Throwaway Packaging, Forever Chemicals

European wide survey of PFAS in disposable food packaging and tableware

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ARNIKA · BUND · IPEN for a toxics-free future · CHEM Trust · HEAL Health and Environment Alliance · TEGEN GIF · ClientEarth · Forbrugerrådet Tænk Danish Consumer Council · générations futures

This project is a joint collaborative of the following organizations:

Arnika Association (Czech Republic) is a non-governmental organisation established in 2001. Its mission is to protect the nature and healthy environment for future generations both at home and abroad. Since the beginning Arnika has been working on protection of consumers from chemically hazardous products. Lately, Arnika has been making own research focusing on persistent organic chemicals in products. Arnika serves as a regional hub for Central, Eastern and Western Europe for IPEN. www.arnika.org

CHEM Trust is a collaboration between CHEM Trust, a UK registered Charity and CHEM Trust Europe eV, a charity based in Germany. Our overarching aim is to prevent synthetic chemicals from causing long term damage to wildlife or humans. CHEM Trust's particular concerns are endocrine disrupting chemicals, persistent chemicals, the cocktail effect of chemicals and the role of chemical exposures in the early life of wildlife and humans. CHEM Trust engages with scientific, environmental, medical and policy communities to improve the dialogue concerning the role of adverse effects of chemicals in wildlife and humans and to harness a wide coalition to drive improved chemicals policy and regulation. CHEM Trust UK Charity Register Number: 1118182; EU Transparency Register Number: 27053044762-72. chemtrust.org

BUND/Friend of the Earth Germany is an association for environmental protection and nature conservation aimed at bringing about sustainable development on a local, regional, national and international level. We are a member-based association with democratic decision-making structures on all levels, within which elected voluntary officials have the final say on goals, strategies and use of the association's resources. We develop long-term strategies and solutions, set goals aimed at protecting the environment and nature, and demonstrate through the realization of individual projects that sustainability can be put into everyday practice in our society. www.bund.net

Danish Consumer Council (Denmark) is an independent consumer organisation created in 1947 which works for the promotion of sustainable and socially responsible consumption. We defend consumer rights and make consumers a power in the market.Through chemical testing and communication to consumers the initiative Danish Consumer Council Think Chemicals specifically helps consumers avoid problematic chemicals when shopping. www.kemi.taenk.dk

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Tegengif - Erase all Toxins(The Netherlands) is a not-for-profit organisation based in Amsterdam. Our aim is a non-toxic living environment. We raise public awareness of consumers' daily exposure to toxic chemicals via appealing research, campaigning and policy influencing. We believe growing awareness will both stimulate the demand for toxin-free products and increase public support for regulations for a toxin-free world. https://www.erasealltoxins.org

Générations Futures (France) has been campaigning on pesticides related topics in France for over 25 years. It has become the reference specialized NGO in France on this issue. GF has a unique expertise on pesticides and health campaigning in France and a strong track record of reaching out to grassroots organizations and the public, as well as to national and European policy-makers and the media. GF extended its activities to other categories of chemicals with a new campaign named 'Desintox'. Its various activities include surveys, conferences, product testing, legal actions and publication of reports to raise awareness among the public and decision makers. www.generations-futures.fr/

IPEN. Established in 1998, **International Pollutants Elimination Network (IPEN)** is currently comprised of over 600 Participating Organisations in primarily developing and transition countries. IPEN brings together leading environmental and public health groups around the world to establish and implement safe chemicals policies and practices that protect human health and the environment. IPEN's mission is a toxics-free future for all. www.ipen.org

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THROWAWAY PACKAGING, FOREVER CHEMICALS

European-wide survey of PFAS in disposable food packaging and tableware

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EXECUTIVE SUMMARY

'Forever chemicals' in disposable food packaging and tableware: a study in 6 European countries and an overview of the implications of PFAS exposure for our health and our environment.

This report is based on a European study, carried out by 8 civil society organisations, into the presence of per- and polyfluoroalkyl substances (PFAS) in paper, board and moulded plant fibre disposable food packaging and tableware, sold in six European countries: The Czech Republic, Denmark, France, Germany, the Netherlands and the United Kingdom.

The aim of this study was to collect evidence on the widespread use of PFAS in disposable food packaging and tableware in Europe, as well as to uncover levels of background (i.e., unintentional) contamination with PFAS chemicals in such products.

MAIN FINDINGS

- **PFAS are widely used in disposable food packaging and tableware in Europe.** This includes food packaging from popular fast-food chains and restaurants.
- **Traces of PFAS were detected in all samples selected for lab analysis** demonstrating the pervasive contamination of both production and supply chains for paper and board food packaging with PFAS chemicals.
- **In some samples, the total organic fluorine (TOF) levels measured were up to 60 times higher than the indicator value set by the Danish Veterinary and Food Administration** to help companies assess whether organic fluorinated substances have been added to paper and board food packaging or not.
- **Intentional PFAS treatment was confirmed in 32 out of the 42 samples sent to the laboratory for analysis.**
- **Less than 1% of the total organic fluorine present in the PFAS-treated samples could be assigned to specific PFAS chemicals identified via targeted analysis. This means that over 99% of the total PFAS load remains unidentified.** This is of great concern, because we know that all PFAS persist in the environment, that exposure to certain PFAS chemicals can have harmful health effects, and that some can migrate from the packaging into the food.
- Our results also indicated that the **PFAS present in some of the food packaging samples tested had the potential to impair thyroid activity.**
- The **highest PFAS concentrations** were consistently found in **moulded fibre products**, (e.g. bowls, plates, and food boxes) advertised as **biodegradable or compostable disposable products.**
- **In Denmark, where the use of PFAS in paper and board food packaging has been banned since July 2020, none of the sampled french fries bags from McDonald's, for example, exhibited any PFAS treatment**. This is in contrast to the results for the same items sampled in the Czech Republic and the United Kingdom. These findings illustrate that **regulations are an effective tool to protect people from exposure to harmful chemicals and to push industry players to find safe replacements. However, this also highlights the lack of EU-wide harmonised regulation and protection when it comes to food contact materials.**
- Because PFAS are very persistent, their widespread presence in disposable food packaging produced in very high volumes, that also by definition have a very high turnover rate, is **of great concern in terms of PFAS accumulation in our environment**. This in turn can **endanger human health and wildlife** in the long term and hinder the achievement of a **clean and circular economy**.

Overall, the findings of our report demonstrate the widespread use of and contamination by PFAS in disposable food packaging and tableware across Europe. These items are by definition and design meant to be used for very short durations before being thrown away. This contrasts with the extreme persistence of all PFAS chemicals. Alternatives to PFAS treatments do exist, and even more importantly, safe, durable and reusable options for food containers and tableware are already widely available. Therefore, the treatment of disposable items with PFAS is a typical example of completely unnecessary and avoidable chemical uses that run counter to achieving a clean circular economy. It is high time that national governments and European institutions phase out all such uses of PFAS and manage these substances as a group.

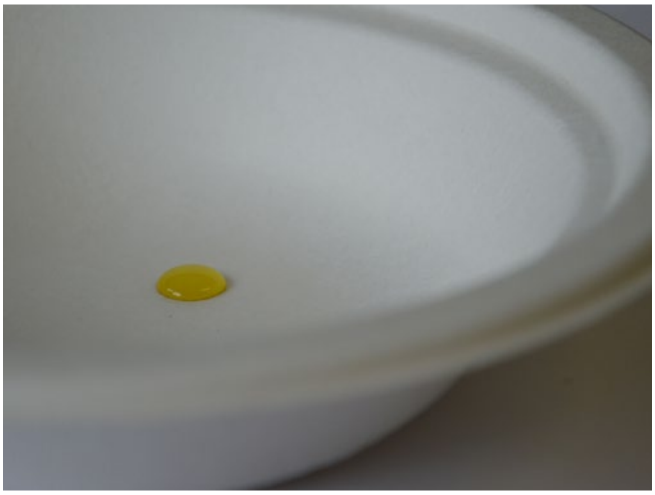
HEALTH AND ENVIRONMENT CONCERNS ABOUT PFAS

PFAS is a large family of over 4,500 compounds [1], also known as *"Forever Chemicals"* due to their extreme persistence in the environment. They are used in a wide variety of consumer products and industrial applications [2], including food packaging, where their ability to repel both grease and water have been considered highly convenient.

However, PFAS are giving rise to increasing concern due to their impacts on health and our environment. PFAS do not degrade easily in the environment. They are mobile, can travel long distances and are already causing water contamination problems across Europe [3]. **Some PFAS emitted today could still be present in the environment in a century, representing a threat for both current and future generations. This raises legitimate questions about their multiple consumer and industrial uses, including their use in disposable products such as fast food packaging and tableware.**

Scientific studies have associated exposure to a number of PFAS with severe adverse health effects, including cancer, and impacts on the immune, reproductive and hormone systems, as well as with a reduced response to vaccinations [4, 5]. In the context of food packaging, studies have shown that PFAS can migrate from the packaging into the food [6], adding to the overall PFAS exposure of the general population. The more we learn about these chemicals, the more reason there is for concern, and the more urgent it becomes to minimise emissions and exposure. By way of illustration, between 2008 and 2020, **the European Food Safety Authority lowered the recommended safe levels of exposure to some PFAS by more than 99% [7, 8].**

Only a few compounds of the large PFAS family have been restricted at the global, regional and/or national levels, but thousands more exist and are available for use. In the context of food contact applications, Denmark is currently the only country that has banned PFAS for use in food packaging [9]. Also, the industry strategy has been to just replace banned, widely used PFAS with others - usually less studied - for industrial applications and/or uses in consumer products [10].



BACKGROUND AND METHODOLOGY

In a collective effort of eight non-profit organisations, and under the supervision of the Czech organisation Arnika, 99 samples of disposable food packaging and tableware made of paper, board and moulded plant fibre were purchased in six different countries between May and December 2020 (e.g., sandwich and bakery bags, take-away food boxes). **The sampling targeted popular fast-food chains and takeaway restaurants, as well as supermarkets. Moulded plant fibre tableware was purchased via online stores**. The latter products are advertised as compostable and are increasingly being used in takeaway restaurants as an alternative to plastic containers.

In order to inform the selection of packaging samples for chemical analysis, the samples were first screened using a simple oil beading test [11]. This test indicates if a sample material is oil repellent, a characteristic of packaging that has been treated with PFAS. **28 oil-beading samples, likely candidates for intentional PFAS treatment, were selected for chemical analysis. 14 samples showing no oil-repellent properties were also selected to assess the level of background contamination in food packaging products**.

All 42 selected samples were analysed by an accredited laboratory for their Total Organic Fluorine (TOF) content, an accepted proxy for total PFAS content. The TOF values were compared to the TOF guiding indicator value set up by the Danish Veterinary and Food Administration to help companies assess whether organic fluorinated substances have been added to paper and board food packaging [9]. **The 42 samples were also sent to an in-**

dependent laboratory for targeted analysis of 55 individual PFAS in order to seek more information regarding the specific nature of the PFAS present in the samples. Furthermore, **17 samples were selected for investigation of any disruption of thyroid activity as a potential unintended health effect of PFAS exposure [12].**

WIDESPREAD USE OF PFAS IN FOOD PACKAGING IN EUROPE RAISES CONCERN FOR HUMAN HEALTH AND THE ENVIRONMENT

The results from this study clearly show that the use of PFAS in disposable food packaging and tableware is a widespread practice across Europe.

32 samples, covering every country surveyed, indicate the use of intentional PFAS treatments according to the Danish Veterinary and Food Administration indicator value for Total Organic Fluorine (TOF) [9]. In some cases, **the TOF levels were up to 60 times higher than the indicator value.**

The **highest concentrations were consistently found in moulded fibre products**, such as bowls, plates, and food boxes **advertised as biodegradable or compostable** disposable products. However, the presence of non-degradable PFAS chemicals clearly contradicts this claim and this loophole should urgently be addressed.

Less than 1% of the total organic fluorine present in the PFAS-treated samples could be assigned to specific PFAS chemicals identified via targeted analysis. This means that over 99% of the total PFAS load remains unidentified. However, the PFAS chemicals that could be identified **are frequently associated with PFAS treatments involving side-chain fluorinated polymers [13].**

Even though less than 1% of the PFAS present in the samples tested could be identified, **the nature of the PFAS identified is already in itself enough to be a source of concern for human health.** The PFAS chemicals identified have been found to migrate from the food packaging into the food, and are associated with adverse health effects such as cancer, liver toxicity, and impacts on the reproductive and hormonal systems [14]. Our ecotoxicity test showed that the PFAS present in some of the food packaging samples tested had the potential to impair thyroid activity. **Their presence in food packaging is a source of repeated exposure for people frequently visiting and eating food from fast-food chains and takeaway restaurants.** The 1% of PFAS that could be identified is, however, only the tip of the iceberg in terms of potential migration into food and impacts for consumers in the long term. Despite not being identified individually, the other 99% of PFAS present cause concern due to their ability to persist and accumulate in the environment.

By definition and design, disposable food packaging and tableware are intended to be used only once and then thrown away after the food has been consumed. **They are produced in high volumes and have very high turnover rates.** PFAS can be emitted into the environment at every stage of these items' life cycle, from production to disposal [15]. **This contributes to the buildup of these highly persistent chemicals in the environment, and to continuous human and wildlife exposure, via the contamination of the food chain and the drinking water.**

PFAS-FREE ALTERNATIVES EXIST AND REGULATION IS A STRONG INCENTIVE FOR COMPANIES TO MOVE AWAY FROM PFAS

Alternatives to PFAS-treated takeaway packaging exist and are available on the market as shown by our results, including disposable paper and board packaging for takeaway food (e.g., sandwich and fries bags, and cardboard bakery and pizza boxes). Durable and reusable alternatives to moulded fibre tableware are also largely available for consumers, restaurants and retailers.

Where regulation has been put in place, it has worked effectively to incentivise companies to move away from the use of PFAS. In Denmark, the use of PFAS in paper and board food packaging has been banned since July 2020 [9]. Our study found that none of the sampled McDonald's french fries bags bought in Denmark exhibited PFAS treatment, whereas intentional PFAS treatment was found for the same items bought in the Czech Republic and the United Kingdom. **This shows that regulation can and does have an impact to protect people from exposure to harmful chemicals and drive companies to produce safe replacements. In Denmark, McDonald's has been able to replace PFAS-treated packaging and comply with the regulation. However, this finding also highlights the lack of EU-wide harmonised regulations for food contact materials, which results in different levels of protection across countries.**

PFAS, A THREAT TO A CLEAN AND SAFE CIRCULAR ECONOMY

It is clear from our study that unintentional PFAS contamination in food packaging challenges the achievement of a clean recycling chain and circular economy. All of the lab-analysed food packaging samples that were not intentionally treated with PFAS were still contaminated with PFAS chemicals. The contamination levels sometimes exceed the indicator value to measure background contamination set up by the Danish authorities [9].This highlights the pervasive contamination of the food packaging production and supply chain with PFAS chemicals. PFAS contamination could take place at the production stage due to the use of PFAS-containing printing inks, or during recycling of PFAS-treated paper and board [16], as several of the samples tested are indicated as containing recycled material. PFAS contamination throughout the production and recycling chains is a problem that needs fixing. This must be addressed by avoiding PFAS at all stages of the supply chain and throughout the life cycle of products.

RECOMMENDATIONS TO REVERSE THE TREND AND PROTECT PEOPLE AND WILDLIFE FROM PFAS EXPOSURE

Our findings illustrate the all-pervasive presence of harmful PFAS chemicals in our daily environments through the example of a specific type of consumer product casually used and discarded by people within a few minutes. Even when no intentional PFAS treatment has been applied, these disposable products are contaminated with these highly persistent chemicals.

It is not only challenging to identify individual PFAS that are being used for specific food contact applications, but also to control them once they are in the environment as a consequence of this use. Overall, this points to the urgent need to drastically change the regulatory approach to PFAS in order to:

\> prevent emissions of all PFAS chemicals,
\> stop the accumulation of these highly persistent chemicals in the environment and our bodies,
\> and protect people and wildlife from exposure to these harmful substances.

It is high time to prioritise preventing emissions by stopping the use of PFAS for all applications that are not necessary for the health, safety and the functioning of society. Their use in disposable food packaging and tableware is one example of such unnecessary uses.

BASED ON THE RESULTS OF THIS STUDY, WE CALL ON:

> **The five European countries (Denmark, Germany, Norway, Sweden, The Netherlands)** currently developing the European restriction on all non-essential uses of PFAS to include the full range of PFAS chemicals in the restriction, including fluorinated polymers, and to guarantee that disposable food packaging and tableware is covered within its scope.

