposed test subjects to high doses over short periods of time to test for acute effects, then extrapolating to lower doses to develop the TDI¹⁸. However, in the case of BPA, the normal hypothesis that risk increases with dosage cannot be assumed¹⁹.

Indeed, detrimental health effects associated with BPA have been found to be present at low doses¹⁸. Studies have demonstrated that the low doses humans and wildlife may be chronically exposed to are disturbing endocrine systems and leading to negative health impacts¹⁸. For example, a study by Howdeshell et.al (1999) found advanced puberty in the female offspring of pregnant mice administered with a low dose of BPA (2.4 µg/kg bodyweight/day) during pregnancy²⁰.

In 2013 the World Health Organisation (WHO) and United Nations Environment Programme (UNEP) updated their scientific assessment of endocrine disrupting chemicals²¹. Characteristics expected to be associated with these chemicals were a focus of this study and one that was highlighted is the ability of these chemicals to produce non-monotonic dose response curves (NMDRCs)^{18,20}. A NMDR dose-response relationship is defined by a curve whose slope changes direction within the range of tested doses¹⁹. For example, a small dose and large dose of an NMDR chemical may both cause significant effects, with a moderate dose having no effect¹⁹. Non-monotonicity presents a challenge to fundamental concepts of toxicology and may mean a change in scope of the research around BPA, BPS and other similar chemicals¹⁹.

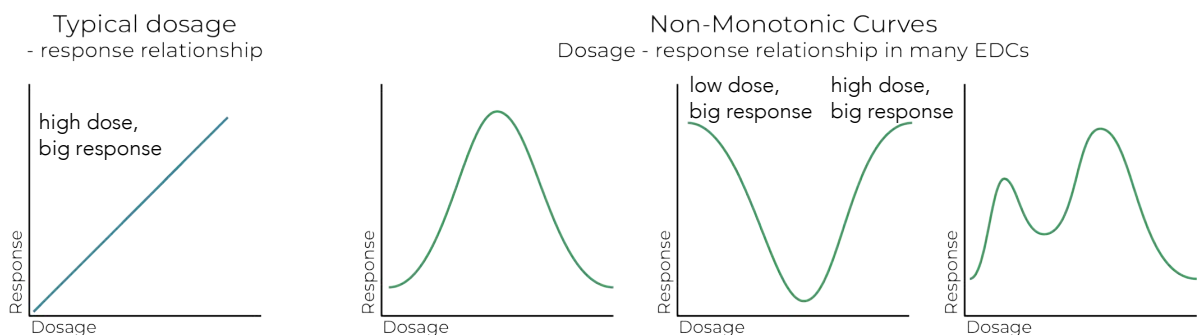
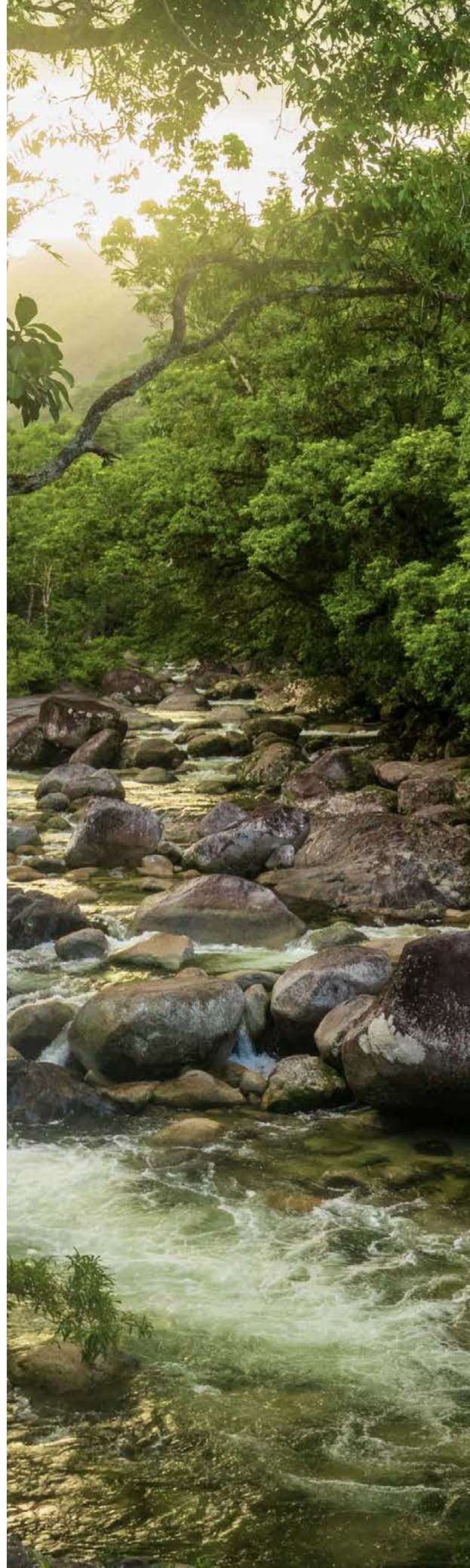


Figure 5: Displayed are graphs depicting a typical dosage-response relationship and three different types of NMDRCs. This includes an inverted U-shaped curve, a U-shaped curve, and a multiphasic curve. In contrast to the usual monotonic (increasing linear or curved) response, all of these are considered NMDRCs because the slope of the curve changes direction one or more times. Note the unexpected big response from a low dose in the U-shaped curve that results from some EDCs.

