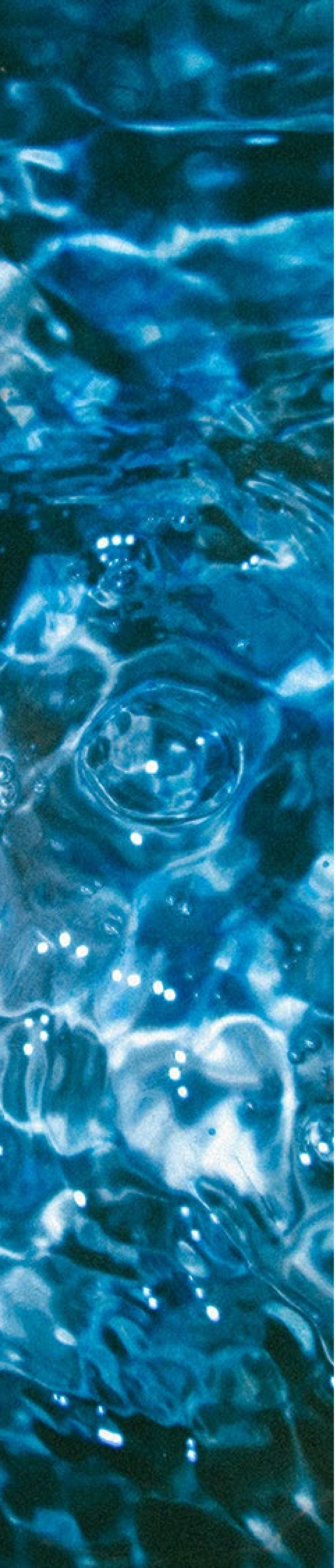
The Health and Environmental Risks of PFAS

A FOCUS ON FOOD CONTACT PACKAGING

Forever Chemicals

VOLUME 2



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Foreword

BY DR BRAD CLARKE

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The innovations that characterise modern life are fuelled by humanity's ability to manipulate atoms, the building blocks of the natural world, to create useful products. Over the past century, our scientific creativity has transformed the lives of most people on the planet, largely for the better. We now take many of these innovations for granted, including the synthetic contraceptive pill, converting inert atmospheric nitrogen into a fertiliser useful for plant growth, the use of plastics in almost all aspects of our daily life and electronics which have become invaluable tools for work and entertainment.

These products are the result of the same field of science – chemistry – and are a revolution in humanity's ability to shape the world around us. Unfortunately, these advancements are not without a cost, particularly to the environment, most notably with climate change but also widespread pervasive environmental pollution.

The contamination of the environment with synthetic chemicals is one of the most serious environmental issues facing contemporary society. While synthetic chemicals are indeed essential for modern society, some can be particularly problematic. The worst of these pollutants:

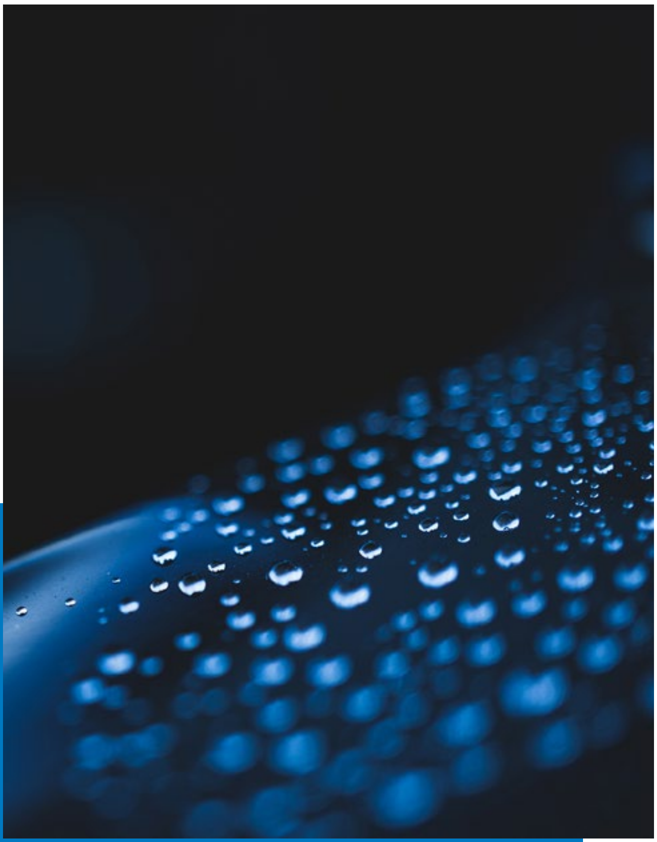
- biomagnify through the food chain, accumulating in humans and wildlife.
- cause negative health impacts including cancer, reproductive health problems, impaired immune function, and neurodevelopmental impairment.
- are detected frequently in all environmental compartments (air, water, soil, biota) across the globe, including 'pristine' locations far from known point sources, where they can persist for decades or even longer.
- can be difficult to remediate or remove by natural processes from environmental matrices due to a combination of unique chemical properties and high cost of treatment.

There are over 250 million unique chemical compounds registered in the Chemical Abstract Service (CAS) database and over 147,000 of these are routinely used for industrial applications. This number is increasing every day. For many recently discovered emerging contaminants, we have no information on their persistence, environmental behaviour and/or toxicology. Current global approaches to chemical management involve the constant introduction of new chemicals with marginal consideration of their potential impact on society and the environment. In fact, we are now engaged in an experiment involving all of humanity, where we are exposed to a mixture of thousands of synthetic chemicals in our daily life.

The examination of food contact paper for synthetic fluorinated chemicals called 'per- and polyfluoroalkyl substances' abbreviated 'PFAS', is an important contribution to understanding the extent of exposure to these synthetic chemicals in the domestic environment. Unfortunately, as shown in this study, we do not even know which chemicals are being used in these applications, only that they eventually break down into versions that we know are problematic and persist in the environment. PFAS can pose a risk to our safety when incorporated in material that comes in direct contact with food we eat and should be avoided where possible. For many of these applications, safe simple PFAS-free alternatives exist and should be adopted.

IMAGE BY: ADRIEN LEDOUX

Executive Summary



What are PFAS and why are they hazardous?

Per- and polyfluoroalkyl substances, abbreviated as the plural “PFAS”, are a group of manufactured chemicals used in many products as diverse as non-stick cookware, water resistant clothing and footwear, cosmetics and food packaging. These chemicals are typically applied as a coating or treatment to products as they are resistant to water, oil and heat, and provide low-friction contact with most materials. PFAS are very effective at what they do, however a growing body of research is exposing them as chemicals that should be avoided. This is because of their persistence and mobility in the environment – as PFAS are not broken down by factors such as sunlight, water, exposure to air or temperature variability. This means that the vast majority of all PFAS that have ever been produced are still circulating today. Where there are ongoing emissions or incomplete removal of these substances, environmental concentrations will increase over time as they circulate in the water cycle and potentially become irreversible[1].

Human health concerns about exposure to PFAS

Studies on human health have demonstrated correlations between high PFAS exposure and a range of health impacts. Primary sources of PFAS exposure include ingestion of contaminated food and drinking water, use of consumer products containing PFAS, transfer from mother to child during pregnancy and breastfeeding and through occupational exposure of those working in production or use of PFAS chemicals or related products.

Some of the health impacts linked to PFAS are breast, testicular and kidney cancers, elevated cholesterol and a range of developmental issues in foetuses. Furthermore, studies have highlighted the ability of PFAS to impair the function of the immune system, reducing the ability to fight disease and the response to vaccines.

Environmental concerns about PFAS

PFAS have been detected in aquatic and terrestrial environments, and the atmosphere. Due to the ability of PFAS to travel in water and in the air as dust and aerosols, they have spread all over the planet, even to remote polar regions. At each stage of the lifetime of PFAS, from production, supply chains, product use to disposal, they are released into aquatic environments, which raises concerns for wildlife that inhabit waterways. Studies have found PFAS in marine mammals, fish and aquatic invertebrates, with detrimental health impacts reported in several species.

On land, PFAS can enter the environment through contaminated water, soil and waste products from humans and wildlife. When product packaging containing PFAS is recycled, in addition to the risk of introducing these chemicals to new products, contaminated wastewater can also enter waterways near recycling facilities. Composting products containing PFAS is of particular concern, especially as compostable packaging items are becoming more widely used. PFAS remains in the composted soil after the products containing it break down and this soil is often then applied to agricultural land, contaminating crops. Terrestrial wildlife can be impacted by their exposure to PFAS, with studies on birds showing negative correlations between exposure to PFAS and chick survival.

One of the significant threats some PFAS pose in both aquatic and terrestrial environments is their ability to bioaccumulate up the food chain. Humans and all other wildlife within affected food webs can be exposed to PFAS by ingesting plant or animal material that has been contaminated due to their ability to persist in the body.

PFAS in fibre-based food packaging

Plastic in packaging is a known threat to our environment, through ocean pollution, fossil fuel resource use in their manufacture, and formation of microplastics. However, the use of PFAS in fibre-based food packaging products poses a lesser-known threat. Studies on microwave popcorn have highlighted the ability of PFAS to be transferred from packaging to the food inside at high temperature and subsequently ingested, unknowingly exposing consumers to PFAS, albeit at low levels.

A recent study from Planet Ark and the Australian Packaging Covenant Organisation (APCO) investigated the presence of PFAS in a large range of fibre-based food packaging products available in Australia. The results confirmed the presence of PFAS significantly above background levels in almost a third of the samples tested, and their concentrations were consistent with those found in comparable studies of food fibre packaging in the US, UK, and the EU.

In another Planet Ark study, the total PFAS in samples of normal greaseproof paper, and those labelled as 'PFAS-free', were measured. The study showed it is possible to produce paper containing undetectable or very low background levels of PFAS, as these greaseproof paper samples labelled 'PFAS-free' had PFAS levels that were either undetectable or negligible.

A case for regulating PFAS in Australia

Planet Ark is interested in supporting initiatives that limit exposure to potentially harmful chemicals. Research into the health and environmental impacts of PFAS is ongoing, but there is enough evidence to state a case for transitioning away from these chemicals. Though the causal relationship with several health endpoints has not yet been fully established, the correlation between high PFAS exposure and detrimental health impacts is apparent. Furthermore, evidence of the widespread dispersal and persistence of these chemicals in the environment has been demonstrated and is cause for concern.

In Europe and some US states, regulations have been put in place to ban the use of PFAS in a range of products. The issue with this transition is that in many cases, PFAS are replaced with 'regrettable substitutes' that also pose risks to human and environmental health. A comprehensive study of data on the human health and environmental hazards of alternatives to PFAS was published recently[2].

Guided by the precautionary principle, Planet Ark recommends avoiding PFAS where possible and transitioning to safe alternatives. The precautionary principle outlines that "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."

The aim of this report is to promote awareness of the health and environmental risks of PFAS and support a transition to the use of lower-risk chemicals. Where alternative food packaging products are available, such as PFAS-free grease proof paper, these should be supported.

In summary, given that PFAS are known to be persistent, can bioaccumulate, and are capable of long-range transport, we expect that without adequate regulation environmental contamination and exposures will continue for as long as PFAS are manufactured or used anywhere in the world. Planet Ark encourages an immediate transition away from PFAS to safeguard human and environmental health in the future.


IMAGE BY: ANNIE SPRATT

What are PFAS and why are they a problem?

Per-and poly-fluoroalkyl substances, with the acronym "PFAS", are a group of synthetic chemicals that have been used since the 1950s in many common household products and industrial processes[3]. In subsequent decades, there have been more than 9,000 PFAS produced, of which 4,730 PFAS-related structures have been identified for commercial use.[4] Now, more than 1,400 individual PFAS are in 200 use categories[5,6].

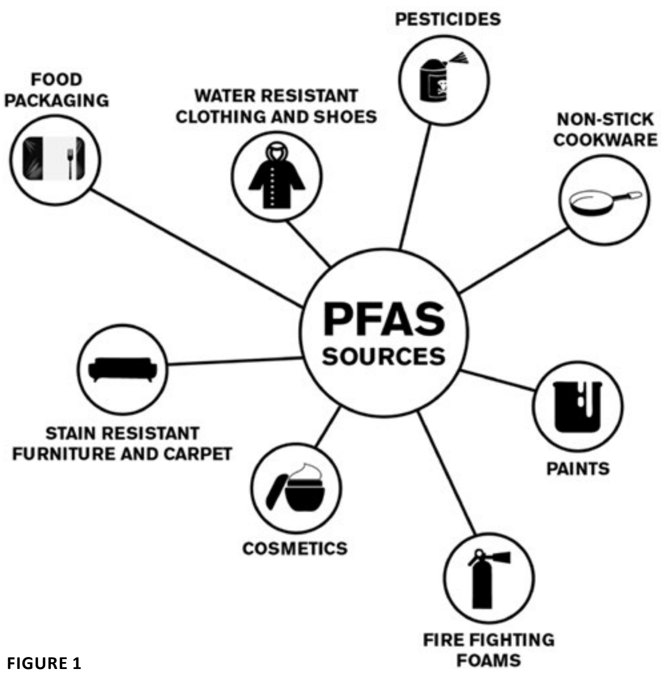


FIGURE 1

PFAS are used in a wide range of products, such as non-stick cookware, stain-resistant furniture and carpet, electrical wire insulation, waterproof clothing (e.g., first responder gear), cosmetics, dental floss, climbing ropes, guitar strings, artificial turf, soil remediation, food packaging, medical devices (e.g., metered dose inhalers), fluids in gas fracking operations, and some types of firefighting foam, among others[3]. In most cases, PFAS are added to the external layer of products, as they are resistant to grease, oil, water, and heat, and provide low-friction contact with most materials. Their ability to protect products from these external factors has meant they have had a wide range of uses over time[5,7].