> **The European Commission**:

As part of its commitments under the Chemicals Strategy for Sustainability

- To support the development of the restriction mentioned above.
- To proceed with the development of the criteria for essential/non-essential uses for chemicals management.
- To proceed with the development of the criteria for Safe and Sustainable by Design chemicals, including to prevent the use of highly persistent chemicals such as PFAS in high turnover disposable and compostable products.

In view of the upcoming reform of the Food Contact Materials legislation:

- To introduce harmonised rules for all materials used for food contact (including paper, board, and moulded plant fibres) in order to guarantee that citizens are evenly protected against the presence of hazardous chemicals in food contact materials and articles.

> **National governments:**

- **In the European Union:** to support the development of a broad-scoped and protective restriction on all non-essential uses of PFAS and thereafter to fully implement it.
- **Worldwide:** to develop similar restrictions.

> **Parties to the Stockholm and Basel Conventions:**

- To work for a class-based approach of listing all PFAS for global elimination under the Stockholm Convention.
- To work for a class-based approach of defining a “low POPs content” level for POPs waste containing PFAS.

> **Companies**

- To commit to phasing out PFAS in their products without waiting for specific regulations to enter into force and join the ChemSec-led ‘No to PFAS’ corporate movement.

> **Citizens:**

- To ask that your national governments support the European move to phase out all non-essential uses of PFAS chemicals, and urge companies to phase out PFAS from the products sold in your countries.
- To bring your own reusable food containers when you visit fast-food chains and takeaway restaurants in order to avoid paper, board and moulded fibre food packaging that could be treated with PFAS chemicals.
- To spread the word on social media - using the #BanPFAS hashtag - to increase public pressure for a phase-out of PFAS chemicals.

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The full report is available at https://english.arnika.org/publications/throwaway-packaging-forever-chemicals-european-wide-survey-of-pfas-in-disposable-food-packaging-and-tableware

"There is PFAS in my lunch box, PFAS in my meals, PFAS in my body, and in the bodies of my children, as well as in the bodies of Inuits living far, far away from me and my colleagues. PFAS affect us all, no one is safe from exposure. I sincerely hope that the joint efforts of the leading European organisations working on this study together for a toxics-free future will trigger permanent and immediate changes in both European and international policies on the toxic and persistent 'forever chemicals'. I do hope that in the future, we will stop finding traces of PFAS in every item sampled in our studies."
Jitka Straková, Arnika Association/International Pollutants Elimination Network (IPEN)

MAIN FINDINGS AND CONCLUSIONS

- **PFAS are widely used in disposable food packaging and tableware in Europe including in samples from popular fast-food chains and restaurants.**

- **PFAS are extensively used in moulded plant fibre tableware.** Single-use bowls made of sugarcane bagasse contained the highest amounts of total organic fluorine among all the analysed samples, which indicates intentional PFAS treatment. These products are advertised as biodegradable and compostable, which the presence of highly persistent chemicals clearly contradicts.

- **The vast majority of the PFAS present in the samples cannot be identified with certainty, as detection and identification methods are lacking for many PFAS.**

- **Paper and board food packaging are unintentionally contaminated with PFAS.** All samples analysed contained PFAS, including the ones that did not indicate any intentional PFAS treatment to achieve oil repellency. One of the likely sources of contamination for these samples is recycled paper.

- **Some of the PFAS identified in the disposable food packaging and tableware have been associated with health disorders such as liver damage, breast cancer and reproductive disorders.**

- **The PFAS present in the disposable food packaging and tableware showed in-vitro endocrine-disrupting activity.**

- **Viable alternatives to PFAS-treated paper and board food contact materials exist and are already in use.** Several paper bags for french fries and hamburgers or cardboard boxes for bakery products and pizza collected for this study showed no PFAS treatment.

- **Regulation is the strongest incentive for companies to move away from PFAS.** Following the PFAS restriction enacted in Denmark, McDonald's switched to PFAS-free alternatives. However, the same company is not moving away from PFAS in other markets, as illustrated by samples from other European countries.

- **The use of PFAS in disposable fast-food packaging and tableware is an unwarranted source of repeated consumer exposure and environmental pollution from "forever chemicals", as well as a barrier to achieving a toxic-free circular economy.**

1. Background

This study of per- and polyfluoroalkyl substances (PFAS) in disposable food packaging and tableware available for sale in Europe was conducted from May until December 2020 under the supervision of the Czech non-profit organization Arnika.

Taking into consideration the fact that PFAS are widely used in grease- and water-resistant food packaging and that PFAS are known to migrate from the packaging into the food [1, 2], Arnika together with partner organizations BUND, CHEM Trust, ClientEarth, Danish Consumer Council, Generations Futures, the Health and Environment Alliance (HEAL), the International Pollutants Elimination Network (IPEN), and Tegengif-Erase all Toxins decided to collect disposable items made of paper and board, or moulded plant fibre used for both wrapping and serving hot and greasy fast food.

The sampled items were purchased in takeaways, e-shops, and supermarkets in six European countries: the Czech Republic, Denmark, Germany, France, the Netherlands, and the United Kingdom. Disposable and single-use items are also of particular concern when it comes to environmental contamination potential due to their high volumes and turn-over rates.

This study aimed to:
1. collect evidence on the scale of the intentional use of PFAS in disposable food packaging and tableware items available on the market in Europe,
2. uncover levels of background contamination of PFAS in paper and board food packaging materials that have not been intentionally treated with PFAS, and
3. generate in vitro toxicological data on PFAS and PFOA-like compounds in consumer products that are scarce in current scientific literature.

This study builds on the momentum towards an EU-wide group restriction of all non-essential uses of PFAS[1] that is currently being developed by five European countries. It also provides further evidence of the widespread use of PFAS in paper and board food packaging and why a far-reaching paradigm shift in the overall regulation of chemicals across sectors is needed.

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[1] https://www.rivm.nl/en/pfas/pfas-restriction-proposal

PFAS OR “FOREVER CHEMICALS”

PFAS or per- and polyfluoroalkyl substances are known as “forever chemicals”. All PFAS have one common feature that makes them highly problematic, and that is the presence of a perfluoroalkyl moiety characterised by a carbon (C) and fluorine (F) bond. This constitutes the strongest chemical bond in organic chemistry and as a consequence, the vast majority of PFAS do not degrade under natural conditions. Instead they stay in the environment for decades or centuries, affecting both current and future generations. Hence their metaphoric nickname of “forever chemicals”.

PFAS are synthetic chemicals used to make products water-, grease- and stain-resistant. These forever chemicals are commonly found in waterproof rain gear and food packaging, but also in non-stick cookware and firefighting foams. Most of the PFAS uses are not essential for the functioning of society and alternatives are available [3].

PFAS are a chemically-diverse group of substances and the OECD global database from 2018 [4] counts over 4,700 of these forever chemicals available on the global market.

PFAS have been found to widely contaminate our environment, including remote areas such as the Arctic [5-7]. The presence of PFAS in adults’ and children’s serum and plasma [8], with the highest levels found in workers and other persons exposed to contaminated drinking water [9-11], is a source of great concern, elevating PFAS among priority chemicals to address today.

The increasing evidence of the significant negative impacts of PFAS on health and the environment raises the alarm and is motivating citizens to call for global action towards the restriction and elimination of PFAS.

THE PFAS PROBLEM

PFAS threaten our environment

PFAS are either highly persistent themselves or degrade into other highly persistent counterparts. The continuous emission of highly persistent PFAS leads to accumulating levels in the environment and to an increasing probability of triggering adverse effects. Such high persistence of PFAS is a sufficient argument for their management and banning them as a chemical class [12].

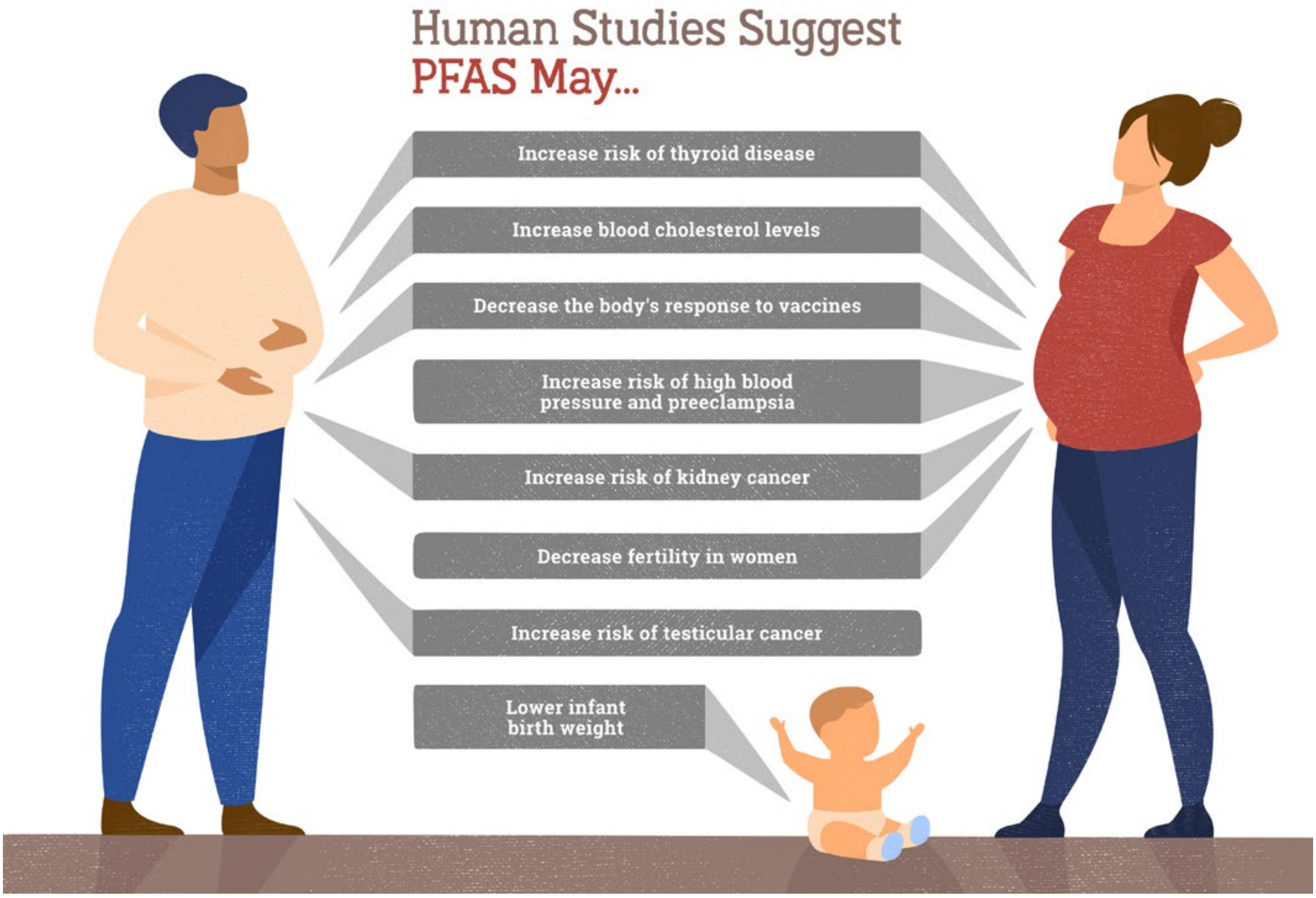
Some PFAS are highly mobile and able to disperse over long distances. Their presence has been reported globally in soil [13], the atmosphere [14] and dust [15, 16], as well as in biota including wildlife and humans [17, 18]. PFAS are ubiquitous in water including surface-, deep sea-, ground-, and drinking waters as well as sediments [19-21]. PFAS are present at wastewater treatment plants [22] and in leachates from landfills [23].

Due to the solubility of many PFAS in water and their low potential to be absorbed to particles, it is very difficult to remove PFAS from the water environment, including drinking water sources, using conventional treatments [24].

PFAS pollute our bodies

PFAS are used in numerous applications across a wide range of sectors [25]; for instance to make cosmetics spread more easily on the skin, in firefighting foams sprayed over burning surfaces, to achieve water or stain repellency in outdoor clothing, to avoid food sticking to the pan when frying, or to block fat soaking through the fast-food wrapping. These numerous professional and

“Toxic PFAS are today present in most living beings and the environment, and are likely to remain so for the foreseeable future because of their persistence. PFOS was the first PFAS to be listed under the Stockholm Convention for global restriction already in 2009, but is still frequently found in the blood of infants and children globally.”
Sara Brosché, International Pollutants Elimination Network (IPEN)



consumer applications of PFAS are responsible for multiple emission routes into the environment and multiple exposure pathways for humans and wildlife.

Some PFAS accumulate in human and animal tissues, others in plants. Due to faster ingestion than excretion rates of some PFAS, the concentration of these PFAS in tissues and bodies of living organisms gradually increases with continuous exposure. The concentrations of PFAS gradually increase as you move up the food chain. This results in an overload for humans, who are at the top of it.

PFAS damage our health

Scientific studies have associated exposure to PFAS with a wide range of health effects — including for the immune, digestive, metabolic, endocrine, and nervous systems as well as for reproduction and development. The recently launched PFAS-tox database[2] has collected no less than 742 scientific studies exploring the health outcomes associated with exposure to 29 selected PFAS that have been measured in the environment or in people, a limited amount of PFAS compounds compared to the wide variety of the group.

PFAS in particular can affect the immune system and the liver; alter puberty; increase the risk for developing breast cancer; and are associated with kidney, testicular, prostate, and ovarian cancers, as well as with non-Hodgkin's lymphoma" [26, 27].

PFAS can also act as endocrine disruptors by impacting thyroid hormone levels, for example by reducing levels of the thyroid hormones triiodothyroxine (T3) and thyroxine (T4) in the human body [28, 29]. Perfluorooctanoic acid (PFOA) has been shown to competitively bind to the thyroid transport protein transthyretin (TTR), which can also lead to reduced thyroid hormone levels [16, 30-32]. Thyroid hormones are important for numerous physiological processes such as the regulation of metabolism, bone remodelling, cardiac function, and mental status. They are particularly critical during fetal development, as the development of the brain is dependent on the mother's levels of thyroid hormones being within the normal range [33].

Health costs associated to PFAS exposure are extensive

Due to their high persistence and extensive use, PFAS have become a global issue of concern. Scientists have warned against poorly reversible exposures and the

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[2] https://pfastoxdatabase.org/

overall underestimation of the risks associated with their widespread uses [34]. For the European Economic Area (EEA) alone, the annual health-related costs associated with PFAS exposure are estimated to EUR 52-84 billion [35]. Paper and pulp production, utilisation of PFAS-treated paper/board food packaging and waste paper dumping are among the significant exposure routes included into the calculations.