Another element of the BPA dosage debate is the issue of single vs repeated dose effects. Some of the studies on endpoint health effects of BPA in rodents have been criticised due to their use of a single dose of BPA (at high or low concentration), rather than repeated doses. Studies where only one dose of BPA was administered to test rodents have recorded negative health impacts. For example, the male offspring of pregnant mice administered a single, low dose of BPA were found to have an increase in size and number of prostate ducts²². This study and other similar ones indicate that even a single dose of BPA can cause lasting and transgenerational health impacts. However, there should be more of a focus on longer term, repeated exposure studies, to ensure scientific validity and to more accurately reflect the way humans and wildlife are exposed to BPA.

A recent study of the metabolism of BPA in humans raised further questions about the analytical techniques used to measure BPA concentrations in urine samples. A study on BPA concentrations in pregnant women measured metabolites (the by-product of metabolism, created when the body breaks down a chemical) of BPA in urine samples. The measurements from this study found average BPA levels to be 44 times higher than the most recent mean levels reported in individuals in the USA²³. Free BPA molecules metabolise very quickly, particularly after oral ingestion, so may have been missed in many previous studies not also analysing metabolites. The speed at which BPA is metabolised makes it difficult to study and may mean that not all the BPA we are exposed to is captured in analysis and we may be exposed to much higher levels than previously thought²³.



3. Environment



BPA can enter the environment during the manufacturing processes of chemicals, plastics and coatings, the water treatment processes and also through leaching from plastic products and waste in landfills²⁴.

In addition to BPA being a potential risk to human health, there is also evidence its presence in the natural environment is having negative impacts. BPA can enter the environment during the manufacturing processes of chemicals, plastics and coatings, the water treatment processes and also through leaching from plastic products and waste in landfills²⁴.

There have been a number of studies on concentrations of BPA in the environment. For example, in studies out of the US, BPA has been detected in surface water, ground water, wastewater, landfill leachate and soil²⁵. These deposits of BPA into the environment can lead to endocrine disrupting chemicals posing health risks to wildlife and whole ecosystems²³.

The water entering and exiting wastewater treatment plants, as well as wastewater sludge have been identified as significant sources of BPA²⁶. Wastewater treatment plants are often a source of secondary BPA pollution due to their inability to effectively remove BPA from the water sources²⁷. BPA can enter wastewater treatment plants through sewerage and storm water influent. If the BPA is not fully removed from the water that is released after the treatment process, it is consequentially integrated with natural water sources, exposing the wider environment to BPA²⁵.

Due to the presence of BPA in freshwater sources, aquatic organisms are particularly at risk of exposure to the potential deleterious health impacts it may cause²⁸. Among freshwater organisms, BPA has been found to affect growth, development and reproduction, with fish and aquatic invertebrates seemingly the most sensitive to the endocrine disrupting impacts of BPA²⁸.

For example, one study that exposed fish embryos to BPA found transgenerational impacts of this exposure. The subsequent generations of the exposed fish were found to suffer reproductive impairment and reduced embryonic survival in their offspring²⁸. Studies into BPA exposure in wildlife have also demonstrated the ability of low doses of BPA to effect specific health endpoints. Structural changes in the gonads of male carp and an increase in the breakdown of oocytes in female carp were found after 1mg/L BPA exposure²⁹. Furthermore, Lahnsteiner et al. (2005) observed reduced sperm quality and delayed ovulation in brown trout following BPA exposure of 1.75 mg/L, while ovulation ceased entirely at 5 mg/L BPA³⁰.