PFAS are not naturally occurring, therefore any PFAS observed in the environment are present due to the release from the manufacture, use, or degradation of industrial and consumer products. The building block of PFAS chemicals is the fluorine-carbon bond, which is the strongest chemical bond in nature. These chemicals are not broken down to simpler innocuous substances by environmental factors such as sunlight, exposure to air, acidic or alkaline conditions in water, or temperature variability, meaning almost all PFAS that have been produced are still present in the environment today. For this reason, they have earned the title of 'forever chemicals'.

Figure 1: Diagram highlighting some of the commonly used products that contain PFAS.

FIGURE 2

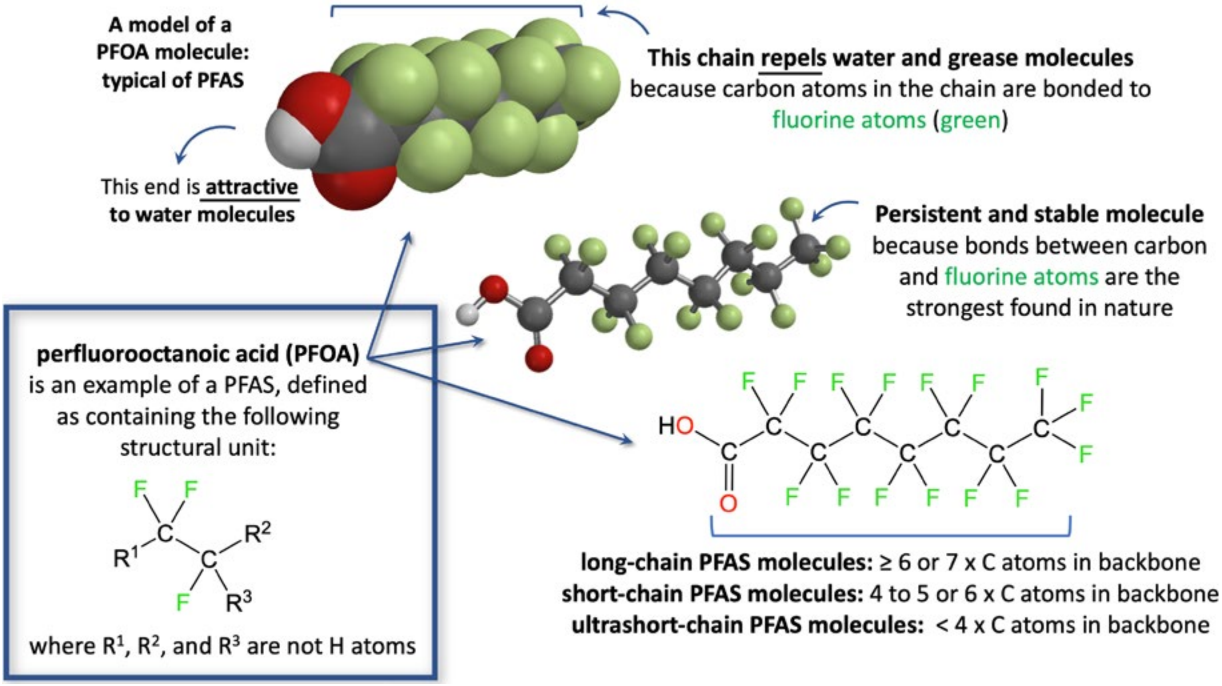


Figure 2: Characteristic features of molecules in PFAS responsible for their chemical stability and behaviour. The carbon chain length determines their mobility in the environment, accumulation in living tissues, and toxicity.

The variety of PFAS is the challenge in understanding them. The molecular structures of PFAS vary from simple molecules like PFOA shown in Figure 2, to more complex structures (PFAS precursors) that can break down to these simpler molecules, through to longer polymeric structures that are much more stable to degradation. These details about PFAS are presented in the Appendix, and they are important when considering the mobility, bioaccumulation, and toxicity of PFAS.

Given the widespread use of PFAS in many commonly used products in Australia and around the world, most people living in developed countries have some PFAS in their body[8]. Over the past couple of decades, studies have highlighted an increasing number of examples of negative health and environmental impacts associated with PFAS exposure[9,10].

Given the widespread use of PFAS in many commonly used products in Australia and around the world, most people living in developed countries have some PFAS in their body[8].


IMAGE BY: ANASTASIIA CHEPINSKA

Health concerns of PFAS

THE RISK OF PFAS TO HUMAN HEALTH DEPENDS ON THE EXPOSURE AND THE TOXICITY (HAZARD) IN THE BODY.

Exposure to PFAS

PFAS are present in a wide range of household items and move through the environment in waterways and as dust, so there are a number of ways we can come into contact with these chemicals. We are exposed to PFAS through diet, drinking water, air, dust, aerosols and direct physical contact with products[7,9,11].

The most common sources of PFAS exposure to humans are through contaminated food and drinking water, use of consumer products containing PFAS, as well as occupational exposure of those working in production of PFAS chemicals or related products[12]. Exposure from mother to child during pregnancy and breastfeeding has also been demonstrated[12,13].

The presence of PFAS in drinking water supplies in the US was highlighted in the 2019 film Dark Waters, based on the book Exposure by lawyer Robert Bilott[14]. Bilott represented victims of high exposure to waste PFAS in drinking water, against manufacturers of PFAS in a successful high-profile legal case. Based on a true story, the film explored the serious and often fatal health impacts of high exposure to PFAS, particularly PFOA (also known as C8), in the water supply of a community in West Virginia, where a Chemours factory (a subsidiary of Du Pont) released chemical waste into water sources.


IMAGE BY: ENGIN AKYURT

We are exposed to PFAS through diet, drinking water, air, dust, and direct physical contact with products[5,7,9].

The case is noteworthy because the C8 Science Panel established connections between high exposure to PFAS and negative health impacts on humans, based on health data collected in 2005/2006 from 69,000 exposed residents. The study collected demographic data, medical diagnoses (both self-reported and medical record review), clinical laboratory testing, and determination of serum (blood) concentrations of 10 PFAS[15].

The data revealed the population had individuals with both very high exposure and also low exposure to PFAS, although they could not explore effects comparable to the general US population. After six years of study, probable links were declared for kidney and testicular cancer, pregnancy-induced hypertension, thyroid disease, high cholesterol, and ulcerative colitis. A probable link is defined as "given the available scientific evidence, it is more likely than not that among class members a connection exists between PFOA exposure and a particular human disease"[16].

PFOA and other long-chain PFAS have been studied to determine their environmental mobility, distribution, and accumulation in the biosphere, and health impacts in animal models. These factors are dependent on the molecular chain length and structure of the PFAS (see Figure 2 and the Appendix). In the case of perfluoroalkyl acids, like PFOA, a long-chain type is defined as one with seven or more carbon atoms in the backbone, but in the case of perfluoroalkyl sulphonates, like PFOS, a long-chain type is defined as one with six or more carbon atoms in the backbone.

Short-chain analogues have four or five carbon atoms, and those with two or three carbon atoms are called ultrashort-chain analogues. Long-chain PFAS have been found to persist in the environment, can bioaccumulate in animal tissues and have been linked to negative health impacts in both humans and wildlife[17]. Bioaccumulation is the gradual build-up of a chemical in a living organism. It occurs either because the chemical is taken up faster than it can be excreted or because it cannot be metabolised.

In the years since the class action lawsuit against Du Pont, several American studies have confirmed the widespread detection of PFAS in drinking water at most of the sites tested across the USA[18]. A 2019 study analysing drinking water at 44 sites across 31 states found only one location without detectable PFAS and only two other sites that had levels low enough to be considered without risk to human health (according to independent studies on tolerable intakes, suggesting an acceptable detection level of PFAS in water should be one part per trillion (ppt)). Concentrations of PFAS ranged between one ppt to 186 ppt[18].

A 2013 study by Perez et.al found the accumulation of PFAS in protein-rich human tissues and confirmed their presence in the brain, kidneys, liver, and lung, with the liver containing the highest concentrations. Additionally, blood, hair, nails, breast milk and urine were also tested for PFAS (specifically PFOS), where it was found predominantly in blood[19].

THE FILM DARK WATERS FOLLOWED THE TRUE STORY OF A COMMUNITY EXPOSED TO PFAS THROUGH DRINKING WATER.

IMAGE BY: FOCUS FEATURES

Toxicity hazard associated with exposure

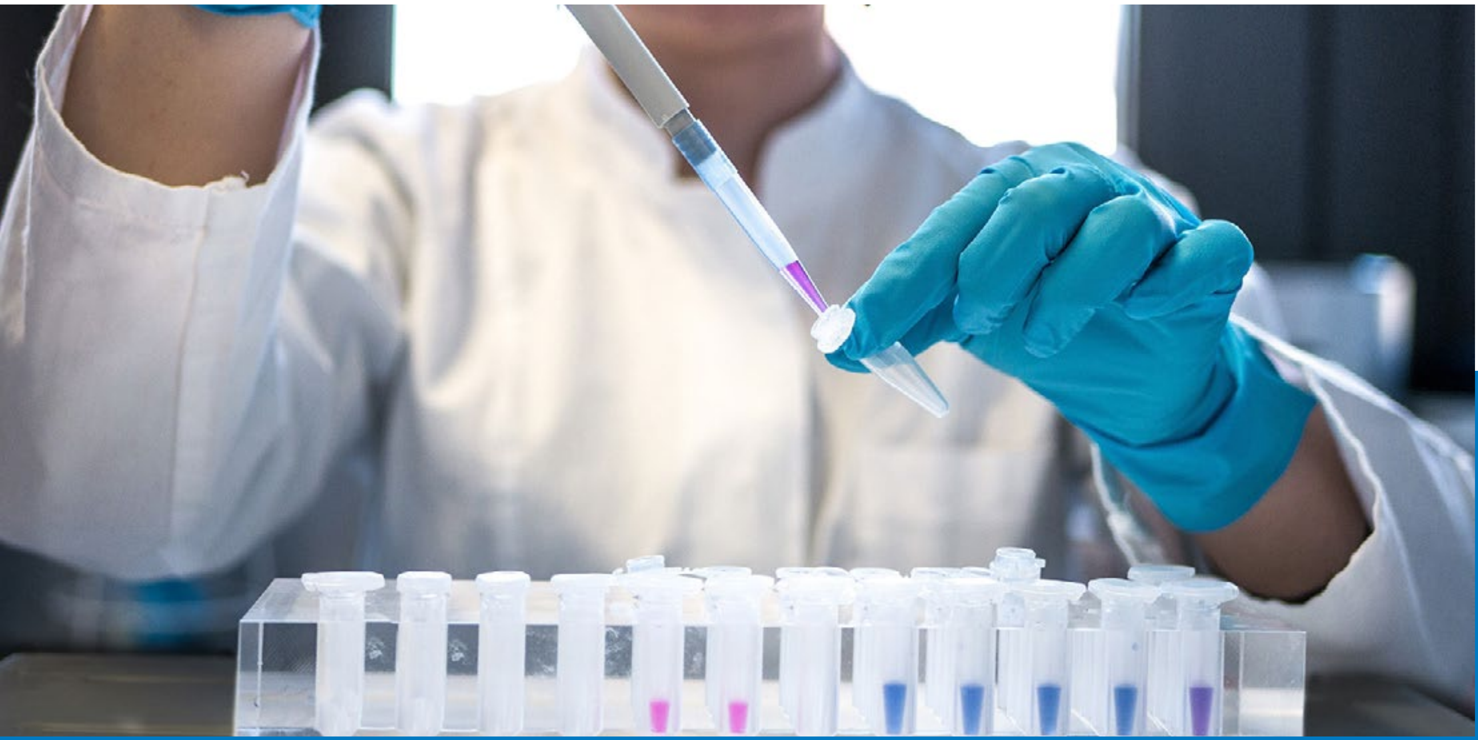
Given that PFAS can accumulate in the human body, epidemiological research into the human health effects of PFAS exposure has been ongoing. The causal relationship with several health endpoints has not yet been fully established, however the correlation between high PFAS exposure and a range of detrimental health impacts is clear[10].

