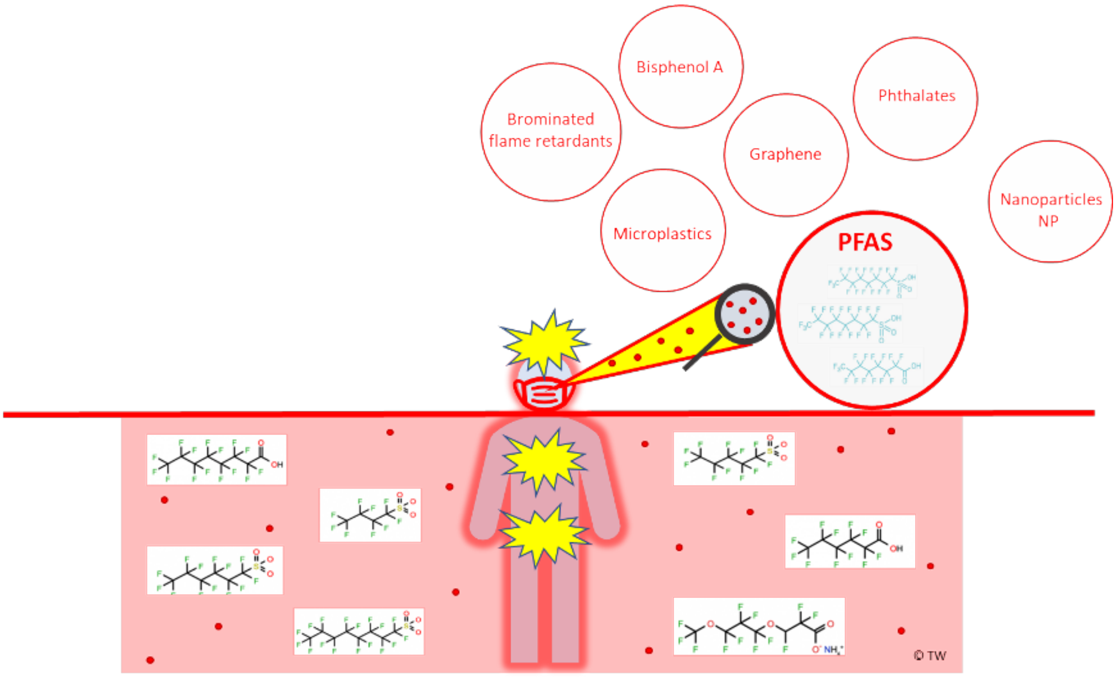
Face masks and the shutdown of brain, heart, and reproduction system



Toxic chemical contamination cross the line to human, environmental exposure

November 2022

TOXICO WATCH

Face masks and the shutdown of brain, heart, and reproduction system

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Abbreviations

Abbreviation	Meaning
6:2 FTOH	1H,1H,2H,2H-perfluoroctanol, telomeer alcoholen
8:2 monoPAP	8:2 Fluorotelomer phosphate monoester
8:2 diPAP	8:2 polyfluoroalkyl phosphate diester
3D-HSE	3D-Human Skin Equivalent
AFFF	Aqueous Film Forming Foam (firefighting foam)
AgNPs	(Silver) Ag NanoParticles
BBB	Blood-brain-barrier
BBP	Butyl Benzyl Phthalate
BEQ	Biological Equivalents
BMI	Body Mass Index
BPA	Bisphenol A
bw	Body weight
c-pentaBDE	Commercial -tetra- and pentaBromoDiphenyl Ether
c-octaBDE	Commercial- hexa- and heptaBromDiphenyl Ether
CPB	Cylindrical Polymer Brushes
CuI	Copper iodide
CuNPs	Copper NanoParticles
CuO	Copper (I) Oxide
Cu2O	Copper (II) oxide
DEHP	Di Bis(2-EthylHexyl) Phthalate
DINCH	1,2-cyclohexanedioic acid diisononyl ester
DINP	DiIsoNonyl Phthalate
DR CALUX®	Dioxin Responsive Chemical-Activated LUciferase gene eXpression
ECHA	European Chemical Agency
EDI	Estimated Daily Intakes
EFSA	European Food and Safety Authority
EOF	Extractable Organic Fluorine
FFP2	Filtering FacePiece (connotation '2' means a filter efficiency of at least 94% of airborne particles)
FITC-T4	Fluorescein IsoThioCyanate L-Thyroxine (T4)
FLG	Few-Layer Graphene
FTOH	Fluorotelomers with an alcohol functional group
FOSE	Perfluorooctane sulfonamido ethanol (var: perfluorooctane sulfonamide ethanol)
GC-MS	Gas Chromatography Mass Spectrometry GC-MS
GenX	Fluorochemicals related to hexafluoropropylene oxide dimer acid (HFPO-DA)
GFN	Graphene-Family Nanomaterials
GNS	Graphene NanoSheets
GO	Graphene Oxide
HBB	HexaBromoBiphenyl
HBCD	HexaBromoCycloDodecane
HDPE	High Density PolyEtyleen
HFPO-DA	Hexafluoropropylene oxide-dimer acid (Gen-X)
LC-MS	Liquid Chromatography Mass Spectrometry GC-MS
LOD	Limit of Detection