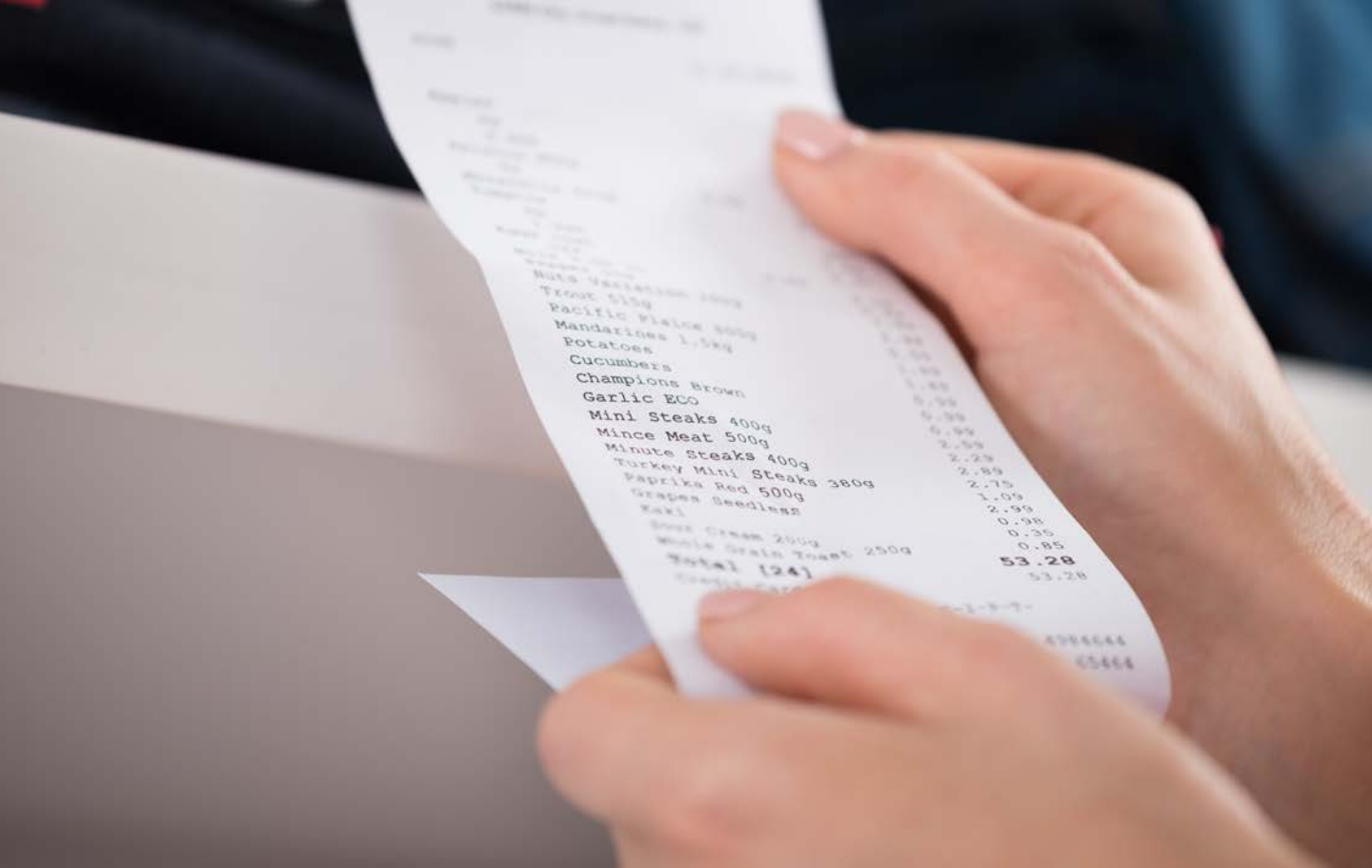
Given the oestrogenic properties of BPA, it has the ability to impact sex determination in certain organisms. The embryos of a species of Caiman (*Caiman latirostris*) were exposed to BPA through their eggshells at a critical time for sex determination during development. All embryos exposed to this treatment were born female³¹. This is particularly startling as Caiman sex determination is also impacted by temperature. Typically, Caiman embryos incubated at 30°C develop ovaries and embryos incubated at 33°C develop testes and, in this study, eggs were split 50/50 between these temperatures³¹. However, here the endocrine disrupting impacts of BPA were enough to override the effect of temperature and create females under conditions that would normally produce males.





BPA in thermal rolls

A health and environmental risk



Thermal paper is another source of BPA that many people interact with frequently. Thermal paper is used to print items such as point of sale receipts, plane and concert tickets, self-adhesive labels, parking tickets, faxes and other commonly used paper items³². Thermal paper is made up of layers and one of these layers is coated in BPA, which reacts with the ink on the paper when exposed to heat from the thermal head in the printer³³.

A study by Liao and Kannan (2011) found BPA present in 94% of all thermal paper receipts tested. Receipts are thought to be the most frequent source of BPA contact through thermal paper products³⁴. Studies comparing thermal paper with other products containing BPA consistently found that BPA levels in human blood and urine samples after contact with thermal paper are always considerably lower than contact with other sources, such as tinned food products³⁴. However, we know in the case of BPA, the typical monotonic dose-response correlation does not necessarily apply (see Figure5), and these lower levels have the potential to cause health problems.

A number of studies have confirmed that concentrations of BPA in urine and blood samples increase with handling time of thermal receipts^{2,32,33}.

The BPA in thermal paper is in an unbonded monomeric form, which moves freely and can be easily transferred to the skin³⁵. Lipophilic chemicals (compounds that are dissolvable in fats/oils) such as BPA are easily absorbed dermally and enter the body through pores in the skin that have contact with the paper³⁸.

Biomonitoring data has shown that 90% of humans studied had BPA present in their urine, showing how frequently we come into contact with it^{2,36}.

Occupational exposure is of particular concern, especially in cashiers due to their constant handling of till receipts at work. A study conducted in the United States measured urinary levels of BPA in pregnant women working as cashiers, as teachers and as industrial workers. The women working as cashiers were found to have the highest levels of BPA³⁷.

Transdermal absorption has also been shown to increase with the use of hand sanitizers, moisturising products and sunscreen. Studies have shown that people that have applied hand sanitizers with dermal penetration enhancing chemicals had much higher levels of BPA in blood samples after applying hand sanitizer when compared with levels before application³³. This increased absorption is likely to occur frequently, as hand sanitizer is often readily available in locations where cashiers are dealing with a constant flow of till receipts (e.g. fast food restaurants, health care offices, retail stores etc).