Three of the best studied and most common mechanisms through which PFAS impacts human health are endocrine disruption, fatty acid mimicry and oxidative stress[20]. Endocrine disruptors are chemicals which either mimic or interfere with the body's naturally occurring hormones, fatty acid mimicking chemicals can trick the body into thinking they are the building blocks of fat cells, and oxidative stress can interfere with the balance between free radicals and antioxidants in the body[21,22]. Each of these mechanisms has the potential to produce negative health outcomes.[20].

Both *in vivo* (live organism) and *in vitro* (laboratory) studies have suggested links between exposure to PFAS and health impacts including hepatotoxicity (liver damage), neurotoxicity, reproductive toxicity, immunotoxicity, thyroid disruption, cardiovascular toxicity, pulmonary toxicity and renal toxicity[23]. Figure 3 on page 12 highlights some of the detrimental impacts associated with PFAS exposure.

PFAS can remain circulating in the body for a long time. For example, PFOS will take an average of 4.8 years for half of the PFOS detected to be eliminated from serum samples, with PFOA taking 3.5 years[12].

IMAGE BY: JULIA KOBLITZ



Given that PFAS can accumulate in the human body, epidemiological research into the human health effects of PFAS exposure has been ongoing.

FIGURE 3

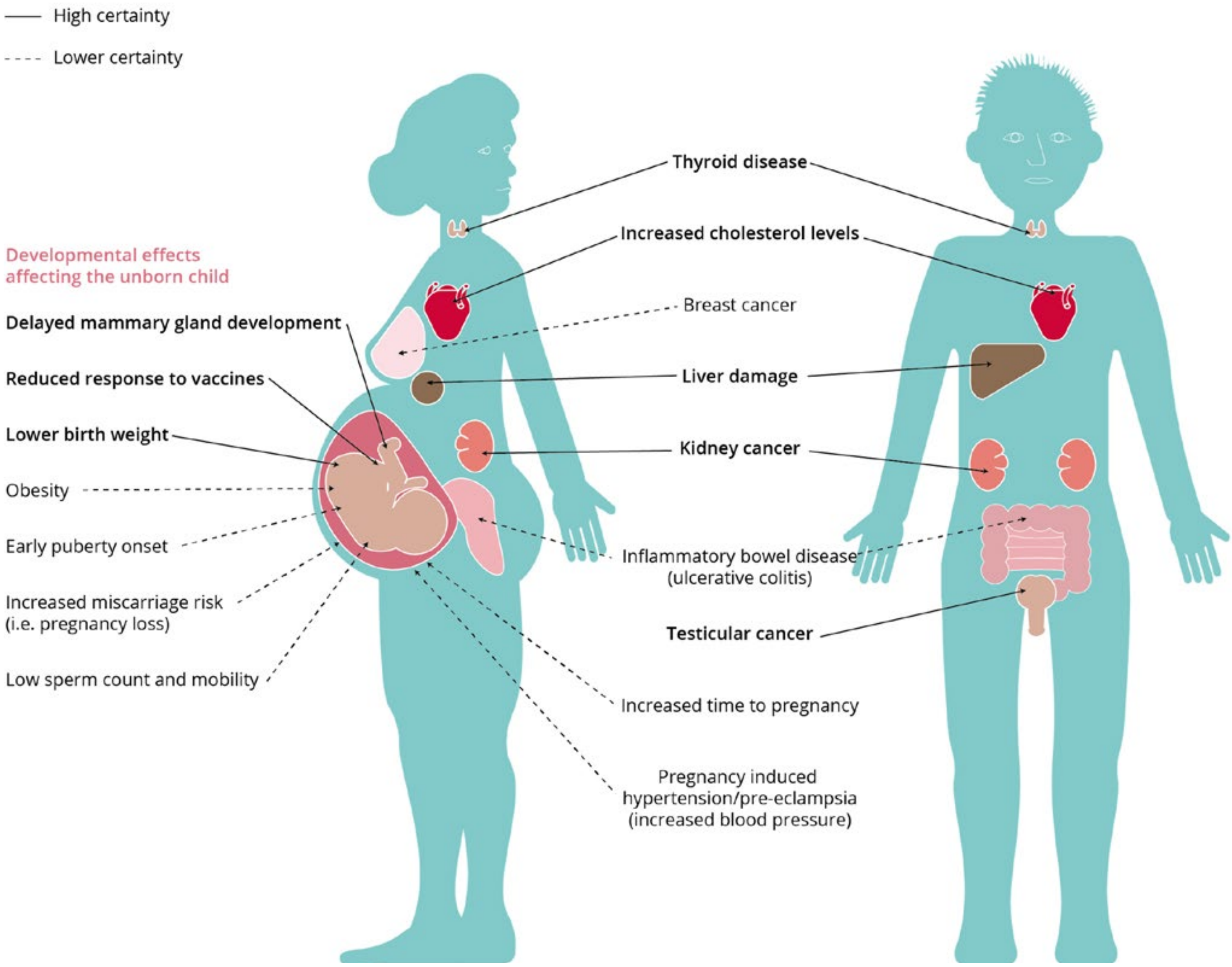
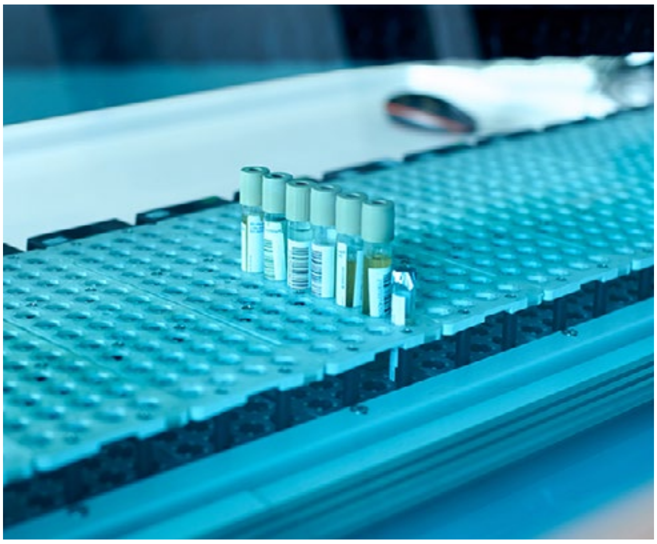


Figure 3: Possible health impacts that have been associated with high PFAS exposure, including level of certainty (dotted lines indicate less certainty). All health endpoints are applicable to both males and females, other than those relating to the reproductive system. Diagram by the European Environment Agency (2019)[24].

Health endpoints associated with PFAS exposure

In 2020, the European Food Safety Authority set a new threshold for a safe intake of PFAS for humans. The Tolerable Weekly Intake (TWI) was set at 4.4 nanograms per kilogram (ng/kg) of body weight per week[13]. Several studies have shown many people are exposed to PFAS levels much higher than this, including a recent study showing the average exposure in adolescents and adult age groups ranged from three to 22 ng/kg body weight per week[13].

PFAS are only very slowly eliminated from the human body, and the difficulty of removing PFAS from exposed humans is an increasing public health concern. There has been no proven method thus far to accelerate the clearance of PFAS in humans[25].



Children at higher risk of exposure

Foetuses, infants, toddlers, and children have been found to have higher exposure levels to PFAS than adults[26]. Long term studies on the presence of PFAS in the US have found that in general, children had higher serum levels of PFAS than adults[26,27]. This higher exposure is likely due to mouthing behaviours, time spent on the floor and in contact with dust particles, different body size to surface area ratios, and exposure through breastfeeding and placental transfer[28].

This increased burden of PFAS exposure in children can affect them in childhood, through developmental phases and potentially later in life. There is evidence of correlations between PFAS exposure and dyslipidaemia (abnormal levels of lipids, for example, cholesterol in blood), kidney function, age of menarche (first menstrual period), and reduced immunity (specifically vaccine response and asthma)[28].

LONGER PERIODS OF TIME SPENT ON THE FLOOR MAY BE LINKED TO HIGH EXPOSURE OF PFAS IN INFANTS.

STUDIES HAVE SHOWN PFAS HAVE THE ABILITY TO REDUCE RESPONSE TO VACCINES.

Impairment of the immune response – the timely threat

Since the emergence of the COVID-19 pandemic, scientists have focussed on the immunotoxicity of PFAS. Both existing and new studies have shown PFAS can impair the function of the immune system, reducing the ability to fight disease and the response to vaccines[29]. Given the reliance we have on vaccines for a range of infectious diseases, and in particular to stop the spread of COVID-19 variants over the next few years, this is of particular concern[30]. The team of experts that determined the TWI of 4.4 ng/kg had previously identified increased cholesterol as the most critical health effect caused by PFAS, however this has recently been changed to decreased immune response[13].


IMAGE BY: MAT NAPO

Challenges of measuring the health impacts of PFAS

There are challenges in measuring the impacts of PFAS on the human body, the main one being how difficult it is to pinpoint the effects of a single chemical at low concentration. Individual PFAS rarely occur in isolation and people, wildlife and plants are exposed to mixtures of PFAS and other chemicals concurrently. This mixture of chemicals is potentially leading to cumulative adverse impacts, yet studies on toxicological endpoints are mostly assessed using single PFAS[31]. Furthermore, exposure to even minute concentrations of PFAS over a long-term period can have a cumulative effect and these processes are associated with chronic inflammation and can lead to cancer[30]. Though due to the minute concentrations and presence of other chemicals, the direct causative link between PFAS exposure and detrimental health endpoints cannot currently be made with certainty.

Toxicity studies in animals show PFAS are harmful, but their relevance to human health is debatable. Mammalian animals (such as rodents) are often used as models for humans in toxicity studies. Long-chain PFCA (like PFOA in Figure 2) have clear adverse effects on the liver, the immune system, the testes, and the female mammary gland in rodents, particularly in mice. PFOA is also carcinogenic in the liver, pancreas, and testes of male rats. However, most of the observed effects in the liver and on the developing rodent may be mediated via rodent-specific pathways. In some cases, toxicity studies in rats show less sensitivity to those in mice. The human relevance of the observed effects of PFCA in rodents is unknown, as the available epidemiology data does not consistently point to similar effects in highly exposed human population cohorts[15].

Australian reviews of the scientific evidence for health impacts of PFAS

In March 2018 an Expert Health Panel for per- and polyfluoroalkyl substances was established to advise the Australian Government on the evidence for potential health impacts associated with PFAS exposure. Their cautious findings, that should be read in the full context of their report, were:

"Although the evidence on health effects associated with PFAS exposure is limited, the current reviews of health and scientific research provide fairly consistent reports of associations with several health outcomes."

However, the panel criticised the veracity of the peer-reviewed literature in the field:

"The published evidence is mostly based on studies in just seven cohorts. These cohorts have generated hundreds of publications but there is a high risk that bias or confounding variables are affecting most of the results reported. There are very large numbers of comparisons being done in many studies, such that the risk of random variation in exposures and outcomes being interpreted as real associations is greatly increased. This is compounded by the fact that there are multiple PFAS, and other environmental or occupational hazards, so that there may be interacting toxic effects, and it is hard to isolate the association with one or two analysed compounds."[10]

In December 2021 the PFAS Health Study published their findings from investigations of the exposure levels and potential health effects of PFAS in areas of known contamination in the communities of Williamtown in New South Wales, Oakey in Queensland, and Katherine in the Northern Territory, Australia. These communities have been contaminated with PFAS due to firefighting activities on nearby Defence Force bases. Members of these communities have been potentially exposed to PFAS, primarily through the consumption of contaminated bore water on their properties, and via eating locally grown foods.

There appears to be a lack of causal and longitudinal studies demonstrating how PFAS exposure at low concentrations interferes with human biochemistry.

IMAGE BY: KELLY SIKKEMA

The review examined 221 scientific publications into the human health effects of PFAS. The overview of findings from the PFAS Health Study accurately reflects the overall conclusions of the Blood Serum Study, Cross-sectional Survey and Data Linkage Study. The key findings were:

- "Sufficient evidence that higher levels of PFOS or PFOA in a person's blood are associated with higher blood cholesterol levels."
- "Limited evidence that higher levels of PFAS in the blood are associated with higher levels of uric acid in the blood, reduced kidney function and chronic kidney disease, kidney and testicular cancers and lower than normal levels of antibodies following some vaccines."

The key findings from the PFAS Health Study were that there was clear evidence of elevated blood serum concentrations of PFAS in residents and workers in the PFAS-affected communities and increased psychological distress in the three exposed communities. The evidence for other adverse health outcomes was generally limited. For most health outcomes studied, they did not find evidence that health was worse in PFAS-affected communities than non-affected communities. Overall, their findings were consistent with previous studies that have not conclusively identified causative links between PFAS and adverse health outcomes. The association between higher PFAS levels and elevated cholesterol levels was consistent with the previous evidence[32,33,34].