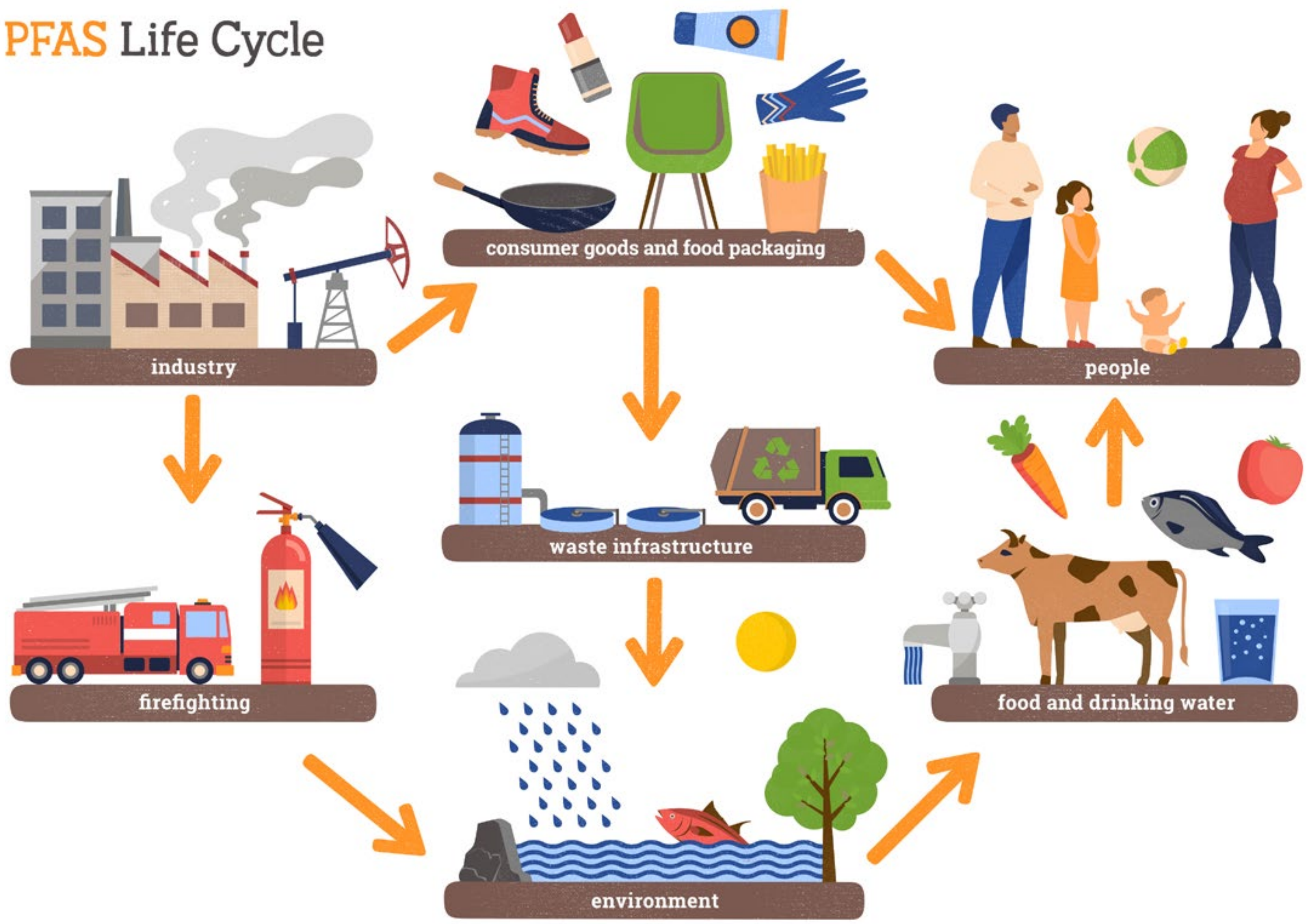
PFAS IN PAPER, BOARD AND MOULDED PLANT FIBRE FOOD WRAPPING AND TABLEWARE

PFAS are known to be widely used for food packaging. However, very limited information is available on the composition and concentrations of specific PFAS used in food contact materials. In general, these chemicals are commonly used by the paper- and pulp industry for producing disposable grease- and water-resistant food packaging and tableware items. PFAS can be added to the pulp or applied as coatings on the surface of paper or board [35, 36]. They are also used in the production of moulded plant fibre packaging [37]. The perceived added value of PFAS comes from the fact that they create a chemical barrier on the surface of the wrapping material, which repels the grease coming from the food [38]. This grease-resistant function makes PFAS widely used in baking paper and cupcake cups, bakery bags, fast-food and take-away containers, microwave popcorn bags, and compostable tableware.

The life cycle of PFAS in paper and moulded plant fibre food packaging and tableware is associated with PFAS emissions at every stage, which is concerning considering the high turnover rates of fast-food packaging and disposable tableware.

STATE OF PLAY OF THE PFAS REGULATION LEGAL RESTRICTIONS OF PFAS

Only a few of the thousands of PFAS compounds are regulated globally and at European level across sectors and uses. At the global level, two of the most extensively studied representatives of the PFAS group, PFOS and PFOA, were listed under the Stockholm Convention on Persistent Organic Pollutants in 2009 and 2019 respectively. PFOS is listed in Annex B of the Convention for Global Restriction, where Parties to the Convention agreed to a range of specific exemptions and acceptable purposes. PFOA is listed for global elimination (in Annex A of the Convention) with specific exemptions. The POPs Review Committee, the expert body of the Stockholm Convention, has recommended PFHxS for global elimination with no exemptions, which is to


PFAS Life Cycle

be discussed at the next Conference of Parties to the Stockholm Convention. The listings under the Stockholm Convention are implemented in the EU legislation through its POPs Regulation.[3]

Since 2020, the governments of Denmark, Sweden, Germany, and the Netherlands have started developing an EU-wide restriction of all non-essential uses of PFAS[4] with the support of the European Chemical Agency (ECHA). The EU Chemical Strategy for Sustainability Towards a Toxic-Free Environment and its accompanying Staff Working Document on PFAS[5] published in October 2020 have confirmed the EU high-level support for this initiative. The restriction proposal fits under the REACH regulation framework, but has the potential to initiate a far-reaching paradigm shift in the overall regulation of chemicals across sectors. Several PFAS representatives are identified as substances of very high concern (SVHCs) under the EU REACH legislation (e.g. GenX, PFBS) and others are proposed for restriction or were recently restricted (i.e. C9-C14 PFCAs, PFHxA, or PFHxS).

However, to date the EU's piecemeal approach to chemicals management has failed to deliver any effective regulation of PFAS in a way that prevents the replacement of legacy compounds with newer, less studied PFAS. This has not been effective in stopping water and air contamination worldwide [3, 11].

Food Contact Materials legislation

Although the EU framework Regulation (EC) No 1935/2004 includes a general safety requirement for all Food Contact Materials (FCMs), there are still only specific harmonised safety measures in place for very few of the different materials used in food packaging and other food contact applications.[6] For paper and board - which are the subjects of our testing and the focus of this study - there are no such harmonised measures. Different countries across Europe can, and do, apply different rules for such materials and the tolerance of the

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[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R1021

[4] https://www.rivm.nl/en/pfas/pfas-restriction-proposal

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0249

[6] https://ec.europa.eu/food/safety/chemical_safety/food_contact_materials/legislation_en

chemical compounds that they can contain - including PFAS. It therefore means that protection levels differ from country to country. The European Commission is currently initiating a revision process of the EU regulation on food contact materials, which could be an opportunity to extend the scope of the materials covered for specific harmonised safety measures, as civil society organisations have long called for.[7] However, the process will take several years and no commitments have yet been made with regards to the inclusion of paper and board in the scope of the revised regulation.[8]

Currently, only Denmark has introduced a regulation that specifically prohibits PFAS in food contact paper and board, which entered into force in July 2020.[9] The ban covers both direct uses (addition of PFAS to make the material water and grease resistant) and indirect uses (addition originating from inks or the use of recycled paper).

In the Netherlands, the Dutch parliament has requested a ban on PFAS in food contact materials. Recently, the Dutch government promised to adapt the national legislation accordingly.[10]

The countries leading the development of the European restriction on non-essential uses of PFAS have announced that food contact materials should be covered in the scope but the exact details remain to be developed.

"The scientific evidence is clear: exposure to PFAS can contribute to serious health disorders, including the disruption of our immune and endocrine systems. Because PFAS are persistent, highly mobile and can travel long distances, our exposure is continuous and keeps building up. A class approach to phase out all non-essential uses of PFAS is the only health protective response to this environmental health threat."
Natacha Cingotti, Programme Lead on Health and Chemicals at the Health and Environment Alliance (HEAL)

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7 See for instance: https://www.env-health.org/how-the-chemicals-in-food-contact-materials-are-putting-our-health-at-risk/ and https://chemtrust.org/5-key-principles-fcm/

8 https://ec.europa.eu/food/safety/chemical_safety/food_contact_materials/specific-eu-policy-initiatives/evaluation-and-revision_en

9 https://www.foedevarestyrelsen.dk/english/SiteCollectionDocuments/Kemi%20og%20foedevarekvalitet/UK-Fact-sheet-fluorinated-substances.pdf

10 Letter of State Secretary for Infrastructure and Water Management to the Dutch Parliament. Dated: 18.01.2021

Methodology used

SAMPLE COLLECTION

In total, 99 samples of disposable food packaging or tableware were collected in May-December 2020 in takeaways, supermarkets and e-shops in 6 European countries: the Czech Republic, Denmark, France, Germany, the Netherlands, and the United Kingdom.

The 99 samples belong to three product categories:

> "Compostables": Plant fibre items made of sugarcane, wheat and palm leaves. The samples in this category included disposable kitchenware and takeaway food boxes that were labelled or understood as compostable products.

> "Takeaway packaging for fatty foods": Paper and board packaging for takeaway fatty foods including bags for burgers, french fries, bakery products and sandwiches, and cardboard boxes for pizza and donuts.

> "Paper/board items for uses other than takeaway food": Paper/board and recycled paper products coming into contact with food, including shopping bags, table napkins and cardboard boxes for cereals and spaghetti.

The study targeted items from global chains such as McDonalds, KFC, Dunkin' Donuts, Subway, or Domino's, as well as items from national and regional brands including Nordsee, Pret a Manger, Papa John's, Greggs or Bageterie Boulevard. In total, 9 samples were purchased in Denmark, 24 samples in the Czech Republic, 26 samples in Germany, 15 samples in France, 10 samples in the United Kingdom, and 15 samples in the Netherlands (see Table 1 for more details).

OIL REPELLENCY TEST WITH DROPLET OF OLIVE OIL (BEAD TEST)

The oil repellency properties of the 99 samples were tested using the olive oil droplet test proposed by the Scottish NGO Fidra [39], also known as the beading test. Olive oil was dripped onto the surface of the paper/board or plant fibre sample, and the observations were then used to group our samples. Samples were categorised as oil-beading when the oil drop formed a bead on the surface of the sample, and as oil-spreading or soaking when the oil drop spread on the surface of the material or soaked into the material. The formation of a bead on the surface of the paper/board or plant fibre samples was interpreted as the result of a PFAS treatment to provide oil repellency. The spreading or soaking of the oil drop was interpreted as an indication that no fluorine-based surfactant was applied to provide oil repellency.

QUANTIFICATION OF TOTAL ORGANIC FLUORINE (TOF)

42 samples were selected for Total Organic Fluorine (TOF) content analysis. Samples were selected to:

> equally represent different countries (6-8 samples per country),

> cover all three product categories (13 compostables, 23 takeaway packagings for fatty foods, and 6 paper/board items for uses other than takeaway food),

> understand the levels of both intentional treatment and background contamination (28 oil-beading samples indicating PFAS treatment) and 14 oil-spreading or soaking samples not-indicating PFAS treatment.

The TOF method was originally developed for Danish authorities to test compliance with their legal ban of PFAS in paper/board food contact materials and is considered as an accepted proxy for total PFAS content. Description of the lab-analysed samples is provided in Annex 1.

The lab analysis was performed by Eurofins Product Testing in Denmark using the accredited and validated method DIN 51723. Fluorinated substances are degraded in a combustion process into hydrogen fluoride, which is quantitatively collected in an impinge with a buffer solution. The amount of collected hydrogen fluoride is determined by ion chromatography. The expanded uncertainty of the method is 30% and the detection limit is 0.33 mg/kg dry weight (dw).

The TOF results were compared with the Danish guided indicator value of 20 mg/kg dw TOF that was established as a means of differentiating between intentionally added PFAS and background levels of PFAS in paper/board food contact materials.

DETECTION AND QUANTIFICATION OF SELECTED PFAS

Targeted analysis covering 55 specific PFAS substances was performed on the 42 samples selected for TOF analysis at the Department of Food Analysis and Nutrition of the University of Chemistry and Technology in Prague, Czech Republic. The analysed substances were selected based on the availability of standards and PFAS reported in food contact materials in previous studies.

The analysis of the 55 specific PFAS involved extraction with a methanol: ethyl-acetate mixture and was carried out using ultra-high-performance liquid chromatography interfaced with tandem mass spectrometry with electrospray ionization in negative mode (UHPLC-ESI-MS/MS) for all PFAS except FTOHs. The selected FTOHs were analysed using gas chromatography coupled with tandem mass spectrometry operated in positive ion chemical ionization (GC-PICI-MS/MS).

The full list of analysed PFAS with their respective limits of quantification is provided in Annex 2.

FLUORINE MASS BALANCE

The fluorine mass balance was calculated according to the method described in Schultes et al. (2019) [40]. It involved converting the concentrations of the specified PFAS identified in a given sample into their fluorine equivalent and then comparing the sum of the identified fluorine with the total organic fluorine amount measured in a given sample. See Annex 3 for more details on the calculations.

TESTS OF THE POTENTIAL OF PFAS TO DISRUPT THYROID ACTIVITY

PFAS and PFOA-like compounds are known to reduce the levels of thyroid hormones in humans and animals [16, 28-32]. A bioanalytical in vitro method to detect and evaluate thyroid hormone disruptors has therefore been developed to rapidly screen the thyroid hormone-disrupting potential of PFAS and other persistent organic

pollutants in environmental samples, house dust, and human serum [31, 41]. This method, the FITC-T4 binding bioassay, has been applied to consumer products samples for the first time in this study.

The FITC-T4 binding bioassay tests in vitro the potential of the PFAS extracted from the samples to interfere with the binding of the thyroid hormone thyroxine (T4) to the plasma transport protein transthyretin (TTR). In the FITC-T4 binding bioassay, competition between a fixed concentration of FITC-T4 and a dilution series of test items is determined. The measurement is based on the difference in fluorescence between bound and non-bound FITC-T4 to the TTR-binding site. The presence of increasing concentrations of PFAS, capable of competing with FITC-T4 for TTR-bindings sites, will result in a decreased amount of TTR bound FITC-T4 and thereby decreased fluorescence. Disruption of FITC-T4-TTR binding is benchmarked against the reference compound PFOA (potency factor = 1).

The bioassays were performed on 17 selected samples by the BioDetection Systems b.v. ("BDS") lab in Amsterdam, the Netherlands. The samples were selected to cover a wide range of products, including compostable moulded plant fibre tableware, takeaway packaging for fatty foods and other paper/board items with various TOF values. PFAS were extracted from the samples at the Department of Food Analysis and Nutrition of the University of Chemistry and Technology in Prague, Czech Republic and shipped to the BDS lab in Amsterdam, the Netherlands for the FITC-T4 bioassay. See Annex 3 for more details on the analytic procedure and sample preparation.

Results

OIL BEADING, AN INDICATION OF PFAS TREATMENT

Among the 99 collected samples, there were indications of potential PFAS treatment due to beaded droplets of olive oil forming on their surfaces in 38 samples: 79% of the collected compostable samples and 33% of the collected takeaway packaging samples (see Table 1 for more details).

In total, 42 samples were selected for further lab analysis. **The analysed samples were grouped as follows:**

> Oil-beading compostables: 13 samples from the "compostables" category;

> Oil-beading takeaway paper: 15 paper samples from the "takeaway packaging for fatty foods"category;

> Oil-spreading or oil-soaking paper/board: 14 paper and board samples in total, 8 from the "takeaway packaging for fatty foods" category and 6 from the "paper/board items for uses other than takeaway foods" category.

TOTAL ORGANIC FLUORINE CONTENT

All of the 42 lab-analysed food contact items made of both paper/board and moulded plant fibre on sale in Europe have total organic fluorine (TOF) concentrations above the limit of detection of 0.33 mg/kg dry weight. This indicates the presence of PFAS in all analysed samples.

32 of the lab-analysed samples (76%) exceeded the indicator value of 20 mg/kg dw established by the Danish authorities to identify paper and board food contact materials intentionally treated with PFAS. This includes 13 oil-beading compostable samples, 15 oil-beading takeaway paper samples and 4 oil-spreading or soaking paper samples bought in all the 6 countries: the Czech Republic, France, Germany, the Netherlands, United Kingdom, and Denmark[11].