In addition to the human health risks posed by BPA in thermal paper, these paper products are also a source of BPA in the wider environment. The primary way that BPA in thermal paper enters the environment is when it is released in waste streams. BPA has also been found in landfills and landfill leachate in the US, as paper products make up a large part of the solid waste stream. This leachate can then seep into the soil and drain into nearby water sources that can potentially come into contact with humans and wildlife²⁵.

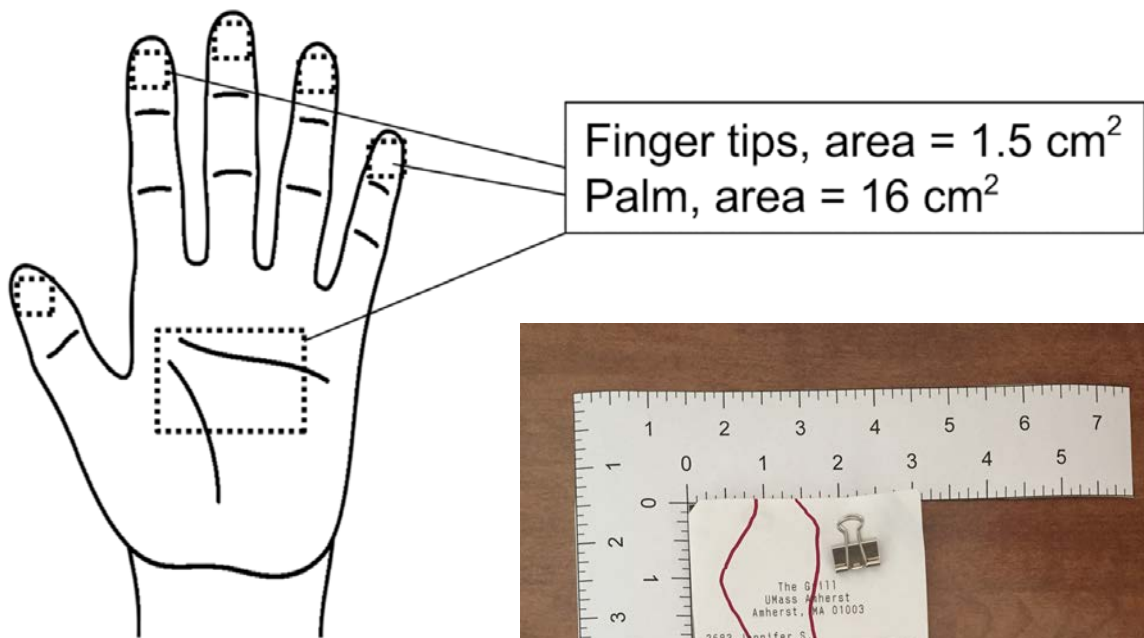
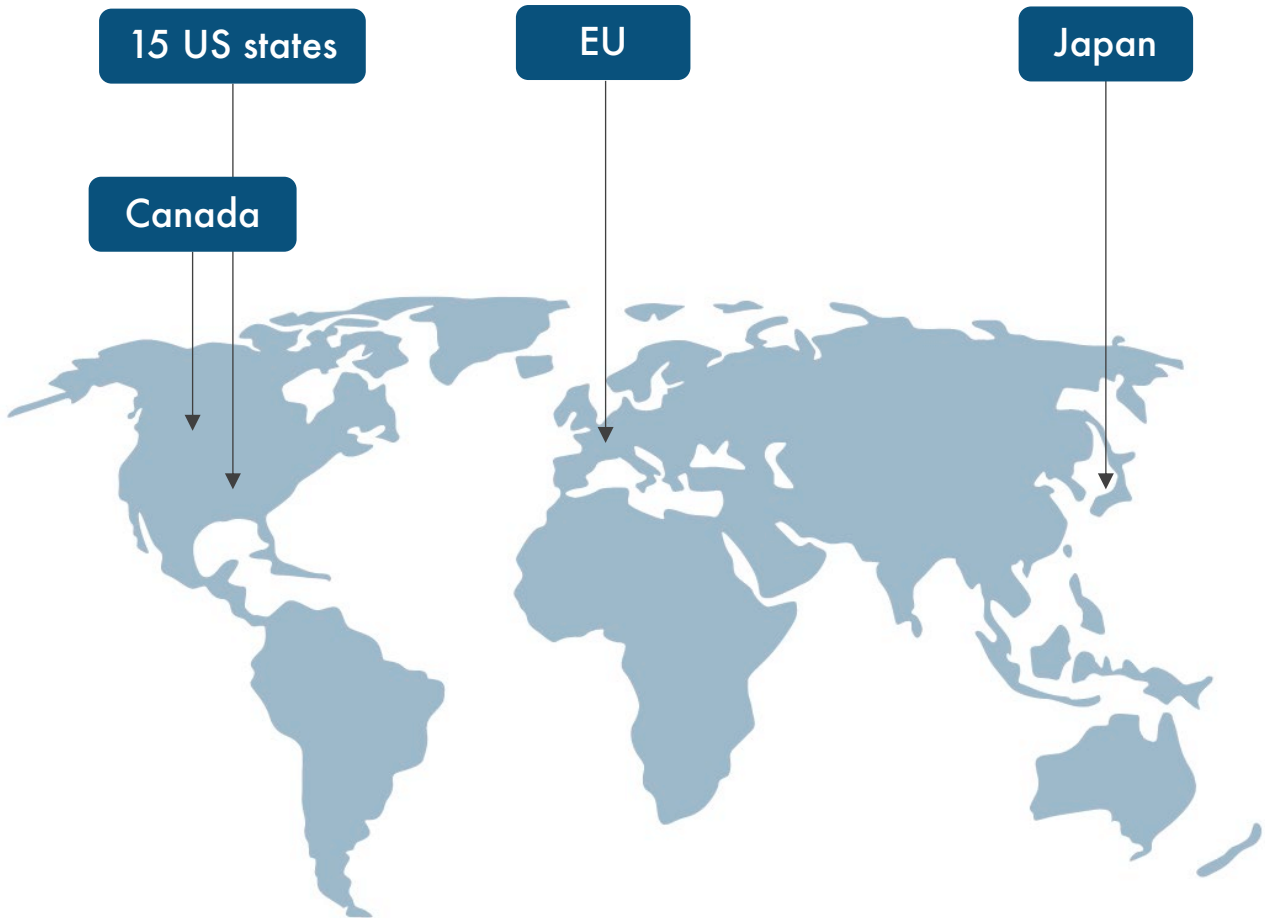