Clearly the scientific evidence to support the claim that PFAS are harmful to human health is equivocal and based mainly on associations in epidemiological studies. A current research gap in Australia is investigation of PFAS exposure and health over time in the exposed communities. There appears to be a lack of causal and longitudinal studies demonstrating how PFAS exposure at low concentrations interferes with human biochemistry.

Environmental concerns of PFAS

The challenge of measuring PFAS in the environment

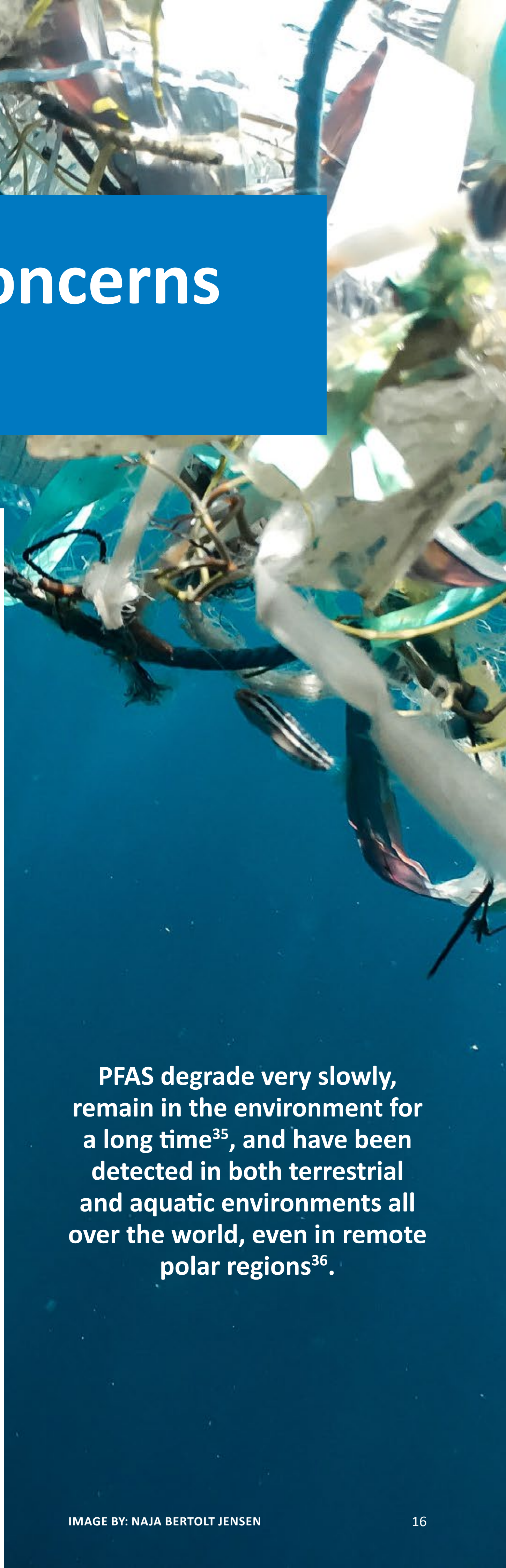
Measuring the types and quantities of all the different PFAS in the biosphere and the environment is a major challenge. Despite recent analytical advancements, most of the PFAS observed in the environment, wildlife, and human tissues remain unidentified[24]. Only a small fraction (sometimes <5%) of the PFAS being detected have been targeted for analysis. Until analytical methods are developed and validated for more members of the class, the full extent of PFAS contamination, despite extensive research, will remain poorly understood.

Persistence and distribution

PFAS degrade very slowly, remain in the environment for a long time[35], and have been detected in both terrestrial and aquatic environments all over the world, even in remote polar regions[36].

In 2001, a series of studies were undertaken on the presence of PFAS in wildlife. Over 900 samples were taken from North American and European marine mammals, birds and fish and North American mink, otter, turtles and frogs. In every specimen sampled, primarily from the blood, liver and muscles of these animals, PFAS were detected with concentrations varying widely between species[37].

In 2019, a study by Muir et.al highlighted an emerging pattern in studies conducted over the last 10 years, with the levels of a few specific PFAS increasing. These trends were most evident in ringed seals in the Canadian Arctic, polar bears in East Greenland and arctic foxes in Svalbard[38]. The continuing presence of PFAS in Arctic areas is unsurprising, given the ability of these chemicals to persist and migrate in the environment.



PFAS degrade very slowly, remain in the environment for a long time[35], and have been detected in both terrestrial and aquatic environments all over the world, even in remote polar regions[36].

IMAGE BY: NAJA BERTOLT JENSEN

Aquatic environments

Decades of study have found PFAS to be distributed ubiquitously throughout the aquatic environment, which raises concerns for the organisms that inhabit streams, rivers, seas and oceans[36]. At each stage of the PFAS lifecycle, including production, supply chains, product use and disposal, they are released into aquatic environments[36].

Wastewater released from facilities that both manufacture PFAS chemicals themselves and products that contain them contaminate nearby bodies of water. Sewerage contaminated with PFAS can also end up in ground and surface water sources[39,40]. An Australian study analysed water entering and exiting 19 wastewater treatment plants and found evidence of PFAS at all of them. The release of this contaminated effluent from treatment plants is a significant source of PFAS in the Australian environment[41].

Landfill leachate that contains PFAS from items disposed of in landfill can also make its way into nearby water sources. As PFAS are used in many firefighting foams, water sources near military bases and firefighting training facilities are often found to be contaminated with PFAS[39,40]. The historic use of firefighting foams containing PFAS has led to contamination of ground water, waterways, and soil at several sites around Australia. There have been multiple class action laws suits in Australia, including a high-profile case in Williamtown, NSW, where PFAS contamination in soil and water was widespread[42]. The PFAS Health Study findings from these exposed communities were described on Page 15.

A recent study of polar aquatic environments highlighted the ability of PFAS to travel long distances, when 11 types of PFAS were discovered in water samples from the Fram Strait, between Greenland and Svalbard (a Norwegian archipelago)[43].

Wastewater released from facilities that both manufacture PFAS chemicals themselves and products that contain them contaminate nearby bodies of water.

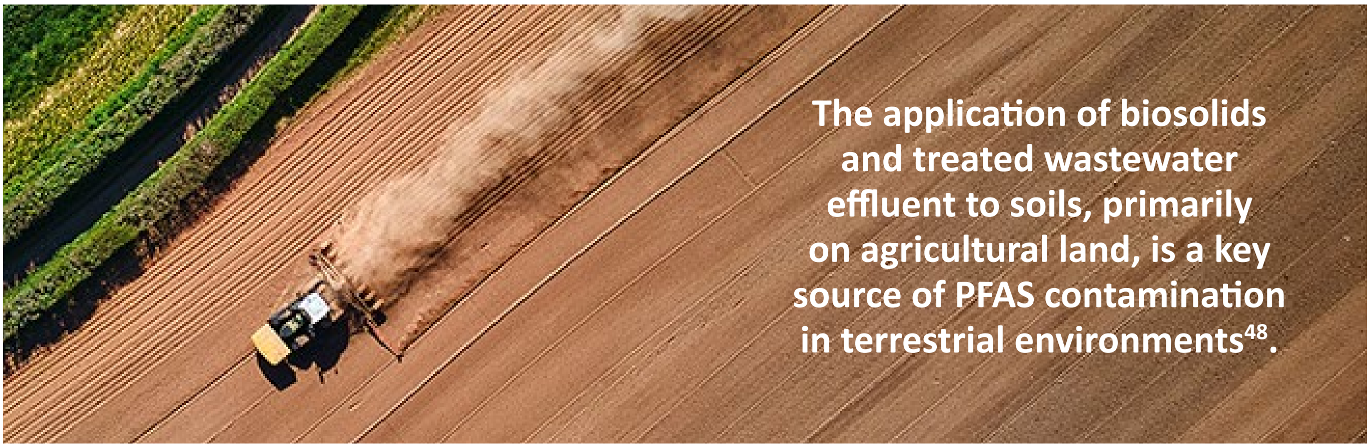
Impacts on health of aquatic wildlife

The long-range transport of PFAS and their bioaccumulation potential means they can contaminate all levels of food webs in marine ecosystems. PFAS have been found to be toxic to aquatic plants and animals. A study on zooplankton, snails, flatworms, and shrimp found PFAS were toxic in each of these invertebrates, all of which are pivotal trophic components of freshwater food webs[44]. These organisms are a critical source of energy and nutrients for organisms higher up the food chain. If PFAS continue to circulate in aquatic systems, we may see a dramatic decrease in the number of these organisms, disrupting entire food webs.

In addition to the toxic impacts of PFAS on aquatic invertebrates, PFAS can also bioaccumulate in these organisms. The fish and other aquatic wildlife that ingest these invertebrates then become contaminated with PFAS themselves[45]. For this reason, it is no surprise that a recent study found PFAS in the livers of mammals (ringed seals, polar bears and orcas) in East Greenland. These mammals at the top of the food chain are exposed to high levels of PFAS as the substances have accumulated through the trophic levels[46].

PFAS HAS BEEN DETECTED IN POLAR REGIONS.

IMAGE BY: ANNIE SPRATT



Terrestrial environments

PFAS can enter terrestrial environments through contaminated water, soil and waste products from humans and wildlife. As PFAS are water soluble, they are excreted in the breast milk, urine, and faeces of humans and other animals[47]. The application of biosolids and treated wastewater effluent to soils, primarily on agricultural land, is a key source of PFAS contamination in terrestrial environments[48]. When contaminated waste is added to soil (or is deposited via air currents) that is supporting the growth of plants used either for human food consumption or food sources for wildlife, these plants become contaminated and pose health risks. A study in China analysed a range of crops destined for human consumption on PFAS-contaminated land and found that all fruit and vegetables tested were able to uptake PFAS from surrounding soil[49].

In Australia, the West Gate Tunnel project in Melbourne is at risk of exposing workers and local communities to PFAS. The soil at this site is contaminated with PFAS and as the earth is moved during construction, PFAS may enter surrounding surface and ground water[50]. Furthermore, given the ability of PFAS to travel in dust particles, the disruption of contaminated soil could see it move through the air to surrounding areas.

Terrestrial wildlife is also at risk of negative health impacts from exposure to PFAS. A study on bobwhite quails found a correlation between PFAS exposure and a reduction in the survivability of chicks[51] and a study on tree swallows found a negative association between PFAS exposure and egg hatching success[52].

Figure 4: Illustration depicting the ways PFAS move through the environment (Source: Fidra, 2021)[53]

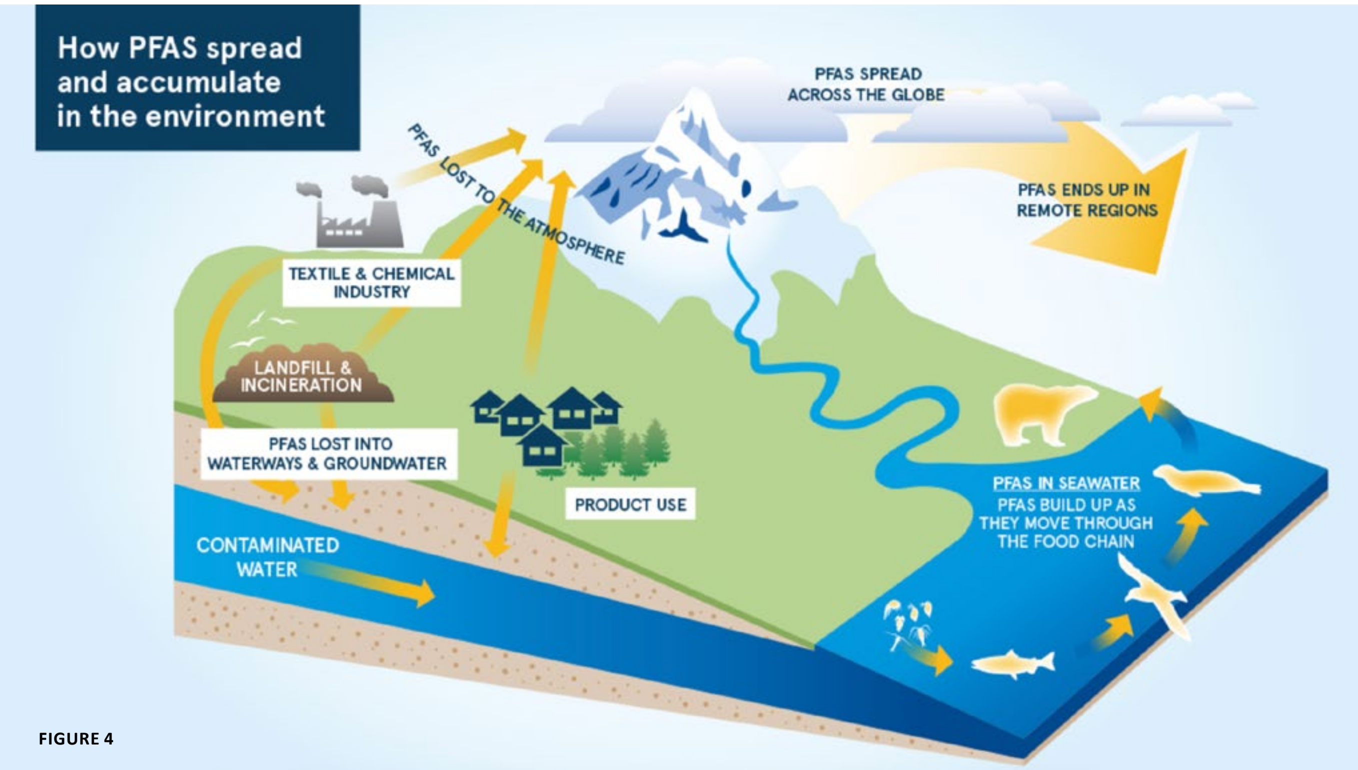


FIGURE 4

Removal of PFAS

Since PFAS do not degrade by natural processes, to date, filtration has been the primary strategy for removing PFAS from drinking water. Filters containing granulated active carbon can absorb PFAS at water treatment plants, however, they are expensive and need to be replaced as soon as the surface area has been saturated by the perfluorochemicals. It has recently been discovered that these filters are not as effective at trapping short-chain PFAS as they are long-chain analogues[54]. There have also been other removal methods used, including ion exchange resins and reverse osmosis filtration, the latter having been the most effective method so far[55].