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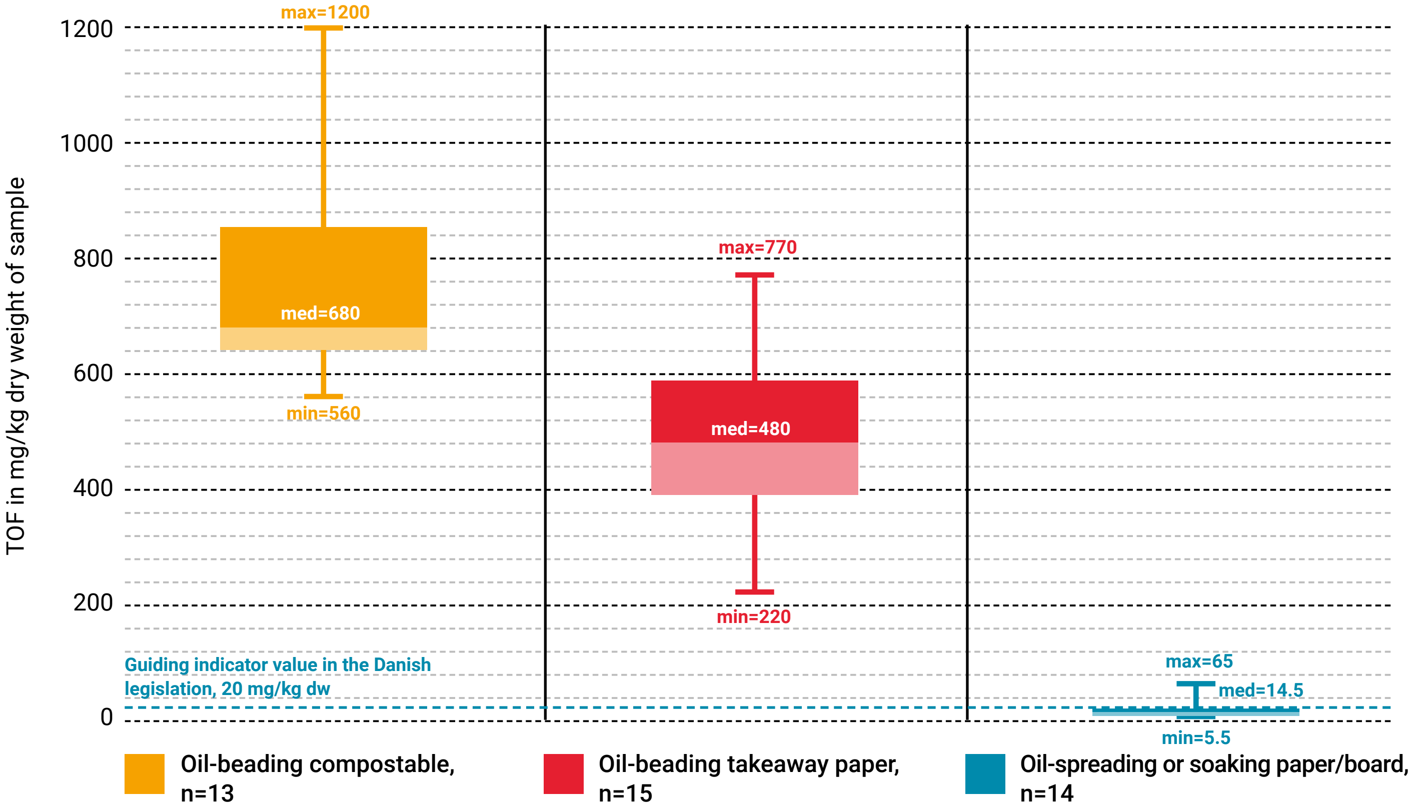
[11] The Danish law restricting the use of PFAS in food contact materials also includes products of moulded plant fibers, but the moulded plant fibre products in this study were bought before the Danish ban entered into force (July 2020) and were therefore at the time of purchasing not in conflict with the legislation.

Table 1: Number of collected/ beading/selected samples for TOF and specific PFAS analysis/selected samples for bioassay per country and product category

	COMPOSTABLES	TAKEAWAY PACKAGING FOR FATTY FOODS	PAPER/BOARD ITEMS FOR USES OTHER THAN TAKEAWAY FOODS
Denmark	7/7/7/2	2/0/1/1	0
Czech Republic	3/1/0/0	17/5/3/2	4/0/3/1
Germany	6/3/2/1	16/6/5/2	4/0/0/0
France	5/5/2/1	5/3/3/1	5/0/1/0
United Kingdom	0	10/5/8/3	0
Netherlands	3/3 /2/2	7/0/3/1	5/0/2/0
Total	**24/19/13/6**	**57/19/23/10**	**18/0/6/1**

Graph 1: Range of TOF concentrations in mg/kg dw per food packaging sample category



Example of sample for each category

Intentionally PFAS-treated food contact materials - compostable and takeaway paper packaging

All samples for which the oil-beading test suggested an intentional PFAS treatment had TOF concentrations exceeding the 20 mg/kg dw indicator value, ranging from 220 to 1,200 mg/kg dw. These results support the interpretation that the 13 oil-beading compostable samples and the 15 oil-beading takeaway paper samples have all been intentionally treated with PFAS.

The products indicating intentional PFAS treatment to achieve oil repellency were of two types:

1) Takeaway tableware and food boxes made of moulded plant fibre and sold as compostable. The samples were bought on the Danish, German, Dutch and French markets. 100% of the samples analysed had concentrations consistent with intentional PFAS treatment. These types of food containers also had the highest TOF concentrations of all the analysed samples (see Graph 1). TOF concentrations for the 13 samples ranged from 560 to 1,200 mg/kg dw, with an average of 795 mg/kg dw and a median of 680 mg/kg dw.

2) White or brown paper bags and wrappers for sandwiches, burgers, fries or bakery products. The samples were bought on the Czech, German, French, Dutch and British markets. 88% of these samples had TOF concentrations consistent with intentional PFAS treatment. The TOF concentrations for the 15 samples ranged from 220 to 770 mg/kg dw, with a median of 480 mg/kg dw.

Food packaging with no intentional PFAS treatment to achieve oil repellency but with unintentional contamination

Fourteen samples with negative oil-beading tests (i.e., spreading or soaking droplets of oil on their surfaces) contained between 6 and 65 mg/kg dw TOF and were of the following types:

1) Cardboard pizza boxes for takeaway. Five pizza boxes bought on the German, Dutch and British markets.

2) White paper bag for fries. One small french fries bag from McDonald's bought on the Danish market.

3) Cardboard takeaway box. One cardboard box for donuts from Dunkin' Donuts bought on the Dutch market.

4) Cardboard food packaging. One spaghetti box and one cereal box bought on the Dutch market.

5) Other: Shopping/grocery bags made of brown paper and paper napkins. Three shopping bags bought on the Czech and French markets, and brown paper napkins bought on the Czech market.

"The present study shows that high total organic fluorine values in combination with oil beading is a good indicator to identify intentional use of PFAS in food packaging materials. Like in Denmark, such non-targeted analysis and indicators could also support an EU-wide future PFAS legislation."
Stine Müller, the Danish Consumer Council

Takeaway packaging of global fast-food chains big brands

Different TOF levels were detected in takeaway packaging of the same type (e.g., paper for burgers or french fries, see Table 2) or brand. Three similar small french fries bags from the global fast-food chain McDonald's were purchased in Denmark, the Czech Republic, and the United Kingdom. The Czech and British samples had similar TOF concentrations of 470 and 480 mg/kg dw respectively, demonstrating intentional PFAS treatment. The Danish sample[12] had the lowest TOF concentration reported for any sample in the study at 5.5 mg/kg dw, demonstrating no intentional PFAS treatment and successful implementation of the Danish legislation restricting PFAS in paper and board food contact materials. A comparison of the oil-beading test results and the TOF concentrations in takeaway food packaging from global fast-food chains operating in Europe is provided in Graph 2.

IDENTIFIED AND QUANTIFIED PFAS

Of the 55 targeted PFAS, only 10 were found to exceed the limit of quantification (LOQ) in the 42 samples analysed. The concentration ranges and medians (calculated from samples above LOQs) of quantified PFAS concentrations are summarized in Table 2.

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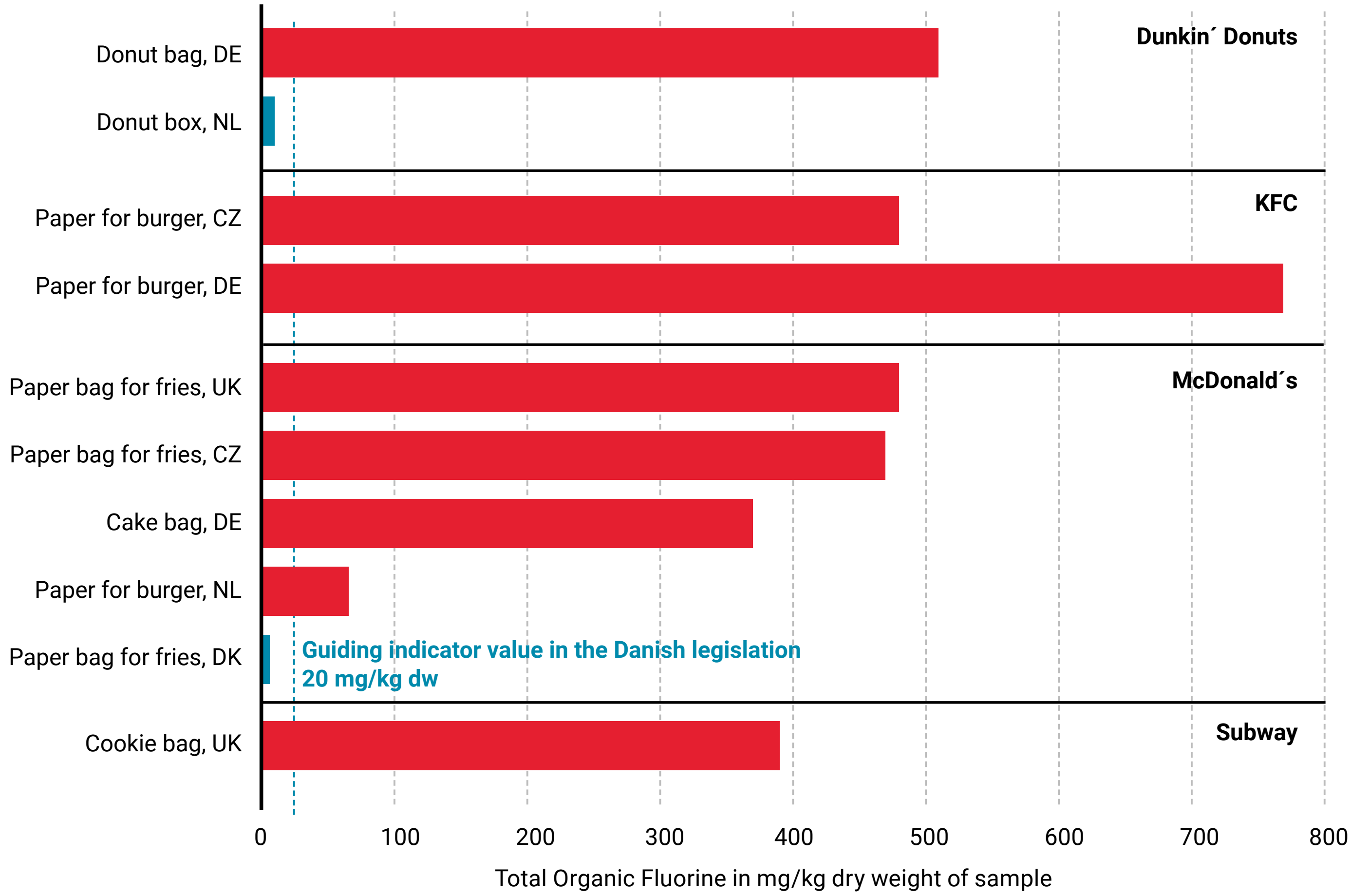
[12] The McDonald's bags for french fries tested in the study were purchased in Denmark in December 2020, i.e., when the restriction on intentional use of PFAS in paper and board food contact materials had come into force (July 2020).

Graph 2: Total Organic Fluorine content of takeaway food packaging from global fast-food chains.



Fluorotelomer alcohols (FTOHs)

The 6:2 fluorotelomer alcohol (6:2 FTOH also known as H4-PFOS) was the most abundant substance among the identified PFAS across all sample categories (see graphs in Annex 4), detected in 39 out of 42 samples. 6:2 FTOH concentrations were also the highest when compared with the other identified PFAS. 6:2 FTOH was detected in all compostable tableware and food box samples and in an overwhelming majority of paper and board food contact materials samples (see Graph 3). The highest concentrations of 6:2 FTOH were found in oil-beading compostables, with maximum and median values of 4,766 and 580 ng/g respectively. 6:2 FTOH was detected in 14 out of 15 oil-beading paper takeaway samples, with a median value of 241 ng/g. This fluorotelomer alcohol was also found in 12 out of 14 oil-spreading or soaking paper/board samples where intentional treatment with PFAS were not indicated for the purpose of maintaining oil repellency, with a median value of 116 mg/kg.

Moreover, 4 oil-beading compostable items contained 4:2 FTOH, but at a 100-fold lower concentration than that of 6:2 FTOH, with a median value of 5 ng/g.

Fluorotelomer sulfonates (FTSs)

Three other fluorotelomer-based substances were found in the paper and board samples (mostly pizza boxes) but not in the compostable moulded plant fibre samples, i.e., fluorotelomer sulfonates (FTS) 4:2, 6:2 and 10:2, in concentrations ranging from 6 to 104 ng/g. The most abundant FTS representative, 10:2 FTS, was found in both PFAS-treated (2 oil-beading takeaway paper samples) and non-treated paper and board items (6 oil-spreading or oil-soaking paper and board samples) with similar concentrations (see Annex 4 for detailed data). 6:2 FTS was detected in only one PFAS-treated oil-beading takeaway paper bag, and 4:2 FTS was found in only one oil-soaking pizza box where intentional PFAS-treatment was not indicated. No FTS representative was identified in compostable samples in quantifiable concentrations.

Other fluorotelomer-based substances (diPAPs)

One sugarcane compostable bowl from Denmark contained two polyfluoroalkyl phosphoric acid diesters (diPAPs), 6:2/8:2 diPAP and 8:2 diPAP at 205 and 290 ng/g respectively. DiPAPs were not found in any other samples in quantifiable concentrations.

Graph 3: Detection frequencies per sample category

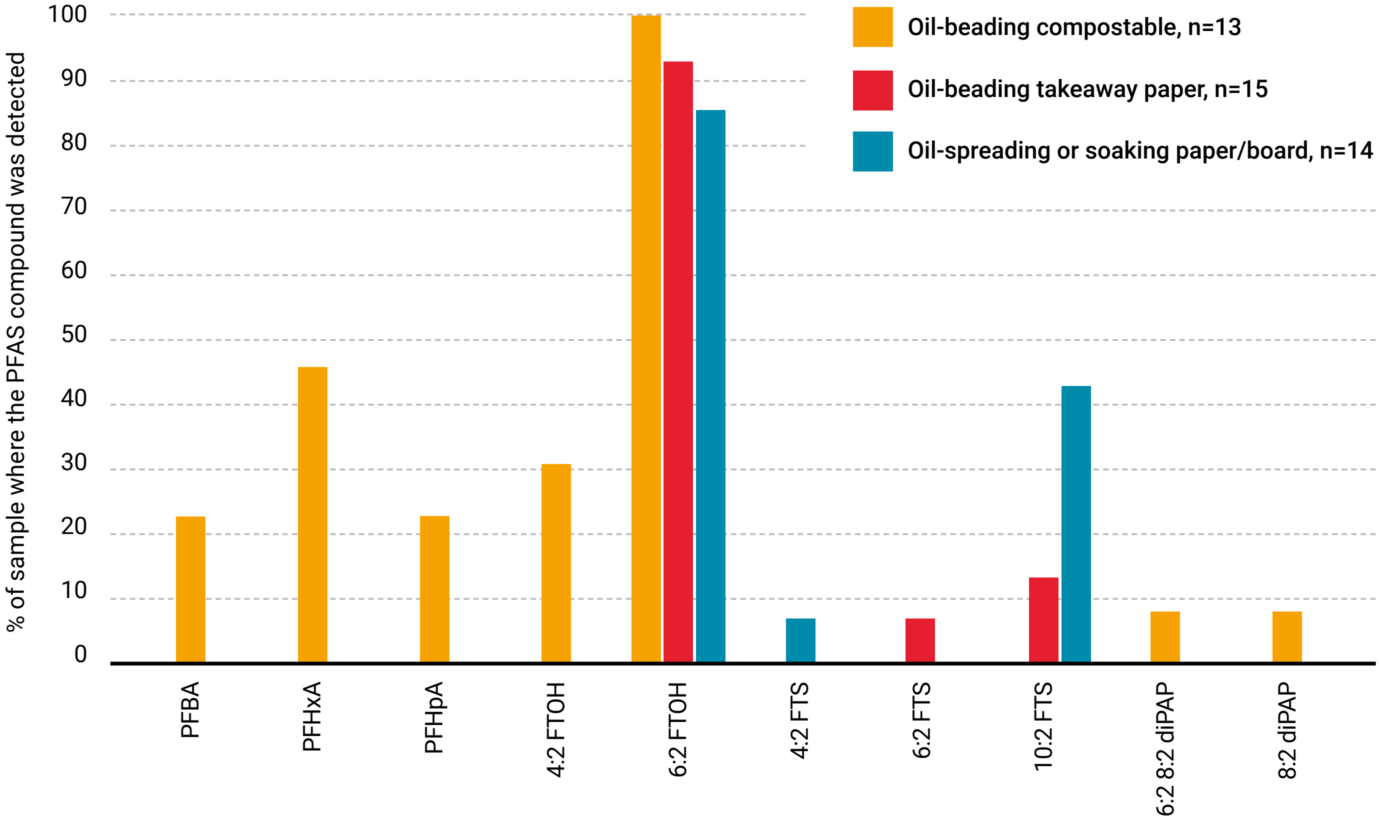


Table 2: Ranges and medians of TOF and specific PFAS concentrations per sample category. Medians are calculated for samples above LOQ.