Figure 6: Conservative estimates of the surface area in contact with thermal paper held by fingertips or in the palm³⁸

BPA Bans



In 2011, a total ban on BPA in baby bottles was put in place in the EU due to safety concerns. Since then, other bans have come into effect in the EU and other parts of the world as more research is conducted on the hazards associated with BPA. In 2016, BPA was added to REACH AnnexXVII restricted substances lists and the EU Commission placed a ban on all thermal paper products containing more than 0.02% BPA by weight. Allowing for a phase out period, the ban came into effect in the EU market as of January 2020³⁹. Japan has also phased out BPA in thermal paper products after conducting studies into the potential hazards

of BPA⁴⁰. Furthermore, Canada and 15 US states have placed some level of ban on products containing BPA, primarily baby bottles and other plastic containers⁴¹.

Australian studies on BPA and its impact on human and environmental health are very limited. Australia has not taken a regulatory approach to limit BPA exposure thus far, as other countries have. A survey of Australian food and exposure to consumers was undertaken in 2016. It concluded that the levels of BPA most Australians are exposed to are not high enough to cause harm⁴².

A photograph of a baby crawling on grass, with hands reaching down to help. The baby is wearing a red and black striped shirt. The background is a blurred outdoor setting with greenery and other people.

The Precautionary Principle

‘When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically’.

As the scientific debate around BPA continues, there is no clear consensus about the health impacts of these chemicals on both humans, animals and the greater environment. Although some of the cause and effect relationships of BPA exposure and endpoint health impacts are not fully established, the potential harm caused by these chemicals warrants a precautionary approach. Planet Ark recommends using the precautionary principle and avoiding exposure where possible.

Many businesses have already made the switch to “BPA free” and/or “phenol free” alternatives in their products.

We support regulatory bans of these potentially hazardous chemicals as have other governments, particularly in light of evidence that the relatively small amounts we are exposed to daily may be causing more harm than we have been led to believe.

As there are still so many questions around BPA, with a growing body of evidence that BPA is indeed harming our health and our environment, we recommend avoidance by individuals and investment in alternative options by businesses as proactive, precautionary actions.