An emerging challenge for these removal methods is the vast diversity of PFAS compounds. Due to the different structures of the 9,000 PFAS chemicals, no one removal method can be used to capture them all. A water treatment plant may install one removal method, only to find it only works well at capturing a few types of PFAS, but not others[55].

PFAS in food packaging

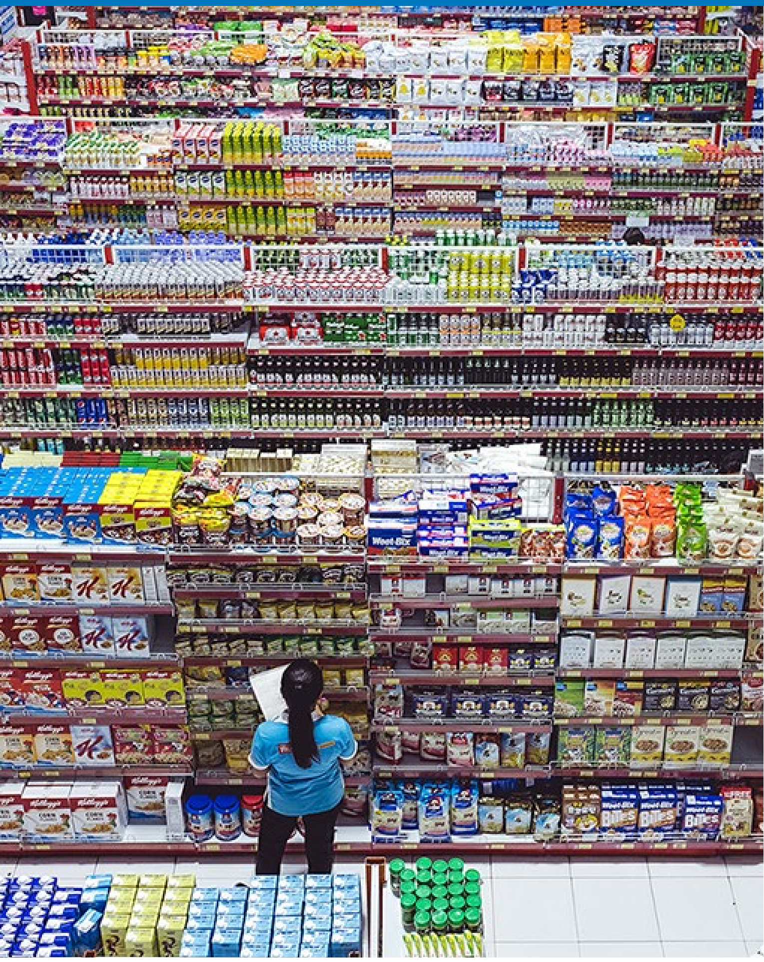


IMAGE BY: BERNARD HERMANT

Plastic in packaging is a known threat to our environment, through ocean pollution, fossil fuel resource use in their manufacture, and formation of microplastics. However, a lesser-known threat to environmental and human health is posed by fibre food packaging, due to the addition of PFAS in many of these packaging products.

The Australian Packaging Covenant Organisation's (APCO) definition of 'problematic plastic packaging' includes packaging that, in Australia, is manufactured with or has contained hazardous chemicals or materials (e.g., PFAS, BPA) that pose a significant risk to human health or the environment[56]. The recent global push to replace plastic packaging has seen the rapid increase of fibre-based packaging requiring additional treatment to provide both water and grease proofing.

This ability of PFAS to repel water, oil and grease has made them a popular choice when coating other products too, including paper, paperboard and other products used in food packaging and food contact products[57]. Environmental exposure occurs during each phase of the lifecycle of a packaging product, from production to disposal.

Figure 5: Food packaging product types that often contain PFAS[58].

FIGURE 5

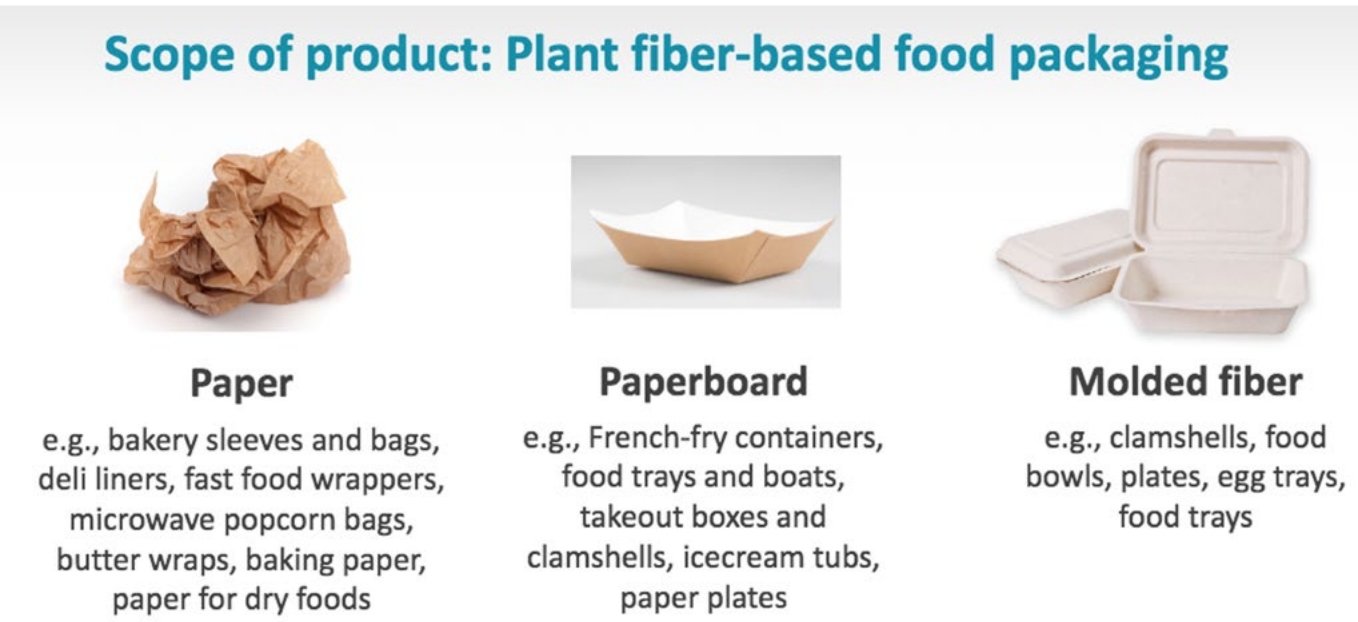


Figure 6: Illustration depicting PFAS contamination and persistence after disposal[63].

During production of fibre packaging, PFAS waste can enter nearby waterways and then either go on to contaminate drinking water, agricultural crops, or animal-based food products, due to exposure of the animal to air, water, or feed containing perfluorinated compounds[59].

A 2017 survey of 400 food contact materials collected from U.S. fast food restaurants (primarily large fast-food chains with [greater than or equal to] 100 U.S. stores) found fluorinated chemicals in 46% of food-contact papers and 20% of paperboard samples[35].

PFAS can also be released from packaging products and directly into the food the packaging is in contact with. The rate at which PFAS migrates from packaging to food contents is dependent on the temperature, acidity, storage time and fat content of the packaged food[60]. It is also dependent on the type of PFAS, as short-chain PFAS are more efficient at migration than long-chain analogues[61]. The prevalence of PFAS in fibre-based food packaging products means they are likely to be a potential source of PFAS exposure for most people[35].

Numerous studies have demonstrated associations between PFAS exposure through food packaging and presence in blood samples[61,62]. One study in particular investigated microwave popcorn as a source of PFAS to humans, as the bags often contain a PFAS coating for its heat and grease resistant properties. The 2019 study by Sussman et.al[62] described a statistically significant positive correlation between consumption of microwave popcorn and PFAS serum levels. Additionally, serum PFAS levels were compared when individuals ate fast food/pizza and food prepared at home (i.e., mostly purchased from grocery stores), with fast food diets being associated with higher PFAS serum levels[62].

After packaging has been used and disposed of, it can continue to release PFAS as it degrades. Figure 6 highlights the ways that PFAS are released and move through the environment and into new products.

Planet Ark study of PFAS in Australian fibre-based food packaging

In 2021 APCO led a study to pilot a scientific methodology to identify the presence and type of PFAS in a range of fibre-based, food contact packaging. A total of 74 confidential packaging samples were provided by nine APCO Member companies for analysis. Testing was conducted by Planet Ark using the Australian Nuclear Science and Technology Organisation (ANSTO) and Envirolab Services and the study was supported with funding from the Commonwealth Department of Agriculture, Water and the Environment (DAWE). The PFAS in fibre-based packaging report was published by APCO in December 2021[58].

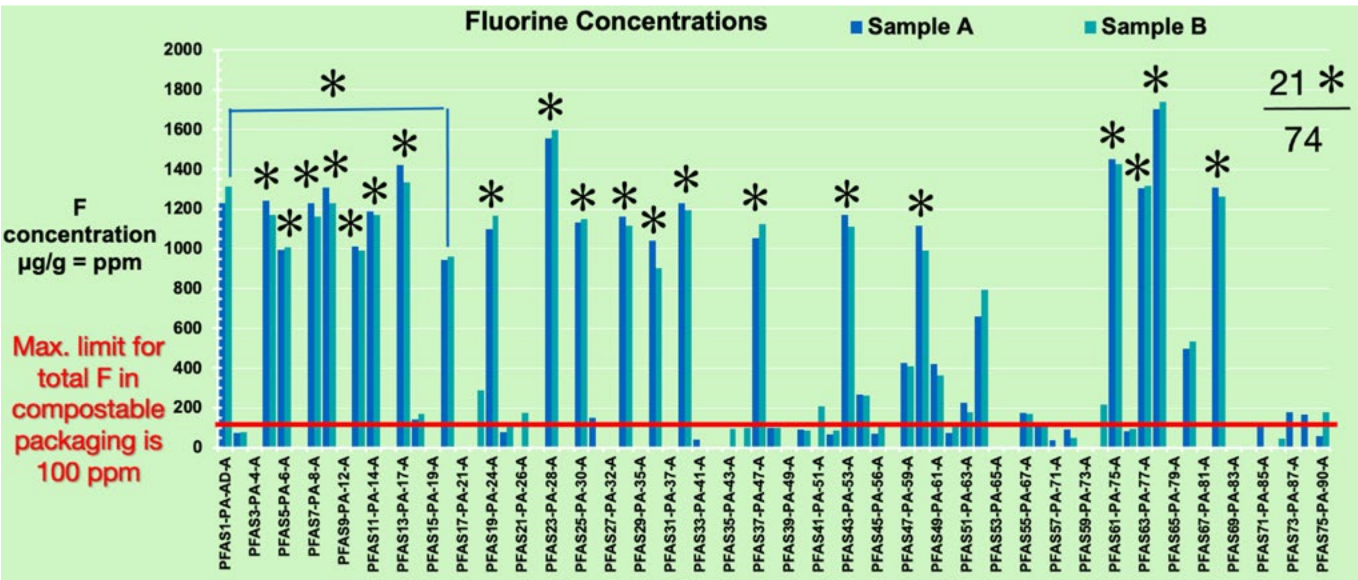
The analysis of samples involved two phases. In the first phase, all 74 samples were tested for 'total fluorine' concentration, which is an indicator of the total concentration of PFAS in each sample. In the second phase, 35 samples were selected for targeted PFAS analysis to see whether they contained any of the 28 specific members of the PFAS class commonly found in the environment. These 28 PFAS are readily identifiable and quantifiable through established analytical methods. To identify and quantify any of the thousands of other PFAS in commercial use is very expensive and only possible in dedicated research facilities.