	OIL-BEADING COMPOSTABLES, n=13	**OIL-BEADING TAKEAWAY PAPER, n=15**	**OIL-SOAKING OR OIL-SPREADING PAPER/BOARD, n=14**
BEAD TEST	BEADING	BEADING	SOAKING/SPREADING
TOF (mg/kg dw)	560 - 1,200 median 680	220 - 770 median 480	6 - 65 median 15
TOF (µg/dm2 dw)	1,550 - 5,550 median 3,080	76 - 400 median 177	2 – 83 median 22
PFBA (µg/kg)	<LOQ – 5 median 3	<LOQ	<LOQ
PFHxA (µg/kg)	<LOQ – 9 median 2	<LOQ	<LOQ
PFHpA (µg/kg)	<LOQ – 5 median 2	<LOQ	<LOQ
4:2 FTOH (µg/kg)	<LOQ– 22 median 5	<LOQ	<LOQ
6:2 FTOH (µg/kg)	92 – 4 766 median 580	<LOQ – 706 median 241	<LOQ – 324 median 116
4:2 FTS (µg/kg)	<LOQ	<LOQ	<LOQ – 6 median 6
6:2 FTS (µg/kg)	<LOQ	<LOQ – 40 median 40	<LOQ
10:2 FTS (µg/kg)	<LOQ	<LOQ – 104 median 69	<LOQ – 47 median 36
6:2/8:2 diPAP (µg/kg)	<LOQ – 205 median 205	<LOQ	<LOQ
8:2 diPAP (µg/kg)	<LOQ– 290 median 290	<LOQ	<LOQ

Perfluorocarboxylic acids (PFCAs)

Oil-beading compostable items were the only sample group where perfluorocarboxylic acids (PFCAs, i.e., PFBA, PFHxA and PFHpA) were detected, with a median value of 5 ng/g. 8 out of 13 compostable samples (62%) contained at least one PFCA.
Details of all analytic results are provided in Annex 4.

MASS BALANCE

The fluorine mass balance calculation is used to identify how much of the total organic fluorine is accounted for by the specific PFAS in a given sample. These calculations revealed that fluorine from the targeted PFAS identified in the samples represents only between 0.01 to 3.4% of the total organic fluorine detected. The average was 0.15% for the PFAS-treated oil-beading compostables, 0.041% for the PFAS-treated oil-beading takeaway papers and 0.92% for the non PFAS-treated oil-spreading or soaking papers/boards.

"The findings of toxic and highly persistent PFAS in food packaging sold in France and other European markets show that there is still much to be done to prevent people from being exposed to substances that have for many years been known to be hazardous."
Fleur Gorre, Générations Futures

Only 1% of the organic fluorine present in our samples could be ascribed to specific PFAS chemicals identified with targeted, compound-specific analysis of 55 PFAS.

THYROID HORMONE DISRUPTION ACTIVITY

Thyroid disruption activity was assessed in vitro with the FTIC-T4 bioassay relative to the standard reference compound PFOA. Potential for thyroid disruption was detected in all the tested packaging samples, with PFOA-equivalent per gram (PFOA-EQ/g) levels well above the limit of quantification. 11 of the 17 analysed samples (65%) did show significant thyroid hormone transport disruption between 39 and 340 µg PFOA-EQ/g sample (PFOA-EQ levels are at least a factor 3 above the limit of quantification). The highest levels (341, 220, 200 and 180 µg PFOA-EQ/g sample) were found in the oil-beading takeaway paper packaging samples such as the KFC burger paper from Germany, the Le Bon emballage sandwich bag from France, the McDonald's burger paper from the Netherlands and the McDonald's bag for cake from Germany, respectively. See the detailed results of the analysis in Annex 4 and in the lab report.[13]

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[13] https://english.arnika.org/publications/testing-of-18-sample-extracts-for-their-potential-to-interfere-with-ttr-t4-binding-using-the-fitc-t4-assay

Discussion

PART 1: RESULTS DISCUSSION

Effective methods to detect PFAS in disposable food packaging and tableware

The results from this study show that the oil-beading test is an efficient ”do it yourself” test to give an indication of potential PFAS treatment of moulded plant fibre, paper and board food packaging for oil-repellency as:

> All oil-beading samples exceeded the indicator value in the Danish legislation (20 mg/kg dw)[14] to identify paper and board food contact materials intentionally treated with PFAS.
> Oil-beading samples have significantly higher TOF values (>220 mg/kg dw) than oil-spreading or oil-soaking samples (<65 mg/kg dw).

The total organic fluorine (TOF) test provided an indication of total PFAS content in the samples and helped identify the most heavily PFAS-treated group of samples - compostables made of sugarcane and wheat moulded fibre, followed by takeaway packaging for fatty foods.

Gas/liquid chromatography and mass spectrometry provided quantification of specific PFAS present in the samples and specific profiles of the most frequently identified PFAS - 6:2 FTOH. However, based on the mass balance calculations, only 1% of the organic fluorine present in our samples has been identified by targeted, compound-specific analysis of 55 PFAS. It might be relevant to include the method of the total oxidisable precursors (TOP assay) in future research on PFAS in food contact materials, because that analytical technique helps to identify additional PFAS such as the ones built in to the structure of fluorinated polymers [42-44].

The FITC-T4 bioassay provides effect- and group-based information by testing the in vitro thyroid hormone-disruptive potential of PFAS [16, 30, 31]. This study is the first instance of using the FITC-T4 to assess the impacts

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[14] https://www.foedevarestyrelsen.dk/english/SiteCollectionDocuments/Kemi%20og%20foedevarekvalitet/UK-Fact-sheet-fluorinated-substances.pdf

of PFAS in paper and moulded plant fibre food packaging and tableware. Further studies using this method would be helpful to understand, for example, if side-chain fluorinated polymers are active in the bioassay.

Nature of the PFAS treatment applied to the compostable and takeaway food packaging samples

Only a very small proportion, less than 1%, of the total organic fluorine present in PFAS-treated samples was identified using targeted analysis of 55 specific PFAS. **However, the gap between the total organic fluorine (TOF) data and the sum of fluorine from the targeted PFAS analysed can be explained by the use of treatment made of side-chain fluorinated polymers in food packaging [45, 46].** The limited number of identified PFAS is consistent with previous studies [40, 45, 47] (and highlights the current limits in available analytical methods; in part due to the lack of standards to allow identification and quantification of all relevant PFAS [40].

During high-temperature combustion (e.g., In TOF analysis with the Combustion Ion Chromatography (CIC) method) PFAS polymers are disintegrated into hydrofluoric acid [48]; however the solvents used to extract PFAS from the substrates for the targeted PFAS analyses are unable to detach the polymers from the fibre. This explains why even sophisticated analytical methods and a wide range of 55 chemical standards do not allow direct identification of over 99% of the organic fluorine present in the samples.

Side-chain fluorinated polymers, and in particular polymers with side chains made of six fluorinated carbon atoms, are commonly used for the treatment of food packaging [45, 49]. These have been reported to degrade to 6:2 FTOH and PFHxA [36, 50, 51]. This is consistent with the findings of this study. The short-chain fluorotelomer alcohol 6:2 FTOH was the most abundant PFAS detected in PFAS-treated samples (96%), as well as the one with the highest concentration detected (up to 4766 ng/g in compostable samples). PFHxA was detected in 46% of the compostable samples. Previous studies of food packaging in the EU and the US have also found 6:2 FTOH and PFHxA [52, 53].

Origin of the PFAS contamination

14 analysed samples (33%) with TOF concentrations between 5.5 and 65 mg/kg dw did not indicate intentional

PFAS treatment in the oil-beading test. However, these TOF concentrations are well above the detection limit of 0.33 mg/kg dw and indicate an unintentional contamination with PFAS, since PFAS do not occur naturally. In Denmark, the suppliers are obliged to submit a declaration of compliance with the food contact material legislation to prove the unintentional presence of PFAS.[15] Ideally, the results for all the samples from all countries in this study should be confirmed by declarations of manufacturers and suppliers.

The PFAS contamination could be of two types. The first explanation could be that PFAS have been intentionally added to the dispersion aids in colorants and pigments of printing inks used in the packaging [36]. This could lead to low levels of PFAS in the product and would be consistent with the study findings. The second explanation could be that the contamination is unintentional, and there are many potential contamination routes, including from recycled paper contaminated with PFAS, PFAS-contaminated processing water and machinery during manufacture, contact with lubricants used in the machines or detergents used to clean the machinery [36].

Considerations regarding the toxicity of the identified PFAS

The presence of fluorotelomer alcohols (FTOHs), as well as perfluorocarboxylic acids (PFCAs) in certain PFAS-treated samples is very concerning, given the information regarding their health impacts. FTOHs and PFCAs have been reported to migrate from food contact materials into the food [1, 2, 54].

Toxicological concerns regarding FTOHs are related to the toxic properties of FTOHs themselves and to the toxic properties of their degradation products. FTOHs break down into PFCAs by metabolic degradation in the human body and also during abiotic degradation. Specifically, 6:2 FTOH is characterised by transformation into PFBA, PFHxA, PFPeA [55], which were all identified in our compostable items.

The toxicological effects of fluorotelomer alcohols and their metabolites (PFCAs) are associated with hepatotoxicity, development of mammary gland cancer, negative impacts on the reproductive system, and with developmental disorders [54].

“It makes me sad that PFAS can be found in our drinking water, vegetables and fruit. We must stop the pollution of our food chain by banning PFAS chemicals in consumer articles such as food packaging.”
Annelies den Boer, Tegengif - Erase all Toxins

This concerning picture is supplemented with the results of the in vitro test of thyroid hormone transport disruption activity[16], another unintented effect of endocrine-disrupting PFAS, conducted for the first time on food packaging samples. All 17 tested samples of takeaway packaging and tableware showed in vitro thyroid hormone-disrupting potential. This is in line with reports in the scientific literature of potential impact of PFAS on the thyroid activity and is of concern as this could affect numerous physiological processes [16, 28-32].

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[15] https://www.foedevarestyrelsen.dk/english/SiteCollectionDocuments/Kemi%20og%20foedevarekvalitet/UK-Fact-sheet-fluorinated-substances.pdf

[16] https://english.arnika.org/publications/testing-of-18-sample-extracts-for-their-potential-to-interfere-with-ttr-t4-binding-using-the-fitc-t4-assay

“Non-degradable hazardous PFAS chemicals have no place in products that are used once and then thrown away. Our casual use of highly persistent and harmful chemicals must stop if we are to safeguard the health of future generations and protect wildlife and the wider environment.”
Dr Julie Schneider, CHEM Trust

PART 2: IMPLICATION FOR PUBLIC HEALTH AND THE ENVIRONMENT

Reasons for concerns

Widespread use of PFAS in takeaway food packaging and tableware in Europe

This study shows that PFAS are being widely used in takeaway food packaging across Europe, despite the numerous concerns raised by the scientific community during the past decades regarding their adverse impacts on human health and the environment.[17]

The intentional treatment of takeaway food packaging with PFAS was demonstrated for samples from all the six European countries included in the study. This includes samples of fatty foods takeaway packaging from major global or national fast-food chains visited by people daily, in particular young people (i.e., McDonald’s, KFC, Subway or Dunkin’ Donuts).

However, the use of PFAS in food packaging is not limited to fast-food chains. The study shows that this also concerns small-scale food businesses serving their food in disposable tableware advertised as eco-friendly.

This study adds to the weight of evidence that PFAS are used extensively in moulded plant fibre food packaging and tableware sold as sustainable alternatives to single-use plastic containers[18] [39]. These containers are advertised as biodegradable and compostable, however the use of non-biodegradable, highly persistent PFAS chemicals clearly contradicts this claim.

Fast-food packaging and tableware, a source of repeated direct exposure

Consumers are exposed to PFAS migrating from the packaging to the food when consuming food, especially fatty food, wrapped in PFAS-treated paper or moulded plant fibre. This adds to the existing dietary exposure caused by the consumption of polluted food and water [1, 2, 56, 57].

The exposure to PFAS from food packaging increases with contact frequency. The popularity of fast-food consumption, especially among European youth, raises concerns regarding the contribution of food packaging to PFAS exposures during crucial times of development. This also adds to the existing dietary exposures caused by consumption of food and water that is contaminated with PFAS and other persistent pollutants [9, 11, 37, 58].

Environmental contamination and indirect exposure

By definition, disposable takeaway packaging are single-use items meant to be thrown away once the food has been consumed. This single-use packaging is produced and disposed of in large amounts[19] to meet fast-food and takeaway market demands.[20] Thus, the extensively produced and discarded oil-repellent food contact materials contribute to indirect exposure related to environmental contamination with PFAS both during the manufacture of the products as well as after their disposal.

Facilities manufacturing PFAS-treated paper emit PFAS into the air and wastewater and pollute the surrounding environment [59-61]. Most of the types of fast-food packaging investigated in this study are likely to end up in landfills or be incinerated, since the food residues prevent them from being recycled. Disposal of PFAS-treated food contact materials in municipal incinerators leads to emissions of PFAS, fluorinated greenhouse gases and other products of incomplete combustion to the surrounding environment [62-64]. Some PFAS remain in the after-incineration fly ash [65],

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[17] Madrid Statement: https://greensciencepolicy.org/our-work/science-policy/madrid-statement/
Zürich Statement: https://ehp.niehs.nih.gov/doi/full/10.1289/EHP4158

[18] https://saferchemicals.org/packaged-in-pollution/

[19] https://ec.europa.eu/eurostat/statistics-explained/index.php/Packaging_waste_statistics

[20] https://www.fortunebusinessinsights.com/industry-reports/food-packaging-market-101941

> *“As McDonald’s succeeded in eliminating PFAS in their Danish fast-food stores, it is easily achievable for McDonald’s to phase out PFAS from its food packaging globally by much earlier than 2025”*
> Karolína Brabcová, Arnika Association

and then contribute to the further environmental exposures when the fly ash is landfilled or used in construction materials [66].

Moreover, items sold as compostable could lead to PFAS-contaminated compost, leading to an accumulation of PFAS in crops grown in that soil. Compost made from these single-use packaging and tableware items will be hazardous due to high concentrations of PFAS [67-69].

All the life stages of PFAS-treated food contact items are related to environmental pollution including drinking water and/or food, which are the main routes of PFAS exposure identified by the European Food Safety Authority (EFSA).[21]

Contamination of the circular economy

This study shows that every single lab-analysed food packaging item analysed contained traces of PFAS, even the samples which were not intentionally treated with PFAS. This demonstrates the pervasive contamination of the paper and board food packaging production chain.

However, paper and board food packaging without food residue might end up being recycled and thus contribute to the contamination of the recycling chain [70]. Several non-PFAS treated samples analysed in this survey showed an indication of recycled paper content.

The PFAS impurities identified in recycled paper items investigated in this study are most likely to come from PFAS-treated source material [71]. Recycling of PFAS-treated paper leads to further contamination of new products, including with legacy PFAS which may find their way into marketed products despite their restricted use. The PFAS-contaminated source paper poses a barrier to the recyclability of paper and board food packaging in the framework of a clean and safe circular economy [70].

The recycling of PFAS-treated food packaging leads not only to exposure of consumers, but also of workers and communities living nearby recycling plants. Workers can be exposed to PFAS when source paper is shredded and grinded, and surrounding communities are exposed when PFAS are emitted into the water [72, 73].

Reasons for optimism

PFAS-free alternatives on the market

This survey shows that paper and board packaging for takeaway food can be produced without PFAS treatment; highlighting that the use of PFAS is not needed for these products. Our bead test results and the TOF values showed that several samples had not been previously treated for oil repellency. These included paper bags for french fries and hamburgers or cardboard boxes for bakery products and pizza.