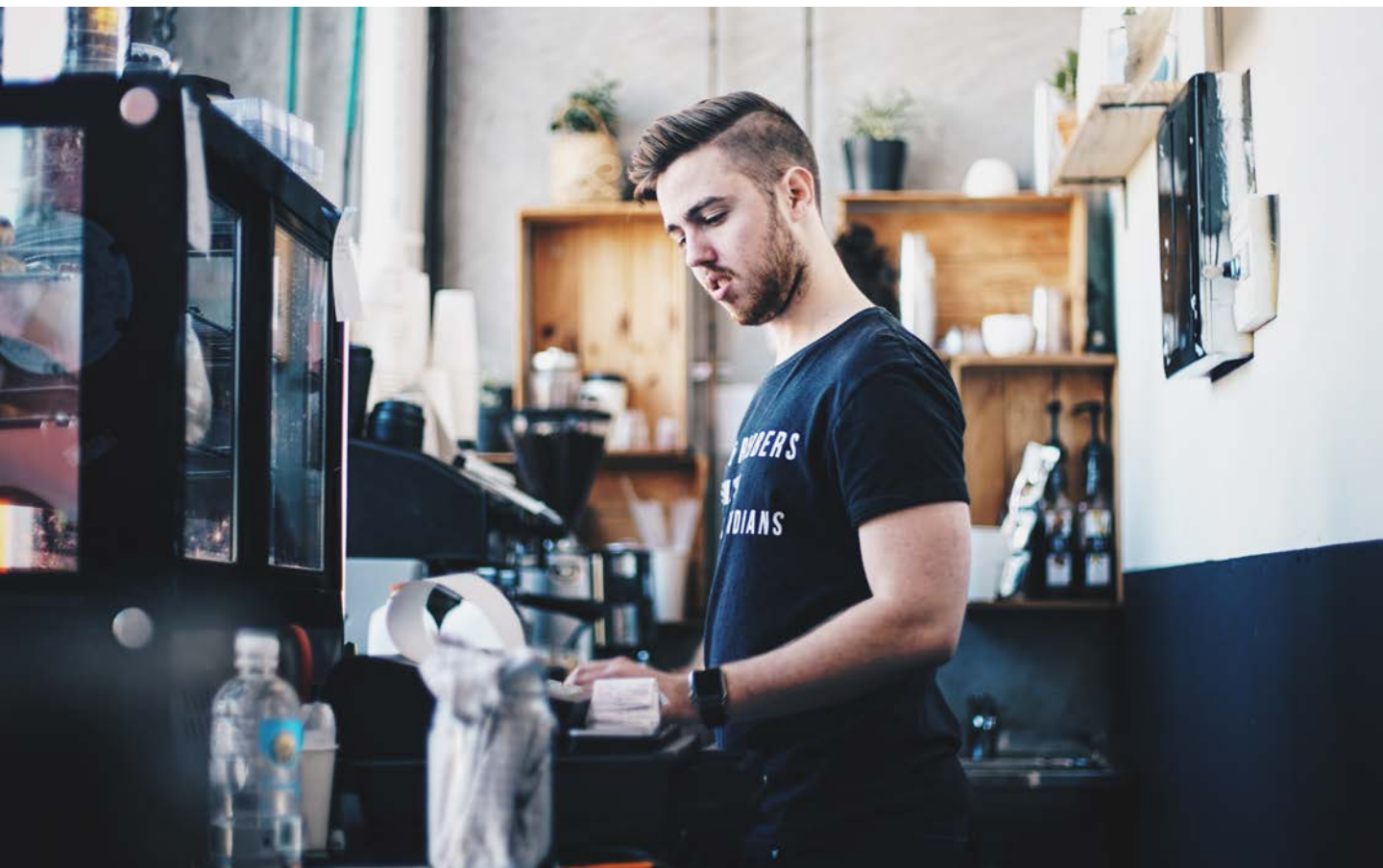
The issue with the “BPA free” claim

To avoid the health and environmental hazards associated with BPA, a total phase out of BPA and its analogues is recommended. This transition, though it has begun in certain parts of the world, is not universal and BPA is still present in both the environment and products we use every day in Australia. Due to increasing concerns over time, many products in Australia including drink bottles, plastic food containers and baby bottles that would once have been a source of BPA, are now made “BPA free”.

Unfortunately, choosing “BPA free” options is not as risk averse as it seems, as the chemicals used in place of BPA are often BPA analogues, such as BPS, and possess endocrine disrupting properties.

Furthermore, a large study conducted on plastics containing a number of other BPA alternatives found that most of these products also released EDCs⁴³.

For this reason, it is recommended to limit all sources of BPA and its analogues where possible. Although BPA is prevalent in the environment and we are almost certainly exposed to it unknowingly on a daily basis, avoiding certain products will eliminate the most significant sources of BPA. Examples of such products that should be avoided if no BPA/phenol free options are available include lined tinned food cans, plastic food storage containers, drink bottles and baby bottles (especially when heated or aged) and thermal paper products.





Solutions

Businesses


Individuals

- ⊘ Based on the precautionary principle, Planet Ark recommends businesses avoid selling and using products containing BPA and its analogues, where possible. The following products are examples of safer alternatives:
1. Phenol free or chemical reaction free thermal paper
 2. Phenol free cans
 3. Phenol free plastic products

- ✓ Workers who are regularly exposed to thermal paper should consider:
1. Asking their employer if the thermal paper contains BPA or its analogues
 2. Washing their hands after handling
 3. Wearing gloves while handling thermal paper
 4. Avoiding use of hand sanitisers and moisturisers when handling thermal paper

- ⊘ Based on the precautionary principle, Planet Ark recommends individuals limit their exposure to products that are likely to contain BPA and its analogues, including:
1. Receipts and other thermal paper products
 2. Canned food
 3. Plastic bottles and food containers made from polycarbonate

- ✓ Some tips when limiting your exposure:
1. Wash your hands after handling thermal paper products
 2. Avoid canned foods by choosing fresh alternatives
 3. Reusable stainless steel or glass water bottles

-  Speak up: ask your local retailers to switch to safer thermal paper receipts that are phenol free





Conclusion

Although there is still no general consensus on the health risk of BPA to human and environmental health safer alternatives should be sought based on the precautionary principle. Planet Ark encourages businesses to move away from both producing and selling products containing BPA and its analogues. A shift in public policy to engage a thorough approvals process for any replacement chemicals is critical to an effective transition to safer alternatives.

Questioning the potentially hazardous products we are handling daily is one of the most powerful ways of creating change as an individual. For example, we recommend consumers use their purchasing power to put pressure on businesses to offer products that do not contain BPA or its analogues. There are already businesses making the switch to safer, phenol free alternatives, particularly in the thermal paper space. Phenol free options have been implemented by some thermal paper suppliers to move away from BPA and its analogues.