The Phase One results indicated that 28% of the 74 samples contained high levels of fluorine (above 800 ppm). The samples with high total fluorine were mainly in the 'bagasse' (sugarcane pulp) category of packaging products. Other packaging types had significantly lower, but variable levels of PFAS. In total, 54% of the samples contained less than 100 ppm, the accepted maximum concentration for compostable packaging in the US[64]. Just 28% of the samples tested had no detectable fluorine.

Figure 7: Total fluorine concentrations in duplicates of the 74 samples tested in Phase 1.

In Phase Two the selected 35 samples were treated with an extraction solvent and the resulting solution tested for the standard 28 PFAS. However, these 28 PFAS were not detected, or only present in very low concentrations in most of the selected samples. This indicated that other members of the PFAS class were responsible for the fluorine levels found in the Phase One results. When the extraction solutions were subsequently treated with a strong oxidising agent (a TOPA analysis) that would degrade any complex PFAS into simpler PFAS that could be identified, the results confirmed the presence of unknown complex PFAS 'precursors' (see Appendix for some examples). While the identity of these unknown PFAS could not be determined easily, these unidentified PFAS should be treated in the same way as known PFAS and steps taken to transition them out of packaging.

FIGURE 7



The most studied packaging type in the literature is the microwave popcorn bag. In the Planet Ark study, the microwave popcorn bag sample had a high fluorine concentration (953 ppm). The presence of PFAS is significant because the popcorn kernels are heated in the oil included in the sealed bag at a high temperature – both conditions that facilitate migration of PFAS into the popcorn during cooking[65]. The clear recommendation, as highlighted by Carnero et.al, is to never heat any food in its fibre-based food packaging.

Some 'PFAS-free' packaging containing undetectable concentrations of PFAS is available in Australia. In another separate Planet Ark pilot study, we collected samples of greaseproof paper and compared the total PFAS in two different samples in duplicate. The imported product sample had a total fluorine concentration of 972ppm, and the locally sourced product sample was under the 60ppm detection limit, clearly showing it is possible to produce essentially 'PFAS-free' paper with the required repellent properties. The PFAS-free greaseproof paper is treated with a starch coating in a commercially confidential way that still makes the paper water- and grease-resistant.

These two studies of PFAS in food packaging by Planet Ark, together with the findings of comparable international studies, demonstrate the presence of PFAS in a significant proportion of commonly used food packaging in the Australian context. Human health is potentially at risk, given the proven ability of PFAS to migrate from packaging to food in microwave popcorn[60,65] and the strong likelihood this transfer also occurs in a range of other packaging items we are exposed to often[62].

The ability of PFAS to enter the environment through the recycling or composting of these packaging products further supports the need to expedite the shift to alternatives.

The problem with alternative types of PFAS

IMAGE BY: JESSICA FURTNEY

With negative health impacts of high exposure to long-chain PFAS established, there has been a shift in industry to the use of short- and ultrashort-chain PFAS. This change, however, has not come without its own set of risks. These shorter chain alternatives have been found to be eliminated from the human body faster and to have less bioaccumulation potential[69]. However, shorter chain PFAS are also highly mobile in the environment, more so than their longer chain counterparts. They are particularly mobile in water and have been detected in seas, oceans, rivers, surface/urban runoffs, drinking waters, groundwaters, rain/snow, and deep polar seas[36]. They have also been found to be preferentially taken up by plants and thereby accumulate up food chains[66].

Little research has been done on the health and environmental impacts of these newer, shorter chain alternatives. Time and further research will tell, but many of these replacements may even be worse, thus constituting a "regrettable substitution"[67]. Manufacturers have also broadened the scope of PFAS used in food packaging, making their identification and quantification very difficult.

Non-fluorinated alternatives to using PFAS

Based on well-established business cases, The Nordic Council of Ministers (2017) concluded that safer and more sustainable alternatives to PFAS in paper and paperboard food packaging products are available for all intended functional uses and food types. They also found that, except for natural greaseproof paper, which can be more expensive, alternatives are cost-neutral for retailers. A summary of potential alternatives to PFAS in food packaging is shown in Table 1.

However, a report published by the OECD Per- and Polyfluoroalkyl Substances (PFAS) project in 2022 demonstrated that the hazard profiles of 18 of the 58 alternatives to long-chain PFAS for paper and paperboard food packaging in that study are not available[68]. Therefore, each alternative should be evaluated individually.

Table 1: Examples of alternatives to existing barriers that can contain PFAS[69].

Alternative type	Examples
Physical barriers	(bio)plastic, silicone, aluminium, clay, (bio)wax
Alternative processing	Natural greaseproof paper, vegetable parchment, mechanical densification, mechanical glazing
Alternative chemical barriers/coatings	Starch, aqueous dispersions of copolymers or waxes, chitosan, silicone
Alternative materials	Palm leaf, bamboo, (bio)plastic

TABLE 1

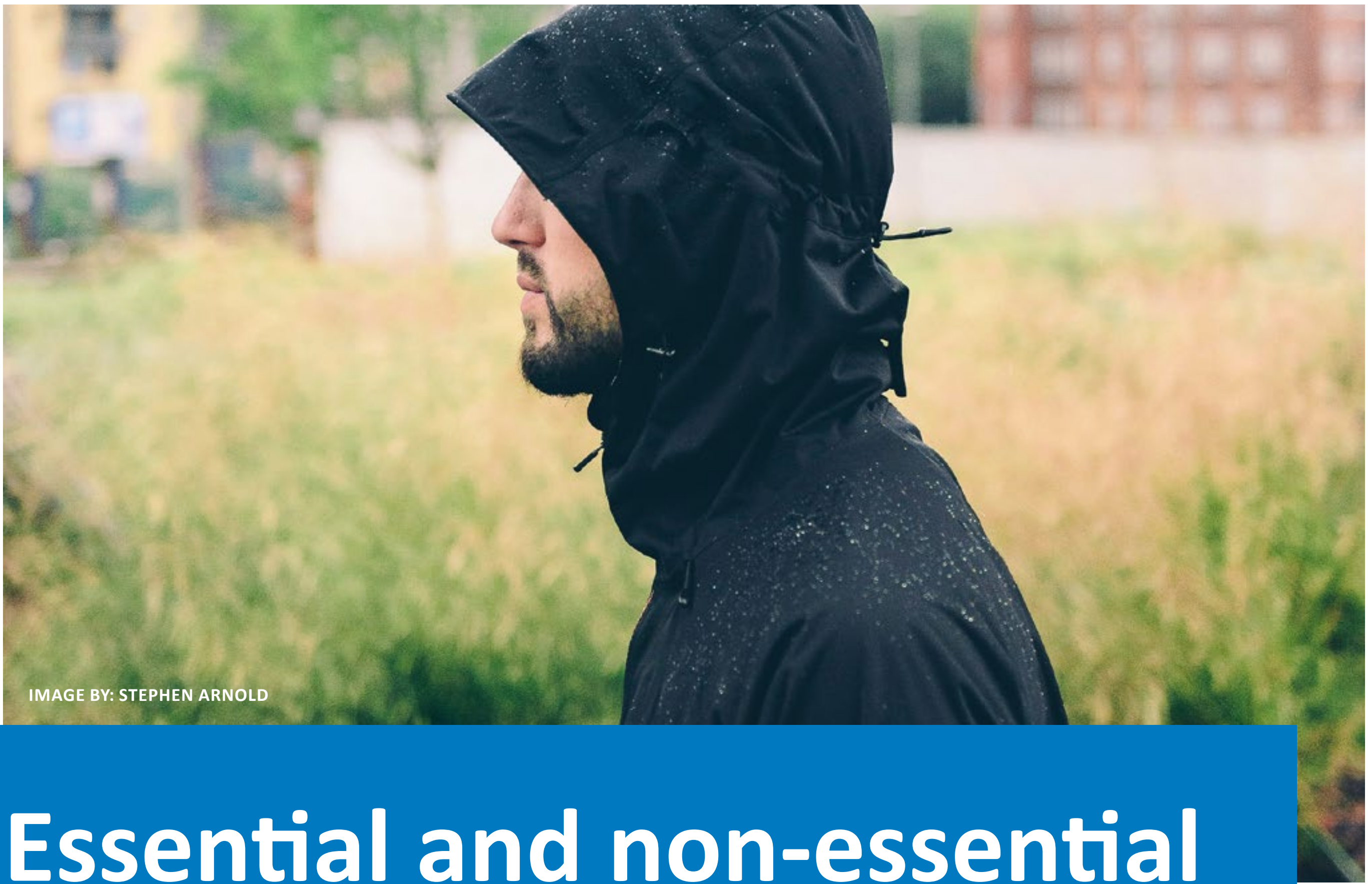


IMAGE BY: STEPHEN ARNOLD

Essential and non-essential uses of PFAS

The unrivalled ability of PFAS to resist grease, oil, and water, and provide low friction, all within a wide range of temperature conditions, with few better alternatives, has meant they have had a range of uses over time[5,7]. The key questions are what uses of PFAS are essential and where are there no alternatives?

An essential use is defined in the Montreal Protocol as one that is necessary for the health and safety of society or for other important reasons, and for which no safer alternatives have been developed. This can be a contentious issue but there is a framework for deciding "essentiality"[70].

One of the non-essential uses of PFAS is in cosmetics where alternative chemical ingredients clearly exist. There are rarely any indications on the label that a given cosmetic contains these substances, and the risk of ingestion, inhalation or absorption is high. Fluorinated ski waxes, dental floss and water-repellent board shorts are other examples of products that do not require PFAS to function.

Sometimes, there are no viable alternatives. One of seven exemptions in the recommendation to ban PFOA in the Stockholm Convention involves protective clothing for medical personnel and workers in the oil and gas industry.

These people need safe protection from both watery and oily fluids, and only PFAS confer that property efficiently in materials. Acceptable substitute chemicals are not available at the present time but may be developed if PFAS were time-restricted as an incentive for innovation. One argument for taking a class approach to regulating PFAS in consumer products is that it would encourage innovation in developing safer alternatives and reducing the risk of regrettable substitutions.

IMAGE BY: IVAN BANDURA

Regulation of PFAS

The debate over limited regulation

FluoroCouncil, representing major manufacturers of products based on PFAS, claims these substances encompass many different classes of chemicals, from small molecules to extensive branched polymers, that vary significantly in their physical and chemical properties, hazard profiles, and uses. Because of this variation, they claim it is inappropriate to impose a one-size-fits-all regulatory approach and legislate restrictions of the uses of PFAS as a single class of chemicals[71].

However, the persistence of PFAS is arguably “the most important single criterion affecting chemical exposure and risk via the environment”[72]. Some have even proposed that high persistence alone should be a sufficient basis for chemical regulation because if adverse impacts are identified, contamination cannot be reversed at scale within a reasonable time frame[73]. Legacy chemicals such as dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs) remain public health concerns decades after their production was banned because of their ability to persist in the environment[74].

Based on the currently available science, it seems it is both ineffective and impractical to regulate this complex class of chemicals with a piecemeal approach. In the case of PFAS, all members of the class have a potential for significant and widespread adverse impacts due to their extremely high environmental persistence, coupled with growing evidence for human and ecological health hazards.

Individual PFAS never occur in isolation, so they cannot be effectively regulated in isolation. The potential for widespread exposures will remain for as long as PFAS continue to be used and concerns over their fate and transport remain inadequately addressed. However, although virtually all PFAS studied show at least suggestive evidence of toxicity, the observed effects are variable. This means that PFAS cannot be regulated as a single class based on a common mode of action or toxicity.

Individual PFAS never occur in isolation, so they cannot be effectively regulated in isolation.

International bans

Some PFAS are regulated under the Stockholm Convention as POPs (Persistent Organic Pollutants), but otherwise regulation varies from country to country. At present, unlike the US, UK and the EU, Australia has not introduced overarching regulation to limit PFAS exposure. A 2021 position statement released by the Australian Government has highlighted the need to move away from the production and use of products containing PFAS where practicable. However, there is an acknowledgement that the continued use of products containing short-chain PFAS may be necessary where there is no available substitute[7].

Targeted bans aimed at certain PFAS sources have been introduced. For example, in New South Wales a ban is in place on firefighting foams that contain PFAS, unless the circumstances are catastrophic[42]. The APCO 2021 Collective Impact Report also highlighted their plans to work with industry to deliver a phase-out of PFAS in fibre- based, food contact packaging[56].