LOQ	Limit of Quantification
MP	MicroPlastics
MPPD	Multiple- Path Particle Dosimetry
MRA	Mixture Risk Assessment
NFT	Nano-Functional Treatment
ng	Nanogram; 10^{-9} gram
Non-woven	Fabric-like material from staple and long fibres, bonded together by chemical, mechanical, heat or solvent treatment.
NP	Nanoparticles
OECD	Organisation for Economic Co-operation and Development
PBDE	Polybrominated diphenyl ethers
PFAS	per- and polyFluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid;
PFDoDA	Perfluorododecanoic acid is a dodecanoic acid (12-carbon chain). All the hydrogens attached to carbon atoms are replaced by fluorines.
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFNA	perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	PerFluoroOctane Sulfonates
PVC	PolyVinyl Chloride
pg	Picogram; 10^{-12} gram
PM	Particulate Matter (PM10), fine (PM2.5) and very fine (PM1.0)
POP	Persistent Organic Pollutants
PUR	PolyURethane
rGO	reduced Graphene Oxide
RPF	Relative Potency Factors
SVHC	Substances of Very High Concern
SVOC	Semi-volatile organic compounds
T3	Thyroid hormone 3,3′,5-triiodo-L-thyronine
T4	Thyroxine hormone 3,5,3′,5′-tetraiodo-L-thyronine
TDI	Tolerable Daily Intake
TOF	Total Organic Fluorine
TSH	Thyroid Stimulated Hormone
TTR	Thyroid transport protein (transthyretin)
TBBPA	Tetrabromo-bisphenol-A
TW	ToxicoWatch
TWI	Tolerable Weekly Intake
µg	Microgram 10^{-3} gram
WAX SPE	Weak Anion-eXchange) Solid Phase Extraction
ZnO	Zinc oxide

Introduction

Biomonitoring emissions of persistent organic pollutants (POPs), like dioxins and PFAS in relation to waste incineration, is the main working field of ToxicoWatch (TW) since 2013. The aim of ToxicoWatch Foundation is to raise public awareness about exposure to toxic chemicals in everyday life. During the past two years, the question became for TW more and more needed to be answered: *What is the content of the enormous ongoing growth of the worldwide waste of mandated single-use face masks?* on behalf of human health and the protection of the environment.

Therefore, TW started the initiative in February 2022, to set up this pilot study on face masks based on questions:

> ***Is PFAS added to face masks****?*

> ***What are the risks for human health if PFAS is added to face masks?***

This research focuses on PFAS and its many pathways into the human body via the skin, respiratory tract, mouth, lungs, eyes, nose, and the blood-brain barrier. TW initially based this research on three types of single-use face mask samples (FFP2, medical), complemented with a literature study on PFAS, toxic chemicals and textiles.

The synergistic effects can occur with other toxic chemicals like phthalates, bisphenols, brominated flame retardants, nanoparticles i.e., graphene as well as microplastics. These all can be found in face masks according to literature research which is referred to in this study. However, toxicological research on chemicals, both single-stress and synergistic, is scarce in relation to face masks. The reason for this scarcity may be industrial patent secrets, industrial competitive interests, or censorship in general.

An increasing number of studies show a relationship between emerging diseases and PFAS. From a point of view of the precautionary principle, highly persistent and toxic substance as PFAS in (medical) textiles - meant to protect our health - will be discussed in this report.