In particular, the study identified a significant shift in the production of cardboard boxes for pizza. Contrary to previous studies [74], none of the pizza boxes purchased in the United Kingdom, the Netherlands and Germany were treated with PFAS. It is likely that the simple mechanical solution to achieve an extra-dense paper that inhibits leakage of fat through the paper is now used by pizza cardboard producers, as an alternative to PFAS treatment [74]. In addition, vegetable parchment or application of starch has been reported as cost-effective alternatives to PFAS treatment of disposable paper and board food packaging [36, 49, 70]. From an environmental perspective, durable and reusable materials are always the favoured option for food packaging

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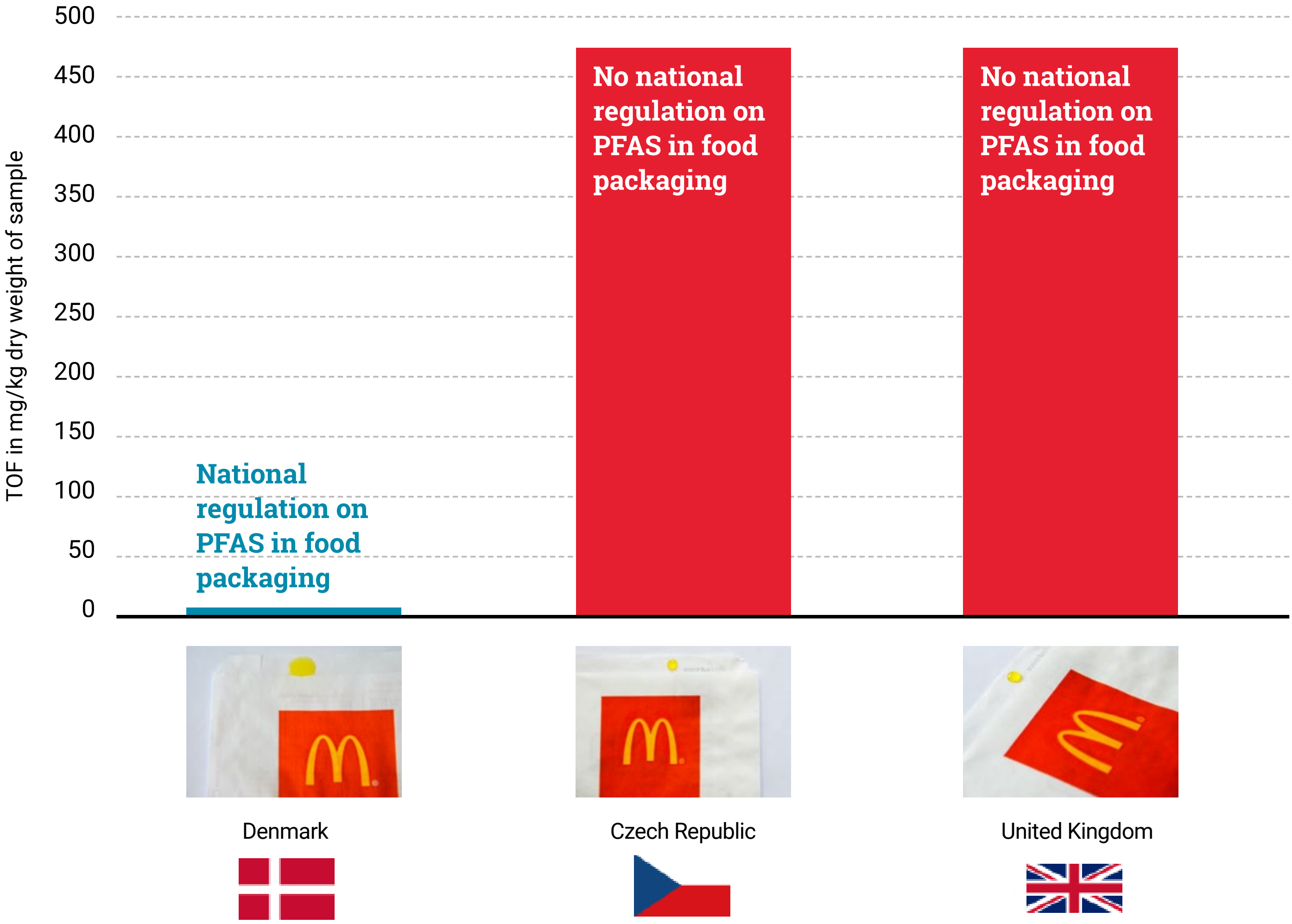
[21] https://www.efsa.europa.eu/en/news/pfas-food-efsa-assesses-risks-and-sets-tolerable-intake

Graph 4: Total organic fluorine (TOF) content in french fries bags from McDonald's bought in three different countries in 2020



and tableware, such as for instance glass jars or ceramic plates.

PFAS use in paper, cardboard and moulded fibres can be eliminated as PFAS function in food contact materials is not essential for society and feasible alternatives exist[22] [3].

Some of the major fast-food chains have already announced that they are abandoning PFAS use in disposable food packaging and tableware due to environmental and health concerns and the availability of viable alternatives.[23] In December 2020, the major online retailer Amazon restricted intentional use of PFAS to all of Amazon's kitchen brand food contact materials in the EU and the U.S. Later in January 2021, McDonald's committed to phase out PFAS globally from its customer packaging by 2025.

Policy incentives drag the change

The McDonald's bags for french fries tested in the study were purchased in Denmark in December 2020, i.e., when the restriction on intentional use of PFAS in paper and board food contact materials had come into force (July 2020). The study showed that McDonald's has abandoned the use of PFAS in Denmark to comply with the Danish restriction. However, the analysis of McDonald's samples from the Czech Republic, Germany and the United Kingdom, bought at the same time, demonstrated intentional PFAS treatment; highlighting different practices and double standards depending on the national regulation (see Graph 4).

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[22] https://saferchemicals.org/wp-content/uploads/2020/11/pfas-free_food_packaging_alternatives_sample_september_2020.pdf

[23] https://chemical-watch.s3.eu-west-1.amazonaws.com/downloads/Food-contact-report.pdf
https://saferchemicals.org/wp-content/uploads/2020/11/pfas-free_food_packaging_alternatives_sample_september_2020.pdf

The McDonald's example shows that companies are able to find alternatives to comply with a PFAS restriction in paper and board food contact materials, including for takeaway packaging for greasy food, as seen in Denmark. However, it also shows that without regulation, the same company is not moving away from PFAS, as seen in other European countries. This is a clear demonstration that regulation is the strongest incentive for companies to clean up their act.

Another positive signal regarding the impact of chemical regulations is the fact that none of the PFAS that have been restricted or banned globally, PFOS and PFOA, were detected in any sample in this survey. Until recently PFOA and PFOS impurities have been frequently reported in food packaging [75-77]. The absence of these substances in our samples could be related to the methodology used in this survey, but it is also a sign that the background contamination of the food packaging production chain with these substances is decreasing over time [78].

Unfortunately, PFHxA-related substances, which are similarly toxic and persistent and thus regrettable substitutes for PFOA-related substances, are present in some of our samples. However, if thresholds for PFHxA and related substances set in the ongoing REACH restriction process is derived based on real data and strict enough, PFHxA and related substances will be kept out of food contact materials and other products in the future.

"In view of the considerable toxic effects of PFAS for humans and wildlife and the high degree of contamination in the EU, we call for a complete phase-out of this hazardous group of chemicals by 2030. Exceptionally urgent is a PFAS ban in consumer items, especially in food contact materials, which should be fully in force by no later than 2025. The Danish PFAS ban for food packaging shows that they are superfluous and safe alternatives are available. As PFAS are a global threat, we also call on national governments and the EU to support a shift from single substance regulation to a global restriction of PFAS as a whole substance group via the Stockholm Convention."
Manuel Fernandez, BUND

SUMMARY OF KEY FINDINGS AND CONCLUSIONS

- According to the oil-beading test results, 38 out of the 99 collected samples (38%) are suspected to have been treated with PFAS chemicals in order to achieve oil repellency.
- According to the total organic fluorine analysis, 32 out of the 42 samples selected for chemical analysis (76%) show intentional treatments with PFAS. They include disposable packaging and tableware from popular fast-food chains and restaurants in six countries.
- All of the 42 lab-analysed samples have measurable concentrations of total organic fluorine. This is indicative of the pervasive contamination of paper and board food packaging production and supply chains with PFAS.
- The highest PFAS concentrations (up to 1200 mg/kg dw total organic fluorine and up to 5196 µg/kg PFAS sum) were consistently found in moulded fibre products, (e.g., bowls, plates, and food boxes).
- The 6:2 fluorotelomer alcohol (6:2 FTOH, also known as H4-PFOS) was the most abundant PFAS across all sample categories, detected in 39 out of the 42 lab-analysed samples.
- Less than 1% of the total organic fluorine present in the PFAS-treated samples could be assigned to specific PFAS chemicals identified via targeted analysis. This means that over 99% of the total PFAS load remains unidentified.
- 11 out of the 17 samples analysed for potential to cause thyroid hormone imbalances (65%) did show significant thyroid hormone transport disruption in the in vitro FTIC-T4 bioassay of between 39 and 340 µg PFOA-EQ/g sample.

Overall, the findings of our report point to the widespread use of and contamination by PFAS in disposable food packaging and tableware across Europe. These items are by definition and design meant to be used for very short durations and then thrown away. This contrasts with the extreme persistence of all PFAS chemicals. Because alternatives to PFAS treatments already exist, and even more importantly, because safe, durable and reusable packaging and tableware are widely available, the treatment of disposable items with PFAS is a typical example of unnecessary and avoidable chemical uses that run counter to the achievement of a clean circular economy. It is high time for national governments and European institutions to phase out all such uses of PFAS and to regulate these substances as a group.

RECOMMENDATIONS FOR POLICY-MAKERS, CONSUMERS, AND INDUSTRY

Based on the findings and conclusions of this survey, we call on:

The five European countries (Denmark, Germany, Norway, Sweden, The Netherlands):

The five European countries (Denmark, Germany, Norway, Sweden, The Netherlands) currently developing the European restriction on all non-essential uses of PFAS to include the full range of PFAS chemicals in the restriction, including fluorinated polymers, and to guarantee that disposable food packaging and tableware is covered within its scope.

The European Commission:

As part of its commitments under the EU Chemicals Strategy for Sustainability:

1. To support the development of the restriction mentioned above.
2. To proceed with the development of the **criteria for essential and non-essential uses** for chemicals management.
3. To proceed with the development of the criteria for **Safe and Sustainable by Design chemicals, including to prevent the use of highly persistent chemicals such as PFAS in high-turnover disposable and compostable products**.

In view of the upcoming review of the Food Contact Materials legislation:

4. To introduce harmonised rules for all materials used for food contact (including paper, board, and moulded plant fibre) in order to guarantee that all EU citizens are equally **protected against the presence of hazardous chemicals in food contact materials and articles made thereof.**

National governments:

1. **In the European Union:** To support the development of a broad and protective **restriction on all non-essential uses of PFAS** and thereafter to fully implement it.
2. **Outside the European Union:** All governments to develop **similar restrictions on non-essential uses of PFAS**.

Parties to the Stockholm Convention:

1. To **ratify the amendments listing PFOS and PFOA**, implement these in national regulations and support the removal of all exemptions and acceptable purposes.
2. To support **listing of PFHxS** for global elimination without exemptions.
3. To work for a **class-based approach of listing all PFAS for global elimination** under the Stockholm Convention.

Parties to the Basel Convention:

1. To **define all PFAS-contaminated waste as hazardous waste** based on their H11 (delayed or chronic toxicity) characteristics.
2. To ratify the Basel Ban amendment, ensuring **not to export PFAS-contaminated waste to developing countries**.
3. To work for a **class-based approach of defining a "low POPs content"** level for POPs waste containing PFAS.

Fast-food chains and food retailers:

1. To adopt and implement a **public policy with clear quantifiable goals and timelines for reducing and eliminating PFAS in all food contact materials** in their shops or restaurants and supply chain.
2. To display their commitment towards moving away from hazardous chemicals by **joining the 'No to PFAS' corporate movement organised by ChemSec** (chemsec.org/pfas).
3. **To ensure substitutes are safer,** at a minimum free of any GreenScreen Benchmark 1 or SINLIST[24] chemicals.
4. **To provide safe reusable food serviceware for in-store dining** and train staff to make this the default for customers dining in.
5. **To publicly report on progress and announce when their food contact materials are PFAS-free.**

Citizens:

1. **To avoid using disposable food packaging whenever possible. Bring your own reusable food containers** when you visit fast-food chains and takeaway restaurants to avoid paper, board and moulded fibre food packaging potentially treated with PFAS chemicals.
2. **To NOT dispose of moulded plant fibre compostables into the compost waste bins or your home compost, as they are heavily treated with PFAS chemicals.**
3. To demand that your national governments phase out all non-essential uses of PFAS chemicals.
4. To contact and urge companies, including fast-food chains and food retailers, to phase out PFAS from the products sold in your countries.

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[24] https://sinlist.chemsec.org/

Annexes

Annex 1. Full list of the lab-analysed samples with their description

OIL-BEADING COMPOSTABLES

SAMPLE ID	COUNTRY	MATERIAL	PRODUCT	BRAND/COMPANY
Compost-NL-3	Netherlands	Sugarcane	Bagasse Budha bowl	Sabert
Compost-DK-3	Denmark	Sugarcane	Bowl (Miljøtallerken dyb)	Abena
Compost-DE-12	Germany	Sugarcane	Metro, bowl for soup	PAPSTAR GmbH
Compost-DE-11	Germany	Sugarcane	Pop star, bowl	PAPSTAR GmbH
Compost-FR-2	France	Sugarcane	Pulp salad tray	Le Bon emballage
Compost-DK-5	Denmark	Sugarcane	Food box (1-rums fiberboks)	N/A/ Plant2Plast
Compost-NL-1	Netherlands	Sugarcane	Bagastro Deep plate	Bagastro/Sier disposables
Compost-DK-4	Denmark	Sugarcane	Plate (Engangstallerken)	PAPCoRn/ Plant2Plast
Compost-DK-1	Denmark	Sugarcane	Plate round	Naturesse
Compost-DK-7	Denmark	Wheat	Plate round	Søstrene Grene
Compost-FR-4	France	Sugarcane	Food box	La boutique du jetable
Compost-DK-6	Denmark	Sugarcane	Food box (Bagasseboks 2-delt stor)	N/A
Compost-DK-2	Denmark	Sugarcane	10 Bio bowls	Duni

OIL-BEADING TAKEAWAY PAPER

SAMPLE ID	COUNTRY	CATEGORY	TYPE OF PRODUCT	BRAND/ COMPANY
DE-PAP-KFC-17a	Germany	Fast food	Burger paper	KFC
FastF-FR-5	France	Fast food	Sandwich bag	Le Bon emballage
FastF-FR-3	France	Fast food	Burger paper	Le Bon emballage
DE-PAP-NRDS-19a	Germany	Fast food	Sandwich paper	Nordsee
FastF-FR-2	France	Fast food	French fries paper bag	Le Bon emballage
DE-PAP-DDNT-20a	Germany	Bakery	Donut bag	Dunkin’ Donuts
FasF-UK-5a	UK	Fast food	French fries paper bag	McDonald´s
CZ-FCM-KFC-06	Czech Republic	Fast food	Burger paper	KFC
CZ-FCM-MCD-01b	Czech Republic	Fast food	French fries paper bag	McDonald´s
FastF-UK-2	UK	Bakery	Bakery bag	Pret a Manger
CZ-FCM-BB-01b	Czech Republic	Fast food	Baguette paper	Bageterie Boulevard
FastF-UK-4	UK	Fast food	Bakery bag	Subway
DE-PAP-MCD-26	Germany	Bakery	Bakery bag	McDonald´s
FastF-UK-3	UK	Bakery	Bakery bag	Coop
FastF-UK-1	UK	Bakery	Bakery bag	Greggs

OIL-SPREADING OR -SOAKING PAPER/BOARD

SAMPLE ID	COUNTRY	MATERIAL	TYPE OF PRODUCT	BRAND/ COMPANY
NL-MCD-01	Netherlands	Paper	Burger paper	McDonald´s
Recycl-CZ-1	Czech Republic	Paper	Shopping bag	Penny Market s.r.o.
PizzaB-UK-2	UK	Paper	Pizza box	Papa Johns
PizzaB-UK-1	UK	Paper	Pizza box	Domino's/ Saica
Recycl-CZ-2	Czech Republic	Recycled paper	Shopping bag	Lidl
PizzaB-UK-3	UK	Recycled paper	Pizza box	Pizza Hut
Recycl-FR-1	d'emballag	Paper	Shopping bag	Biocoop
Recycl-CZ-4	Czech Republic	Recycled paper	Table napkin	Industry Celtex S.p.A.
FastF-NL-1	Netherlands	Paper	Pizza box	New York Pizza
FastF-NL-5	Netherlands	Paper	Donut box	Dunkin´ Donuts
Recycl-NL-4	Netherlands	Paper	Cereal box	Kellogg's
DE-PAP-DMN-24a	Germany	Paper	Pizza box	Domino's
Recycl-NL-1	Netherlands	Recycled paper	Spaghetti box	Barilla
DK-PAP-MCD-1	Denmark	Paper	French fries paper bag	McDonald´s

Annex 2. Full list of analysed PFAS with respective limits of quantification (LOQ)