Internationally, there has been more movement to restrict the use of PFAS. The EU is moving to phase out PFAS in line with the timeframe of the UN Goals for Sustainable Development, beginning in 2025 and to be in effect by 2030[71]. Its new Chemicals Strategy[75] includes a list of commitments that places emphasis on PFAS as chemicals that require immediate attention[53].

A group of five European nations (Germany, Netherlands, Norway, Sweden and Denmark) have undertaken a plan to gather further information on products containing PFAS currently being used in the EU and the available alternatives. A restriction proposal will then be prepared to limit the availability of products containing PFAS[76]. Denmark has taken this a step further and already placed a ban on PFAS in paper and cardboard food packaging materials, effective from the 1st of July 2020[77].

In the USA, bans on the use of PFAS vary across the country, with states having different levels of restrictions. So far, seven states have enacted phase-outs of PFAS in food packaging – Maine, Minnesota, California, Vermont, New York, Washington and Connecticut. It has also been banned for use in firefighting foams in nine states[78].

Corporations are also taking it upon themselves to ban PFAS and other forever chemicals for use in their products. For example, in 2020 Amazon banned the use of PFAS, phthalates and Bisphenol A (BPA) in food packaging materials in their Amazon Kitchen brand[79].

PFAS IN FIREFIGHTING FOAMS ARE BANNED IN NSW.

Targeted bans aimed at certain PFAS sources have been introduced.

A way forward

Circular innovation and designing for the environment

As we search for and introduce alternatives to PFAS, the need to ensure these new chemicals do not present their own set of risks to human and environmental health is of great importance. Substitute chemicals, as with a wide array of other food additives made for human consumption, will need to be designed in a way that does not threaten or degrade the environment. As the world shifts towards a circular economy, where products and materials are designed to be kept in use and at their highest value for as long as possible, PFAS alternatives will need to fit into this system[80].

When reuse or repair are not applicable or available, recycling and composting (for organic materials) are central to keeping products and materials in use. Given that PFAS could be re-incorporated into recycled products and could contaminate wastewater from recycling plants, there is a need for safe alternatives that will not cause harm when repurposed[58]. Furthermore, with the increased use of compostable packaging products, many of which contain PFAS, compost will be increasingly contaminated[58,81]. As large-scale composting is a crucial part of the way forward in tackling greenhouse gas emissions from organic matter, finding safe alternatives is important to prevent contamination of soil, plants and animals[31,82]. Most PFAS do not break down when composted and the few that do can form other PFAS[58].

While there is not yet a clear consensus on the health impacts of exposure to low concentrations of PFAS, their mobility and persistence in the environment are well-documented and a clear cause for concern.

IMAGE BY: SILAS BAISCH

Safe transitions

Although research into the health and environmental impacts of PFAS is ongoing, there is enough evidence to state a case for transitioning away from these chemicals. While there is not yet a clear consensus on the health impacts of exposure to low concentrations of PFAS, their mobility and persistence in the environment are well-documented and a clear cause for concern. Guided by the precautionary principle, Planet Ark recommends preventing exposure to PFAS, regulating their use in non-essential applications where possible, and a transition to safe alternatives.

There should be a presumption of harm for replacement PFAS chemicals that have been identified as having harmful effects on human health. There should be extended producer responsibility for PFAS producers and those selling products that contain PFAS to fund further human health research including biomonitoring and observational health studies. Industry should prioritise research into alternatives and be required to establish safety prior to registration of replacement PFAS.

Organisations are already working to find safer alternatives to PFAS – one example of this in Australia is in the food packaging space, where greaseproof paper products that do not contain PFAS are being produced. Additionally, organisations are focusing on identifying alternatives to PFAS in firefighting foams used on military bases, airports, and fire training grounds, as these are a primary source of PFAS contamination of drinking water[83].

Furthermore, as recommended by the Cancer Free Economic Network (CFEN), it will be crucial to develop a consensus-based definition of safer alternatives and resources for manufacturers to verify and communicate that their replacement chemicals are not equally as toxic as PFAS. An increase in demand for alternatives to encourage support of and investment in companies developing safe alternatives is also needed to give momentum to the transition away from PFAS[83]. Given the additional cost of substituting PFAS with non-fluorinated alternatives is the main obstacle for manufacturers, this increase in public demand for PFAS-free options is critical[57].

IMAGE BY: WILL TURNER

IMAGE BY: MED BADR CHEMMAOUI

Solutions

Individuals:

Based on the precautionary principle, Planet Ark recommends individuals limit their exposure to products that are likely to contain PFAS and look for 'no added PFAS' verification. Look for labels on products, and where the information is not available, contact the brand for details.

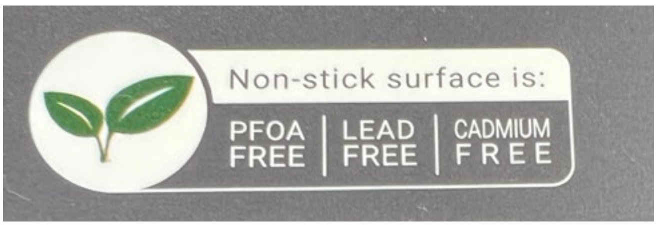
Some products to look for:

- Food packaging/contact materials that are verified 'no added PFAS'
- Clothing and footwear with waterproof coating that are verified 'no added PFAS'
- Utensils and cookware with non-stick coatings, such as stainless-steel pots and pans

Some tips for limiting exposure:

Look for alternatives with no added PFAS where available

- Use products made from alternative materials, such as glass, aluminium, wooden or glass cookware and utensils
- Never heat food in fibre-based packaging (e.g. clamshell boxes, produce trays, chip buckets)
- Speak up – use your voice as a consumer to drive change from manufacturers and purchasers selling products that contain PFAS, and encourage a shift to safe alternatives
- Raise your concerns with your local member of Parliament and request regulation



Planet Ark recommends individuals limit their exposure to products that are likely to contain PFAS

Businesses:

Based on the precautionary principle, Planet Ark recommends businesses avoid selling and using products that contain PFAS chemicals and seek verification of their products. The following products are examples of safer alternatives:

- Baking paper and food contact products with no added PFAS
- Non-stick cookware with no added PFAS
- Cosmetics and other self-care products such as shaving cream and shampoo with no added PFAS

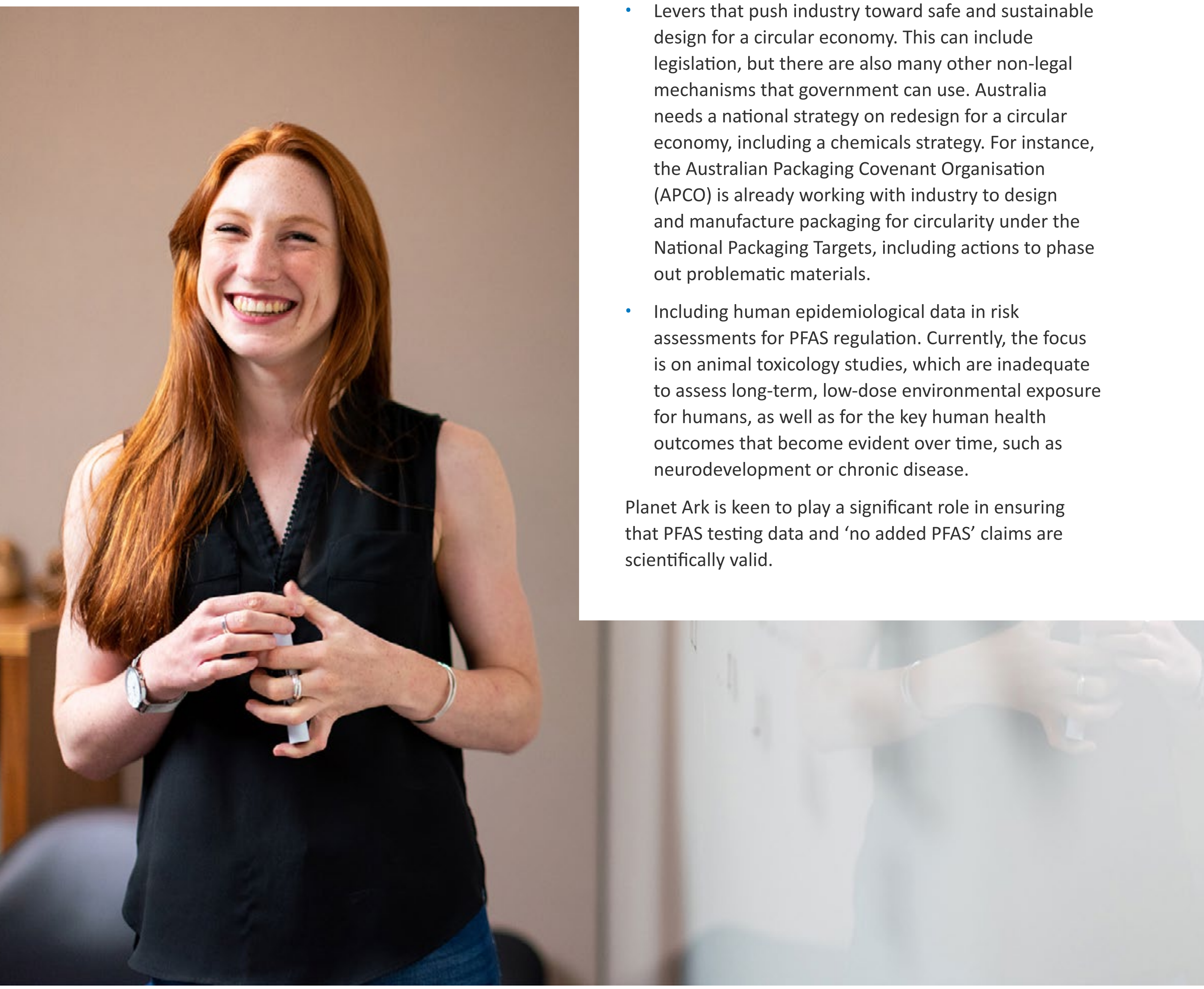
In addition to choosing alternatives without added PFAS, it is possible to test your products for their total fluorine concentrations as in the Planet Ark study described above to learn if they do contain PFAS.

Policy makers

Planet Ark recommends that policy makers consider —

- Restricting the use of PFAS through the Industrial Chemicals Environmental Management Standard (IChEMS), establishing restrictions on food contact materials through the Food Code, through restrictions under the Australian Consumer Law, and through the Poisons Schedule. For example, industrial chemicals listed in the Stockholm Convention and not yet ratified by Australia (including PFOS and PFOA) have already been prioritised for scheduling under IChEMS.
- Monitoring PFAS entering the country through products. Whilst the Australian Industrial Chemicals Introduction Scheme (AICIS) can monitor PFAS in industrial chemicals and nurdles, there is no monitoring of PFAS in products. There needs to be an appropriate body to monitor PFAS in consumer products.
- Levers that push industry toward safe and sustainable design for a circular economy. This can include legislation, but there are also many other non-legal mechanisms that government can use. Australia needs a national strategy on redesign for a circular economy, including a chemicals strategy. For instance, the Australian Packaging Covenant Organisation (APCO) is already working with industry to design and manufacture packaging for circularity under the National Packaging Targets, including actions to phase out problematic materials.
- Including human epidemiological data in risk assessments for PFAS regulation. Currently, the focus is on animal toxicology studies, which are inadequate to assess long-term, low-dose environmental exposure for humans, as well as for the key human health outcomes that become evident over time, such as neurodevelopment or chronic disease.

Planet Ark is keen to play a significant role in ensuring that PFAS testing data and 'no added PFAS' claims are scientifically valid.



Conclusion

PFAS do not degrade in nature so the vast majority of the PFAS that have been produced to date are still circulating everywhere, and some are in everyone.

Although there is still not complete certainty around the causal relationships between PFAS exposure and human and animal health endpoints, there is clear scientific evidence for the persistence and bioaccumulation of these chemicals, so safer alternatives should be sought.