Although these alternative technologies exist for thermal paper, there is no one replacement solution for all industrial applications of BPA. It is acknowledged, however, that switching to alternative chemicals involves trade-offs, additional expense and investment in new equipment.

As BPA is such a widely used, cheap and accessible chemical, this phase out process will take time and financial outlay. However, given the potential for harm that these chemicals possess, the time to act is now and move toward a healthier future for all.

Further information go to <https://planetark.org/research/forever-chemicals.cfm>

References

1. Vandenberg LN, Chahoud I, Heindel JJ, Padmanabhan V, Paum-garten JR, Schoenfelder G, (2010), Urinary, circulating and tissue biomonitoring studies indicate widespread exposure to bisphenol A, *Environ. Health. Perspect*, 118:1055-1070
2. Ndaw S, Remy A, Jargot D, Robert A, (2016), Occupational exposure of cashiers to Bisphenol A via thermal paper: urinary biomonitoring study, *Int Arch Occup Environ Health*, 89:935-946
3. Raloff, J, (2010), BPA passes easily through the skin: finding may explain high levels of chemical seen in cashiers, *Science News*, 4 Dec. 2010, p. 10, Accessed 8 Oct. 2018.
4. NTP (National Toxicology Program), (2017), Research Report on Biological Activity of Bisphenol A (BPA) Structural Analogues and Functional Alternatives. NTP Research Report 4. Research Triangle Park, NC: National Toxicology Program. <https://doi.org/10.22427/NTP-RR-4>
5. Moon, MK, (2019), Concern about the Safety of Bisphenol A Substitutes, *Diabetes Metab*. 43:46-48
6. Langlois, V.S. (2015). Plasticizer endocrine disruption: Highlighting developmental and reproductive effects in mammals and non-mammalian aquatic species. *General and Comparative Endocrinology* 219, 74–88
7. Schug TT, Janesick A, Blumberg B, Heindel J, (2011), Endocrine Disrupting Chemicals and Disease Susceptibility, *J Steroid Biochem Mol Biol*, vol 127: 204-215
8. Rochester JR, Bolden AL, (2015), Bisphenol S and F: A Systematic Review and Comparison of the Hormonal Activity of Bisphenol A Substitutes. *Environmental Health Perspectives*, vol 123: 643- 650
9. Rochester JR, (2013), Bisphenol A and human health: A review of the literature, *Reproductive Toxicology*, vol 42:132-155
10. Cioci M, Apfelbacher M, Strong P, Innes A, (2015), Reducing use of BPA and BPS in Thermal Receipt Paper in the Hospitality Sector, Minnesota Pollution Control Agency
11. Erler C, Novak J, (2010), Bisphenol A Exposure: Human Risk and Health Policy, *Journal of Pediatric Nursing*,
12. Garyard V, Lacroix MZ, Grandin FC, Collet SH, Mila H, Viguié C, Gély CA, Rabozzi B, Bouchard M, Léandri R, Toutain P-L, (2019), Oral Systematic Bioavailability of Bisphenol A and Bisphenol S in Pigs, *Environ. Health Perspect.*, vol 127
13. Ferguson M, Lorenzen-Schmidt I, Pyle WG, (2019), Bisphenol S rapidly depresses heart function through estrogen receptor- β and decreases phospholamban phosphorylation in a sex-dependent manner, *Scientific Reports*, vol 9
14. Konieczna A, Rutkowska A, Rachoń D, (2015), Health risk of exposure to Bisphenol A (BPA), *Rocz Panstw Zakl Hig*, vol 66: 5-11
15. European Food Safety Authority, (2015), *Report on the two-phase public consultation on the draft EFSA scientific opinion on Bisphenol A*.
16. Food and Drug Administration, (2014), *2014 Updated Review of Literature and Data on Bisphenol A*.
17. Scientific Opinion on the risks to public health related to the presence of bisphenol A (BPA) in foodstuffs: Part 1- Exposure assessment. (2015) *The EFSA Journal*, vol 13
18. Vandenberg LN, Ehrlich S, Belcher SM, Ben-Jonathan N, Dolinoy DC, Hugo ER, Hunt PA, Newbold RR, Rubin BS, Saili KS, Soto AM, Wang HS, vom Saal F, (2013), Low dose effects of bisphenol A – An integrated review of in vitro, laboratory animal and epidemiology studies, *Endocrine Disruptors*, vol 1
19. Lagarde F, Beausoleil C, Belcher SM, Belzunces LP, Emond C, Guerbet M, Rousselle C, (2015), Non-monotonic dose-response relationships and endocrine disruptors: a qualitative method of assessment, *Environ Health*. Vol 14: 259-276
20. Howdeshell KL, Hotchkiss AK, Thayer KA, Candenberg JG, vom Saal FS, (1999) Exposure to bisphenol A advances puberty, *Nature*, vol 401: 763-764
21. World Health Organisation (WHO), (2013), State of the science of endocrine disrupting chemicals – 2012. An assessment of the state of the science of endocrine disruptors prepared by a group of experts for the United Nations Environment Programme (UNEP) and WHO.