CHEMICAL	FULL NAME	SYNONYM	CAS	CATEGORY	LOQ (MG/KG)
PFBA	Perfluorobutanoic acid		375-22-4	Perfluorinated carboxylic acid (PFCA)	1.7
PFPeA	Perfluoropentanoic acid	Perfluorovaleric acid	2706-90-3	Perfluorinated carboxylic acid (PFCA)	1.7
PFHxA	Perfluorohexanoic acid		307-24-4	Perfluorinated carboxylic acid (PFCA)	1.7
PFHpA	Perfluoroheptanoic acid		375-85-9	Perfluorinated carboxylic acid (PFCA)	1.7
PFOA	Perfluorooctanoic acid	Pentadecafluorooctanoic acid	335-67-1	Perfluorinated carboxylic acid (PFCA)	1.7
PFNA	Perfluorononanoic acid	Heptadecafluorononanoic acid	375-95-1	Perfluorinated carboxylic acid (PFCA)	1.7
PFDA	Perfluorodecanoic acid	Nonadecafluorodecanoic acid	335-76-2	Perfluorinated carboxylic acid (PFCA)	1.7
PFUnDA	Perfluoroundecanoic acid	Henicosafluoroundecanoic acid	2058-94-8	Perfluorinated carboxylic acid (PFCA)	1.7
PFDoDA	Perfluorododecanoic acid	Perfluorolauric acid	307-55-1	Perfluorinated carboxylic acid (PFCA)	1.7
PFTrDA	Perfluorotridecanoic acid	Pentacosafluorotridecanoic acid	72629-94-8	Perfluorinated carboxylic acid (PFCA)	1.7
PFTeDA	Perfluorotetradecanoic acid	Perfluoromyristic acid	376-06-7	Perfluorinated carboxylic acid (PFCA)	1.7
PFHxDA	Perfluorohexadecanoic acid	Perfluoropalmitic acid	67905-19-5	Perfluorinated carboxylic acid (PFCA)	1.7
PFODA	Perfluorooctadecanoic acid	Perfluorostearic acid	16517-11-6	Perfluorinated carboxylic acid (PFCA)	1.7
PFPrS	Perfluoropropane sulfonic acid		423-41-6	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFBS	Perfluorobutane sulfonic acid	Nonafluorobutanesulfonic acid	375-73-5	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFPeS	Perfluoropentanesulfonic acid		2706-91-4	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFHxS	Perfluorohexane sulfonic acid	Tridecafluorohexane-1-sulfonic acid	355-46-4	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFHpS	Perfluoroheptanesulfonic acid		375-92-8	Perfluoroalkyl sulfonic acid (PFSA)	1.7

CHEMICAL	FULL NAME	SYNONYM	CAS	CATEGORY	LOQ (MG/KG)
br-PFOS	Branched isomer of perfluorooctanesulfonic acid		1763-23-1	Perfluoroalkyl sulfonic acid (PFSA)	0.3
L-PFOS	Linear-chain isomer of perfluorooctane sulfonic acid		1763-23-1	Perfluoroalkyl sulfonic acid (PFSA)	1.3
PFNS	Perfluorononanesulfonic acid	Nonadecafluoro-1-nonanesulfonic acid	68259-12-1	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFDS	Perfluorodecane sulfonic acid		335-77-3	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFDoS	Perfluorododecane sulfonic acid		120226-60-0	Perfluoroalkyl sulfonic acid (PFSA)	1.7
PFOSA	Perfluorooctanesulfonamide		754-91-6	Perfluoroalkyl sulfonic acid (PFSA)	1.7
N-MeFOSA	N-Methylperfluorooctane-sulfonamide	Heptadecafluoro-N-methyloctanesulphonamide	31506-32-8	Perfluoroalkane sulfonamide and derivatives (FASA)	1.7
N-EtFOSA	N-Ethyl-perfluorooctane sulfonamide	sulfluramid	4151-50-2	Perfluoroalkane sulfonamide and derivatives (FASA)	1.7
ADONA	Ammonium 4,8-dioxa-3H-perfluorononanoate	carbazochrome sodium sulfonate	958445-44-8	Perfluoroether carboxylic acid (PFECA)	1.7
HFPO-DA	Hexafluoropropylene oxide-dimer acid		13252-13-6	Perfluoroalkyl ether carboxylic acids	1.7
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonate	Potassium 9-chlorohexadecafluoro-3-oxanonane-1-sulfonate	73606-19-6	Chlorinated polyfluorinated ether sulfonate	1.7
11Cl-PF3OUDS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonate	Potassium 11-Chloroeicosafluoro-3-oxaundecane-1-sulfonate	83329-89-9	Chlorinated polyfluorinated ether sulfonate	1.7
4:2 FTOH	4:2 Fluorotelomer alcohol	2-(Perfluorobutyl)ethanol	2043-47-2	(n:2) Fluorotelomer alcohols (FTOH)	0.8
6:2 FTOH	6:2 Fluorotelomer alcohol	2-(Perfluorohexyl)ethanol	647-42-7	(n:2) Fluorotelomer alcohols (FTOH)	1.6
8:2 FTOH	8:2 Fluorotelomer alcohol	2-(Perfluorooctyl)ethanol	678-39-7	(n:2) Fluorotelomer alcohols (FTOH)	1.6
10:2 FTOH	10:2 Fluorotelomer alcohol	2-(perfluorodecyl)ethanol	865-86-1	(n:2) Fluorotelomer alcohols (FTOH)	16
12:2 FTOH	12:2 Fluorotelomer alcohol	2-(Perfluorododectyl)ethanol	39239-77-5	(n:2) Fluorotelomer alcohols (FTOH)	detected/ not detected
14:2 FTOH	14:2 Fluorotelomer alcohol	2-(perfluorotetradecyl)ethanol	60699-51-6	(n:2) Fluorotelomer alcohols (FTOH)	detected/ not detected
16:2 FTOH	16:2 Fluorotelomer alcohol	2-(Perfluorooctodecyl)ethanol	65104-67-8	(n:2) Fluorotelomer alcohols (FTOH)	detected/ not detected
18:2 FTOH	18:2 Fluorotelomer alcohol	2-(perfluorodecyl)ethanol	65104-65-6	(n:2) Fluorotelomer alcohols (FTOH)	detected/ not detected

CHEMICAL	FULL NAME	SYNONYM	CAS	CATEGORY	LOQ (MG/KG)
20:2 FTOH	20:2 Fluorotelomer alcohol	2-(Perfluoroicosyl)ethanol		(n:2) Fluorotelomer alcohols (FTOH)	detected/ not detected
4:2 FTS	4:2 Fluorotelomer sulfonic acid		757124-72-4	(n:2) Fluorotelomer sulfonic acids (FTSAs)	5.2
6:2 FTS	6:2 Fluorotelomer sulfonic acid		27619-97-2	(n:2) Fluorotelomer sulfonic acids (FTSAs)	26
8:2 FTS	8:2 Fluorotelomer sulfonic acid		39108-34-4	(n:2) Fluorotelomer sulfonic acids (FTSAs)	26
10:2 FTS	10:2 Fluorotelomer sulfonic acid		120226-60-0	(n:2) Fluorotelomer sulfonic acids (FTSAs)	26
12:2 FTS	12:2 Fluorotelomer sulfonic acid		120226-60-0	(n:2) Fluorotelomer sulfonic acids (FTSAs)	detected/ not detected
14:2 FTS	14:2 Fluorotelomer sulfonic acid		149246-64-0	(n:2) Fluorotelomer sulfonic acids (FTSAs)	detected/ not detected
16:2 FTS	16:2 Fluorotelomer sulfonic acid		1377603-17-2	(n:2) Fluorotelomer sulfonic acids (FTSAs)	detected/ not detected
6:2 PAP	6:2 Polyfluoroalkyl phosphoric acid monoester		57678-01-0	(n:2) Fluorotelomer phosphate monoester (PAP)	260
8:2 PAP	8:2 Polyfluoroalkyl phosphoric acid monoester		57678-03-2	(n:2) Fluorotelomer phosphate monoester (PAP)	260
6:2 diPAP	6:2/6:2 Fluorotelomer phosphate diester		57677-95-9	(n:2) Fluorotelomer phosphate diester (diPAP)	26
6:2 8:2 diPAP	6:2/8:2 Fluorotelomer phosphate diester		943913-15-3	(n:2) Fluorotelomer phosphate diester (diPAP)	26
8:2 diPAP	8:2/8:2 Fluorotelomer phosphate diester		678-41-1	(n:2) Fluorotelomer phosphate diester (diPAP)	26
PFBPA	2,3,4,5,6-Pentafluorobenzylphosphonic acid	Pentafluorobenzylphosphonic acid	52299-24-8	Perfluoro phosphonic acid (PFPA)	260
PFHxPA	Perfluorohexyl phosphonic acid	(Tridecafluorohexyl) phosphonic acid	40143-76-8	Perfluoro phosphonic acid (PFPA)	26
PFOPA	Perfluorooctyl phosphonic acid	(Heptadecafluorooctyl) phosphonic acid	40143-78-0	Perfluoro phosphonic acid (PFPA)	26
PFDPA	Perfluorodecyl phosphonic acid	(Heneicosafluorodecyl) phosphonic acid	52299-26-0	Perfluoro phosphonic acid (PFPA)	26

Annex 3. Methodology in details

Mass balance calculation

The concentrations of the individual PFAS identified in the samples were converted into fluorine equivalents using the following equation
(1):

(1) $C_{F\_PFAS} = n_F \times A_F / MW_{PFAS} \times C_{PFAS}$

C_{PFAS} : Given PFAS concentration (nanograms of PFAS per gram of sample)

C_{F_PFAS} : Corresponding fluorine concentration of a given PFAS (nanograms of fluorine per gram of sample)

n_F : Number of fluorine atoms on the given PFAS molecule

MW_{PFAS} : Molecular weight of the given PFAS

A_F : Atomic weight of fluorine

$\Sigma C_{F\_PFAS(identified)}$, the sum of all the fluorine from the given PFAS identified in a sample corresponds to the identified fraction of organic fluorine. The fraction of unidentified organic fluorine is then derived using the following equation (2):

(2) $C_{F\_unidentified} = C_{F\text{-}TOF} - \Sigma C_{F\_PFAS\ (identified)}$

$C_{F\_unidentified}$: Concentration of unidentified organic fluorine in a given sample (nanograms of fluorine per gram of sample)

C_{F_TOF} : Total concentration of organic fluorine in a given sample (nanograms of fluorine per gram of sample)

$\Sigma C_{F\_PFAS\ (identified)}$: Concentration of identified organic fluorine in a given sample (nanograms of fluorine per gram of sample)

The percentage of identified fluorine was calculated using the following equation (3):

(3) % identified fluorine = $\Sigma C_{F\_PFAS(identified)} \times 100 / C_{F\_TOF}$

FITC-T4 bioassay - analytic procedure

The sample extracts were cleaned up by a weak anion exchange (WAX) solid-phase extraction (SPE) before the FITC-T4 bioassay analysis. The cartridge was first conditioned (4 ml of MeOH with 0.1% NH_4OH; 4 ml of MeOH and 4 ml HPLC water), then transferred to the cartridge and washed (4 ml 25 mM NH_4Ac pH 4 and 8 ml THF:MeOH; 75:25). After washing, the cartridge was dried for 30 minutes by applying vacuum. A 15 ml tube was placed under the cartridge and the sample was eluted using 4 ml of MeOH with 0.1% NH_4OH. The extract was evaporated to dryness under a gentle stream of N_2 and re-dissolved in 50 µL of DMSO. From this DMSO extract a series of dilutions was made.

For the FITC-T4 binding assay, serial dilutions of the sample extracts (2 µl) and reference material (2 µL) were incubated in Tris-buffer (pH 8.0) for 20 minutes in the presence of TTR (0.30 µM) and FITC-T4 (109 nM). The total incubation volume was 202 µl. After incubation, the fluorescence induction was measured using a Berthold Mithras LB 940 applying an excitation wavelength of 490 nm, an emission wavelength of 535 nm and a measuring time of 0.1s.

Annex 4. Analytical results

Tables with analytic results

(ng/g = µg/kg; LOQ = limit of quantification; NA = not analysed)

OIL-BEADING COMPOSTABLES

SAMPLE ID	TOF (mg/kg dw)	TOF (µg/ dm2 dw)	PFBA (ng/g)	PFHxA (ng/g)	PFHpA (ng/g)	4:2 FTOH (ng/g)	6:2 FTOH (ng/g)	6:2 8:2 diPAP (ng/g)	8:2 diPAP (ng/g)	% identified fluorine	TTR - FITC-T4 activity (µg PFOA/g)	TTR - FITC-T4 LOQ (µg PFOA/g)
Compost-NL-3	**1200**	5550	<LOQ	<LOQ	<LOQ	<LOQ	**339**	<LOQ	<LOQ	0.019	**27**	10
Compost-DK-3	**1200**	4470	**5.27**	<LOQ	<LOQ	<LOQ	**92.1**	<LOQ	<LOQ	0.0055	13	8.1
Compost-DE-12	**1100**	4070	<LOQ	<LOQ	<LOQ	<LOQ	**296**	<LOQ	<LOQ	0.018	**23**	5.6
Compost-DE-11	**850**	2840	<LOQ	**6.77**	**2.31**	**6.34**	**3 422**	<LOQ	<LOQ	0.27	NA	-
Compost-FR-2	**800**	3450	<LOQ	**8.80**	**5.08**	**3.03**	**1 263**	<LOQ	<LOQ	0.11	21	7.4
Compost-DK-5	**730**	2560	**2.12**	<LOQ	<LOQ	<LOQ	**362**	<LOQ	<LOQ	0.034	**74**	7.7
Compost-NL-1	**680**	4240	<LOQ	<LOQ	<LOQ	<LOQ	**204**	<LOQ	<LOQ	0.020	**18**	4.9
Compost-DK-4	**670**	3080	<LOQ	**4.19**	<LOQ	**2.99**	**1 018**	<LOQ	<LOQ	0.10	NA	-
Compost-DK-1	**650**	1550	<LOQ	**3.33**	<LOQ	<LOQ	**1 330**	<LOQ	<LOQ	0.14	NA	-
Compost-DK-7	**640**	1900	<LOQ	**2.61**	<LOQ	<LOQ	**580**	<LOQ	<LOQ	0.062	NA	-
Compost-FR-4	**630**	2020	**2.77**	**7.27**	**1.89**	**21.6**	**4 766**	<LOQ	<LOQ	0.52	NA	-
Compost-DK-6	**630**	1790	<LOQ	<LOQ	<LOQ	<LOQ	**310**	<LOQ	<LOQ	0.033	NA	-
Compost-DK-2	**560**	3710	<LOQ	<LOQ	<LOQ	<LOQ	**4 701**	**205**	**290**	0.63	NA	-