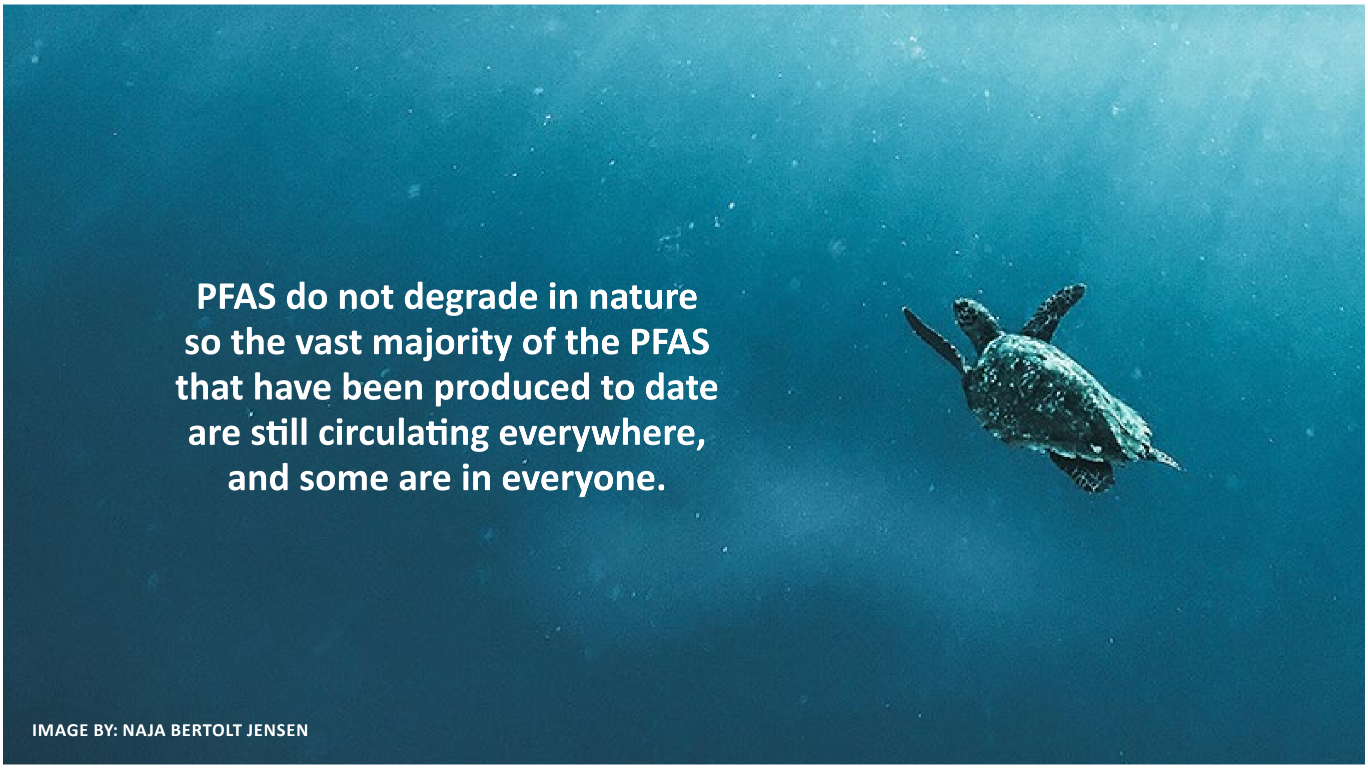


IMAGE BY: NAJA BERTOLT JENSEN

Planet Ark encourages businesses to move away from both producing and selling products containing PFAS and to research and invest in alternatives that are being introduced to the market. Additionally, it is crucial that we as consumers question the potentially hazardous products we are handling daily, as this is one of the most powerful ways of creating change as an individual. For example, we recommend consumers put pressure on businesses to offer products that do not contain PFAS.

There has been considerable progress in the PFAS space in recent years, particularly in Europe where bans have been introduced and transitions to safe alternatives are well under way.

A shift in public policy to introduce overarching legislation regulating the use of PFAS is also critical in the transition away from PFAS. As concerned citizens, we can reach out to local politicians and call for change.

There has been considerable progress in the PFAS space in recent years, particularly in Europe where bans have been introduced and transitions to safe alternatives are well under way. PFAS have proven to be very versatile chemicals with a wide range of uses and some of these, such as in specific medical applications are still deemed essential. The shift to safe alternatives will involve significant research, financial investment, and trade-offs. However, given the potential for harm that PFAS pose to human and environmental health, the time to act is now and move toward a healthier future for the planet and ourselves.

Appendix

Variation in the structures of PFAS and its implications

PFAS exist in two main structural forms – as chains of repeating molecular units (polymers) or separate molecules (see Figure 1A below). Their structural form and composition determine not only their desired function and behaviour, but their ease of degradation to other PFAS, mobility in water or air or soil, and potential toxicity when released to the environment.

The carbon backbone chain length covered with bonded fluorine atoms is an important feature of PFAS. For example, PFOA and PFOS are long-chain PFAS (see Figure 2). In the case of perfluoroalkyl acids, like PFOA, a long-chain type is defined as one with seven or more carbon atoms in the backbone, but in the case of perfluoroalkyl sulphonates, like PFOS, a long-chain type is defined as one with six or more carbon atoms in the backbone. Short-chain analogues have four or five carbon atoms, and those with two or three carbon atoms are called ultra-short chain analogues[3].

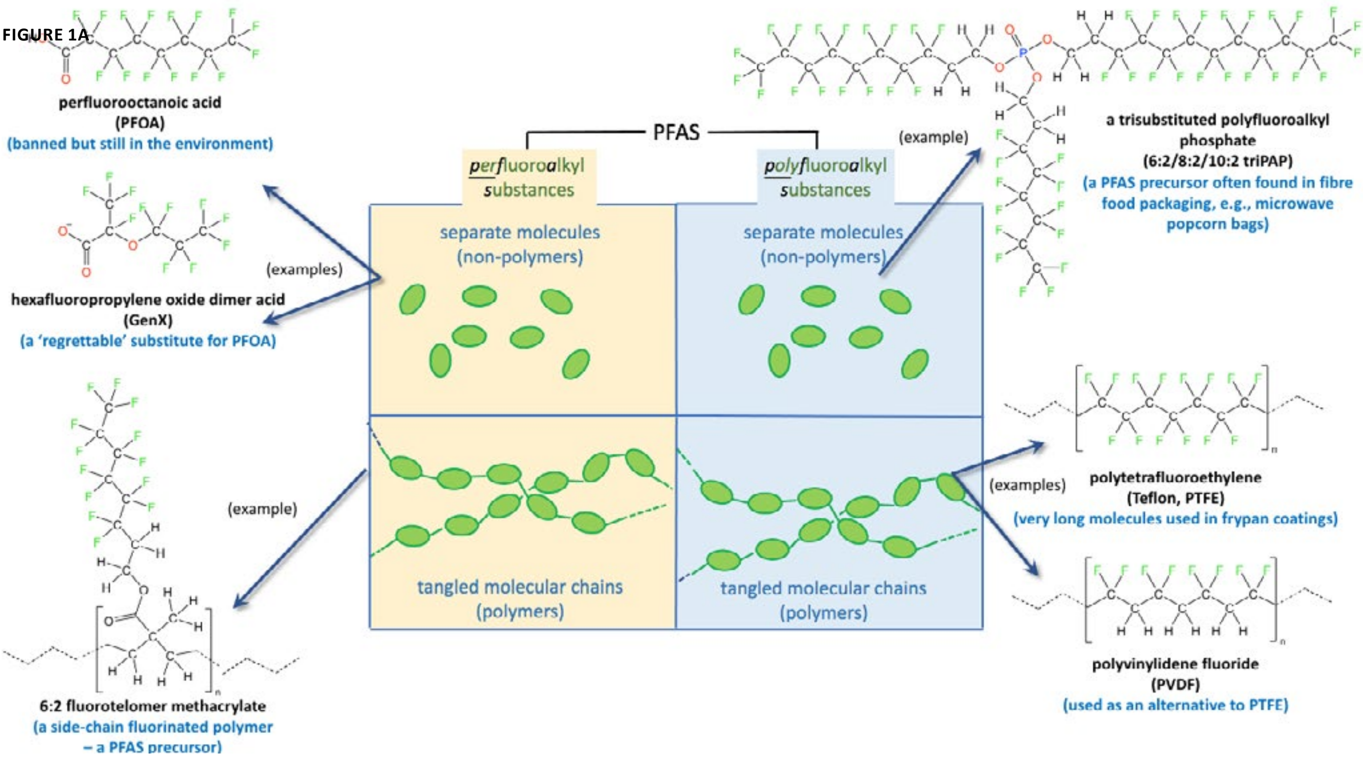
Most PFAS currently used in consumer products are precursors such as side-chain fluorinated polymers, in which the fluorinated side chains are attached to a polymeric backbone (see Figure 1A) and can cleave off, leading to PFAS degradation products, mainly perfluoroalkyl acids, PFAA[15,16].

The structural form also determines their bioaccumulation in the biosphere. PFAS build up in the fatty tissues of prey and predators with increasing concentration towards the top of the food chain, ending up in some cases in humans. For instance, as a guideline long-chain PFAS take longer to be excreted from the body than short-chain PFAS.

With negative health impacts of high exposure to long-chain PFAS established, there has been a shift in industry to the use of short- and ultrashort-chain PFAS. This change, however, has not come without its own set of risks. Although these chemicals are assumed to have lower bioaccumulation potential, they have been found to be highly mobile in both soil and water, meaning they can move more freely through the environment. Short- and ultrashort-chain PFAS have been found in a range of aquatic environments all over the world – oceans, rivers, drinking water, ground water and even deep polar seas[3].

Figure 1A. PFAS are classified as perfluoroalkyl substances or polyfluoroalkyl substances, depending on the extent of fluorination on the carbon backbone in their molecules. They are further distinguished by their molecular structure depending on whether they exist as separate molecules, or as polymers (tangled molecular chains with a repeating pattern). The examples shown are commonly found in food packaging or cookware.

FIGURE 1A



Possibility that plastic food packaging might contain PFAS

The molecular structures of several PFAS shown in Figure 1A reveal a common feature – extended carbon backbones covered with bonded fluorine atoms. Containers composed of polyethylene (extended carbon backbones) can be treated with fluorine gas (Figure 2A) to produce a similar fluorine covering. This treatment prevents food and cosmetics, as well as cleaning products, agricultural chemicals, petroleum-based fluids, and other liquids from exposure to moisture or oxygen by providing a better barrier. With respect to food, these containers can be used to hold vegetable oils, flavouring agents, liquid dairy products, or nearly any liquid that is prone to spoil by reaction with water or oxygen in air permeating through the walls of the container.

This fluorination process was approved by the US Food and Drug Administration (FDA) in 1983, but in August 2021 the FDA officially reminded manufacturers that only certain processes are allowed for fluorinating polyethylene containers used to store food[84], otherwise there is the distinct possibility of PFAS contamination of the food contents.

Evidence for the formation of PFAS like PFOA (Figure 2) through fluorination of polyethylene pesticides containers was recently published by the US Environmental Protection Agency[85]. There is a need to monitor take-away plastic packaging to ensure this is not common in food packaging in Australia.

FIGURE 2A

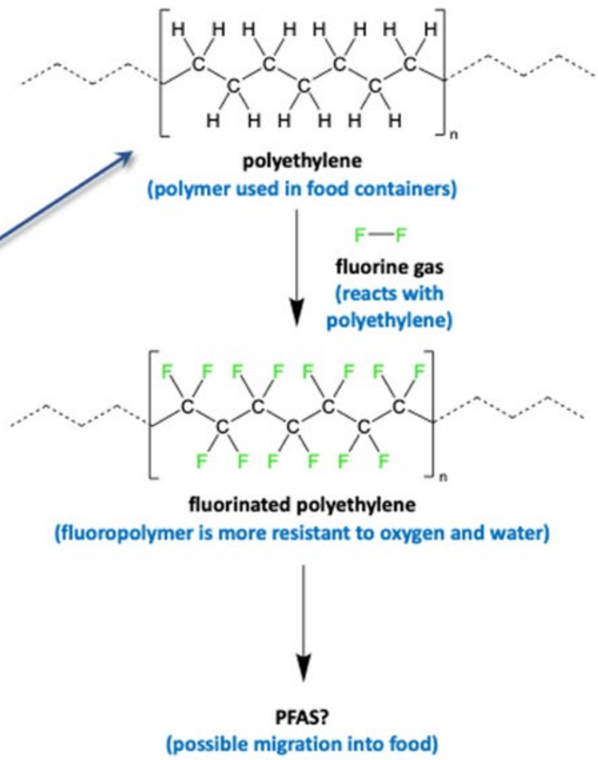


Figure 2A. Treating high-density polyethylene food containers with fluorine in the presence of water, oxygen, or gases other than nitrogen can lead to the formation of PFAS that can migrate into the food. The FDA has recently officially warned manufacturers to only fluoridate these containers in the presence of nitrogen gas to minimise this possibility.

Alternatives to PFAS as outlined in the APCO Action Plan:

Physical barrier (non-chemical alternative that confers repellence): elephant grass, cellulose pulp, bamboo, vegetable parchment, Clay, wheat straw, microfibrillar cellulose (MFC), cellulose nanocrystals (CNCs), cellulose nanofibrils (CNFs).

Chemical alternative (a 'drop-in substitute' that performs the same chemical function): NGP plus additives, silicone materials, TopScreen formulations, Chitosan, copolymer dispersions, aqueous wax dispersions, starch, stone plus resin, hydroxyethyl cellulose (HEC), Polyvinyl alcohol (PVOH), Alkyl ketene dimer (AKD), Alkyl succinic anhydride (ASA).

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