22. Palanza P, Howdeshell KL, Parmigiani S, vom Saal FS, (2002), Exposure to a Low Dose of Bisphenol A during Fetal Life or in Adulthood Alters Maternal Behavior in Mice, *Endocrine Disruptors*, vol 110: 415-422
23. Gerona R, vom Saal FS, Hunt PA, (2019), BPA: have flawed analytical techniques compromised risk assessments? *Lancet Diabetes Endocrinology*, vol 8: 11-13
24. Crain A, Eriksen M, Iguchi T, Jobling S, Laufer H, LeBlanc GA, Guillette LJ Jr, (2007), An ecological assessment of bisphenol-A: Evidence from comparative biology, *Reproductive Toxicology*, vol 24: 225-239
25. United States Environmental Protection Agency, (2015), Bisphenol A alternatives in thermal paper
26. Fürhacker M, Scharf S, Weber H, (2000), Bisphenol A: emissions from point sources, *Chemosphere*, vol 41: 751-756
27. Umar M, Roddick F, Fan L, Aziz HA, (2013), Application of ozone for the removal of bisphenol A from water and wastewater – A review, *Chemosphere*, vol 90: 2197-2207
28. Bhandari RK, Deem SL, Holliday DK, Jandegian CM, Kassotis CD, Nagel SC, Tillitt DE, vom Saal FS, Rosenfeld CS, (2015), Effects of the environmental estrogenic contaminants bisphenol A and 17 α -ethinyl estradiol on sexual development and adult behaviors in aquatic wildlife species. *Gen. Comp. Endocrinol*, vol 214: 195-219
29. Mandich A, Bottero S, Benfenati E, Cevasco A, Erratico C, Maggioni S, Massari A, Pedemont F, Viganò L., (2007), In vivo exposure of carp to ganded concentrations of bisphenol A, *Gen. Comp. Endocrinol*, vol 153: 15–24.
30. Lahnsteiner F, Berger B, Kletzl M, Weismann T, (2005), Effect of bisphenol A on maturation and quality of semen and eggs in the brown trout. *Salmo trutta fario*, *Aquatic Toxicology*, vol 75: 213-224
31. Stoker C, Rey F, Rodriguez H, Ramos JG, Sirosky P, Larriera A, Luque EH, Muñoz-de-Toro M, (2003), Sex reversal effects on *Caiman latirostris* exposed to environmentally relevant doses of the xenoestrogen bisphenol A, *General and Comparative Endocrinology*, vol 133: 287-296
32. Lv Y, Lu S, Dai Y, Rui C, Wang Y, Zhou Y, Li Y, Pang Q, Fan R, (2017), Higher dermal exposure of cashiers to BPA and its association with DNA oxidative damage, *Environment International*, vol 98: 69-47
33. Hormann AM, vom Saal FS, Nagel SC, Stahlhut RW, Moyer CL, Ellersieck MR, Welshons WV, Toutain PL, Taylor JA, (2014), Holding Thermal Receipt Paper and Eating Food after Using Hand Sanitizer Results in High Serum Bioactive and Urine Total Levels of Bisphenol A (BPA), *PLOS ONE*, vol 9
34. Liao C, Kannan K, (2011), Widespread Occurrence of Bisphenol A in Paper and Paper Products: Implications for Human Exposure, *Environmental Science and Technology*, vol 45: 9372-9379
35. Demierre A-L, Peter R, Oberli A, Bourqui-Pittet M, (2012), Dermal penetration of bisphenol A in human skin contributes marginally to total exposure, *Toxicology Letters*, vol 213: 305-308
36. Pirard C, Sagot C, Deville M, Dubois N, Charlier C, (2012), Urinary levels of bisphenol A, triclosan and 4-nonylphenol in a general Belgian population, *Environment International*, vol 48: 78-83
37. Braun JM, Kalkbrenner AE, Calafat AM, Bernert JT, Ye X, Silva MJ, Barr DB, Sathyanarayana S, Lanphear BP, (2011), Variability and Predictions of Urinary Bisphenol A Concentrations during Pregnancy, *Environmental Health Perspectives*, vol 119
38. Bernier MR, Vandenberg LN (2017) Handling of thermal paper: Implications for dermal exposure to bisphenol A and its alternatives. *PLoS ONE* 12(6)
39. European Chemicals Agency, (2019) Annex XVII to REACH
40. Liao C, Liu F, Kannan K, (2012), Bisphenol S, a New Bisphenol Analogue, in Paper Products and Currency Bills and Its Association with Bisphenol A Residues, *Environmental Science and Technology*, vol 46: 6615-6522
41. National Conference of State Legislatures, 2019, retrieved 20th December 2019 from: <https://www.ncsl.org/research/environment-and-natural-resources/policy-update-on-state-restrictions-on-bisphenol-a.aspx>
42. Food Standards Australia New Zealand, (2016), 24th Australian Total Diet Study – Phase 2, retrieved from: www.foodstandards.gov.au
43. Bittner GD, Yang CZ, Stoner MA, (2014), Estrogenic chemicals often leach from BPA-free plastic products that are replacements for BPA-containing polycarbonate products, *Environmental Health*, vol 13



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