OIL-BEADING TAKEAWAY PAPER

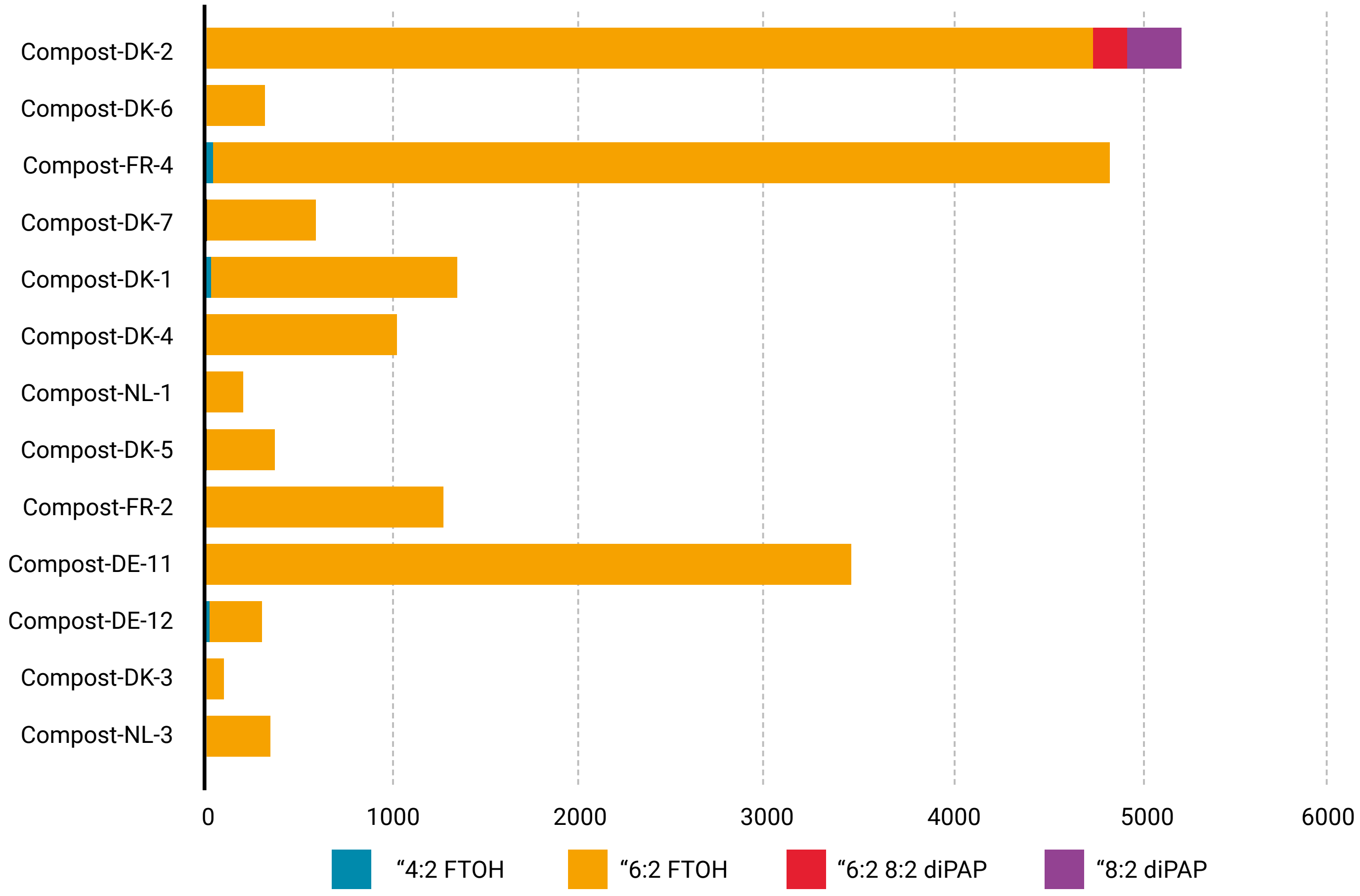
SAMPLE ID	TOF (mg/kg dw)	TOF (µg/dm2 dw)	6:2 FTOH (ng/g)	6:2 FTS (ng/g)	10:2 FTS (ng/g)	% identified fluorine	TTR - FITC-T4 activity (µg PFOA/g)	TTR - FITC-T4 LOQ (µg PFOA/g)
DE-PAP-KFC-17a	**770**	247	**528**	<LOQ	<LOQ	0.047	**341**	26
FastF-FR-5	**700**	215	**706**	<LOQ	<LOQ	0.068	**220**	29
FastF-FR-3	**670**	224	**192**	**39.5**	**104**	0.033	NA	-
DE-PAP-NRDS-19a	**640**	291	**234**	<LOQ	<LOQ	0.025	NA	-
FastF-FR-2	**530**	351	**219**	<LOQ	<LOQ	0.028	NA	-
DE-PAP-DDNT-20a	**510**	270	**194**	<LOQ	<LOQ	0.026	NA	-
FasF-UK-5a	**480**	157	**16.9**	<LOQ	<LOQ	0.0024	39	19
CZ-FCM-KFC-06	**480**	134	**634**	<LOQ	<LOQ	0.090	69	33
CZ-FCM-MCD-01b	**470**	176	**335**	<LOQ	<LOQ	0.048	**52**	16
FastF-UK-2	**440**	177	<LOQ	<LOQ	**34.4**	0.0050	60	30
CZ-FCM-BB-01b	**400**	400	**345**	<LOQ	<LOQ	0.059	NA	-
FastF-UK-4	**390**	125	**248**	<LOQ	<LOQ	0.043	NA	-
DE-PAP-MCD-26	**370**	159	**132**	<LOQ	<LOQ	0.024	**180**	26
FastF-UK-3	**340**	162	**317**	<LOQ	<LOQ	0.063	NA	-
FastF-UK-1	**220**	76.3	**168**	<LOQ	<LOQ	0.052	NA	-

OIL-SPREADING OR OIL-SOAKING PAPER/BOARD

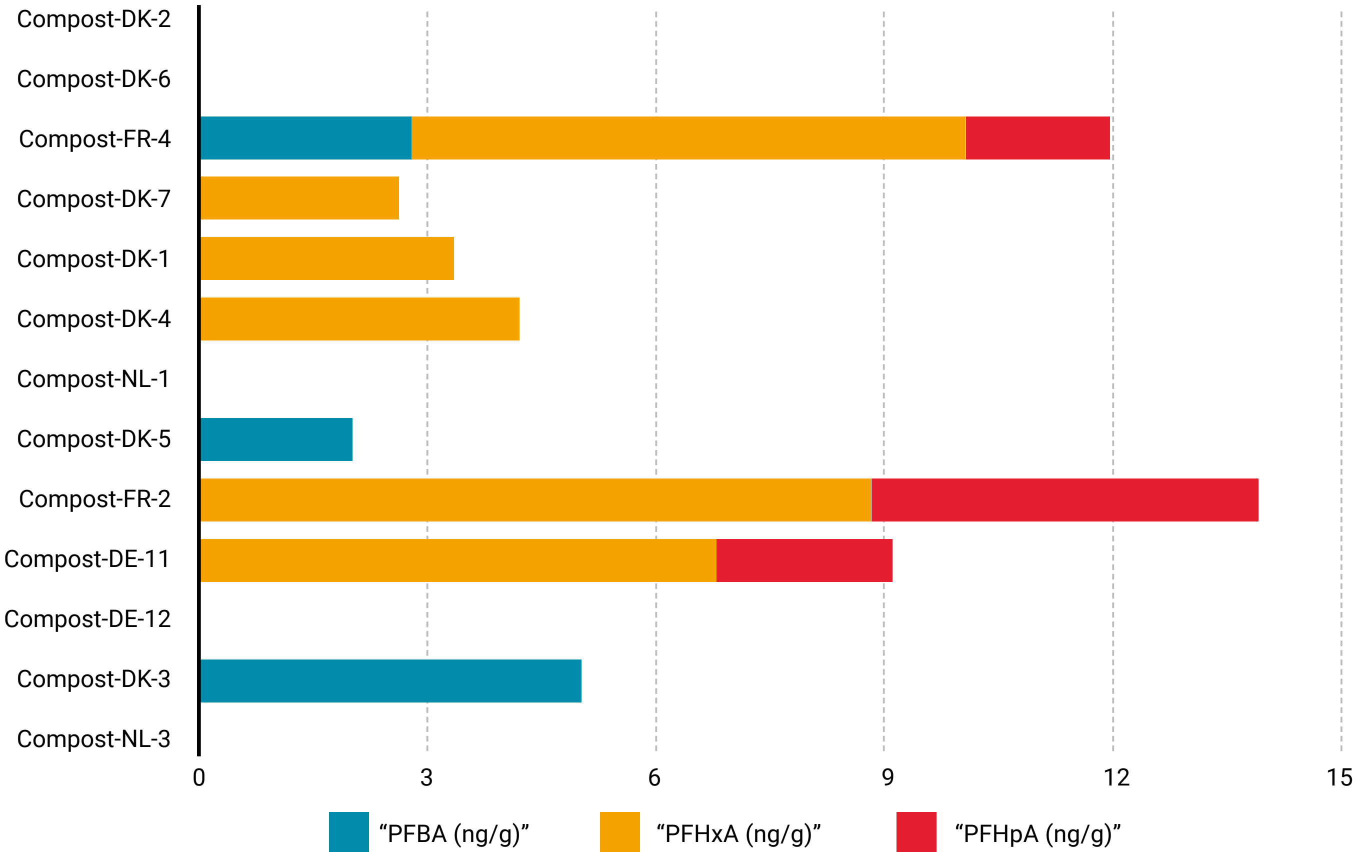
SAMPLE ID	**Bead test**	**TOF (mg/kg dw)**	**TOF (µg/dm² dw)**	**6:2 FTOH (ng/g)**	**4:2 FTS (ng/g)**	**10:2 FTS (ng/g)**	**% identified fluorine**	**TTR - FITC-T4 activity (µg PFOA/g)**	**TTR - FITC-T4 LOQ (µg PFOA/g)**
NL-MCD-01	spreading	**65**	18.5	**114**	<LOQ	<LOQ	0.12	**200**	33
Recycl-CZ-1	soaking	**25**	24.9	**104**	<LOQ	**36.5**	0.38	**73**	14
PizzaB-UK-2	soaking	**23**	83	<LOQ	<LOQ	**34.4**	0.10	**26**	8.3
PizzaB-UK-1	soaking	**21**	67.2	**15.8**	<LOQ	**43.2**	0.18	NA	-
Recycl-CZ-2	soaking	19	18.8	**46.5**	<LOQ	<LOQ	0.17	NA	-
PizzaB-UK-3	soaking	17	55	<LOQ	<LOQ	**35.1**	0.13	NA	-
Recycl-FR-1	soaking	15	15.7	**324**	<LOQ	**46.8**	1.7	NA	-
Recycl-CZ-4	soaking	14	4.4	**44.5**	<LOQ	<LOQ	0.22	NA	-
FastF-NL-1	soaking/ spreading	13	47.7	**166**	<LOQ	**32.8**	1.0	NA	-
FastF-NL-5	spreading	9	28.4	**95.5**	<LOQ	<LOQ	0.72	NA	-
Recycl-NL-4	soaking	7.5	24.8	**124**	<LOQ	<LOQ	1.1	NA	-
DE-PAP-DMN-24a	spreading	5.9	14.7	**117**	**5.77**	<LOQ	1.4	NA	-
Recycl-NL-1	soaking	5.7	11.2	**194**	<LOQ	<LOQ	2.3	NA	-
DK-PAP-MCD-1	spreading	5.5	1.9	**277**	<LOQ	<LOQ	3.4	51	23

Graphs with analytic results

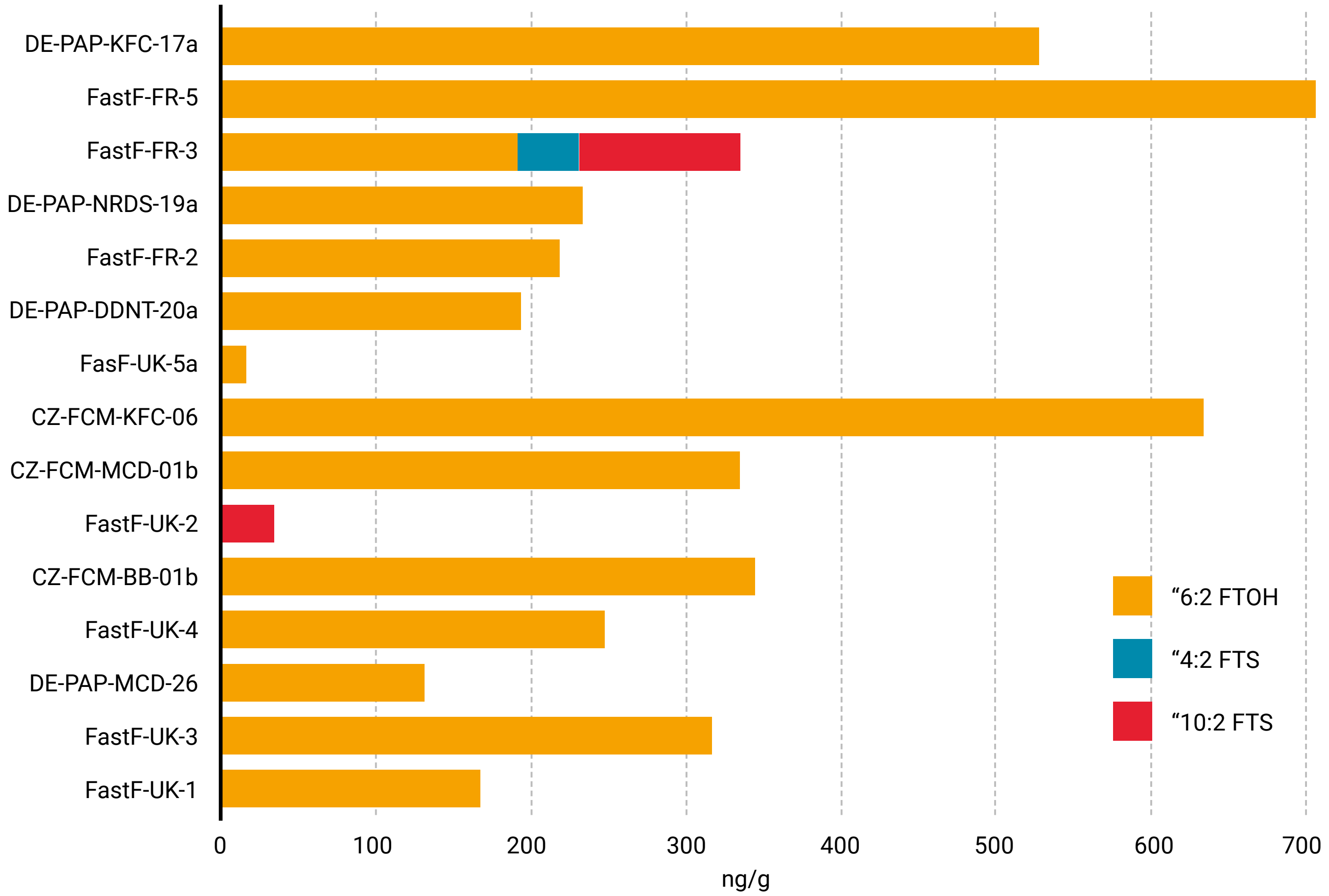
FTOHs and diPAPs concentrations (ng/g) in Oil-beading compostable samples



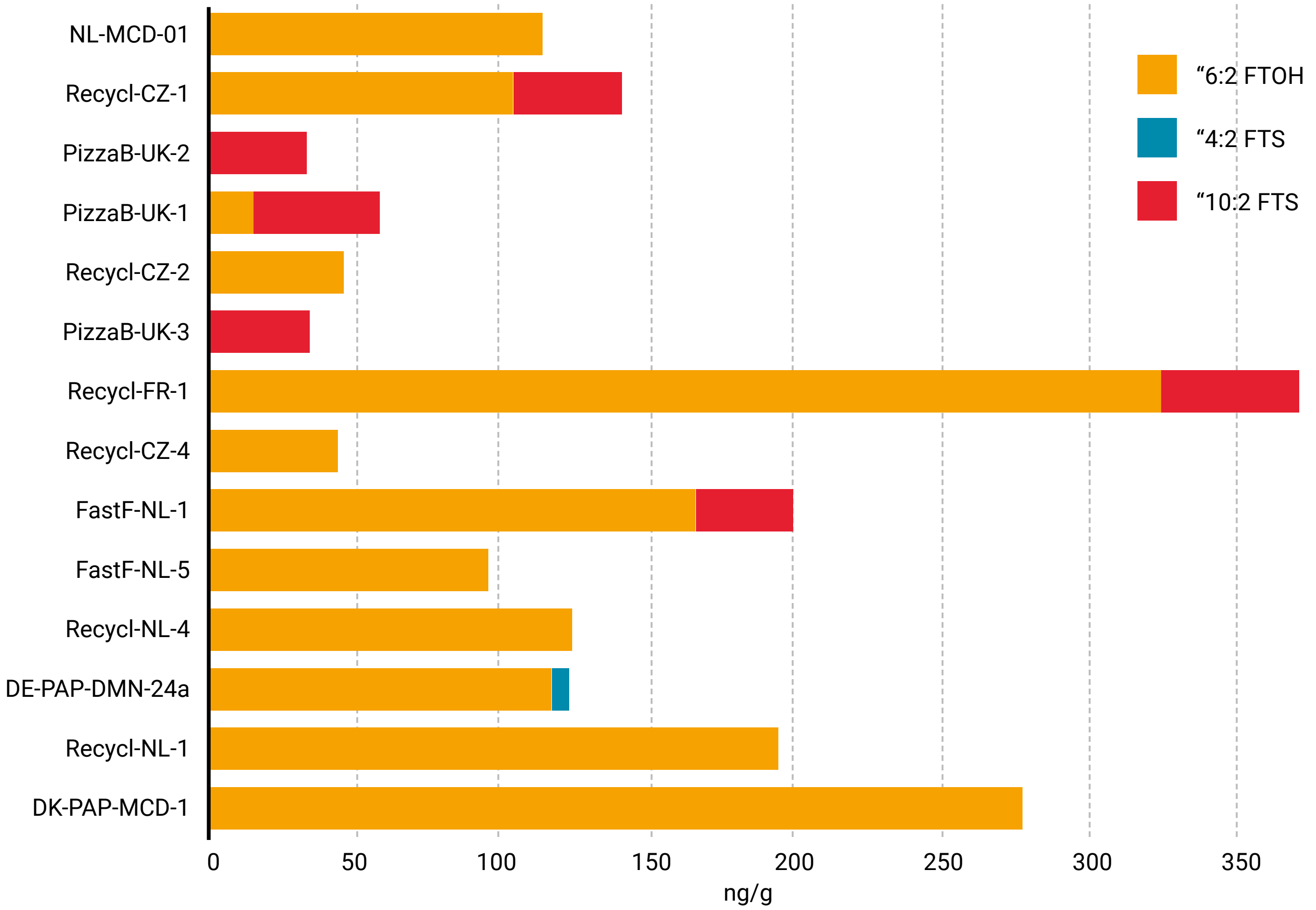
PFCAs concentrations (ng/g) in Oil-beading compostable samples



FTOH and FTS concentrations (ng/g) in Oil-beading takeaway paper samples



FTOH and FTS concentrations (ng/g) in Oil-spreading or soaking paper/board samples



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