Key points TW research PFAS in face masks

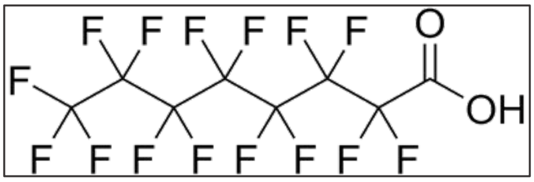
- All three (3) different types of face masks in this pilot research contain PFAS (µg PFOA equivalent/gram product).
- The most equipped laboratories can only identify about 0,1 % of the possible PFAS substances.
- In this study, the first-time bioassay of FITC-T4 analysis is applied to face masks.
- Studies on literature about PFAS and face masks (although scarce) confirm the use of PFAS in face masks, mainly because of the water-repellent feature.
- Human health risks associated with PFAS are cardiovascular disorders, immunotoxicity, thyroid hormone suppression, kidney & testicular cancers, lowered fertility, and endocrine and neurological disorders.
- The Tolerable Weekly Intake (TWI) for PFAS is 4.4 ng /kg bw/week, according to European Food Safety Authority (EFSA) advice.
- Results of PFAS in the face masks in this research: 7.3 – 31.0 µg PFOA equivalent/gram product.
- Expressed in square meters: the results of PFAS in the face masks in this research are 331.0 - 1424.0 µg PFOA equivalent /m^2, while the safe limit for textile is set on 1 µg PFOA eq./m^2, meaning these results are an exceeding of the EU limit for textiles by a factor of 331 - 1424.
- There are multiple pathways for PFAS to enter the human body:
    - Mouth (swallowing, oral uptake of microplastics)
    - Lungs (pulmonary uptake)
    - Skin (dermal uptake)
    - Nose (intranasal, inhalation and mucosal uptake)
    - Brain (cerebral uptake, blood-brain-barrier)
    - Eyes (Ocular uptake)
- Face masks can also contain other chemicals such as bisphenol, phthalates, and brominated flame retardants, as well as microplastics.
- Other studies highlighted the containment of antimicrobial agents like nanoparticles such as graphene and metals in face masks which are still poorly regulated.
- The application of the precautionary principle is urgently needed for the unrestrained use of toxic chemicals and technical applications in face masks.

What are PFAS?

There are several definitions of PFAS, new definitions may be developed, but all will have implications for regulation and even for analyses. One approach is to review "all organofluorines'' as PFAS, even including all organofluorine pharmaceuticals. That would fit more the gap found between the extractable organic fluorine (EOF) and the known (targeted) PFAS. The definition of the Organisation for Economic Co-operation and Development (OECD) includes 107 (30%) organofluorine pharmaceuticals. However, the oppositions and especially interests remain. A clear, universally agreed-upon definition of PFAS would be ideal, but hard to get. When no agreement can be reached, there is a real danger of not adopting any definition and the consequential delay in decision-making about PFAS.[1]

Fluorinated substances were first developed in the 1940s and applied in numerous industrial branches and consumer products. Despite a wide range of industrial and commercial applications, the polyfluor industry is very scarce in providing information, while science lags seriously behind in analytical capabilities and reference materials. PFAS possess thermal, chemical, and biological stability, non-flammability, and surface-active properties. It is applicated in numerous everyday products such as, for example, clothing, make-up, electronics, baking paper, dental floss, solar panels, wind turbines, firefighting extinguishing foam and so on. Figure 1 shows a list of branches with PFAS applications.[2]

Their high applicability combined with chemical stability has led to an inevitable accumulation of PFAS in the environment and can be found in air, sewage, rivers, drinking water, dust, food, and food packaging material, in every living organism on this earth. Fluoropolymer manufacturing has caused extensive environmental contamination. Fluoropolymer microplastics are a pollution problem worldwide [3] and, the end-of-life incineration of fluoropolymer-containing products can be a source of hazardous air emissions.



Molecule structure Perfluorooctanoic acid, PFOA

Other use categories	
Aerosol propellants	Metallic and ceramic surfaces
Air conditioning	Music instruments (3)
Antifoaming agent	Optical devices (3)
Ammunition	Paper and packaging (2)
Apparel	Particle physics
Automotive (12)	Personal care products
Cleaning compositions (6)	Pesticides (2)
Coatings, paints and varnishes (3)	Pharmaceuticals (2)
Conservation of books and manuscripts	Pipes, pumps, fittings and liners
Cook- and bakingware	Plastic, rubber and resins (4)
Dispersions	Printing (4)
Electronic devices (7)	Refrigerant systems
Fingerprint development	Sealants and adhesives (2)
Fire-fighting foam (5)	Soldering (2)
Flame retardants	Soil remediation
Floor covering including carpets and floor polish (4)	Sport article (7)
Glass (3)	Stone, concrete and tile
Household applications	Textile and upholstery (2)
Laboratory supplies, equipment and instrumentation (4)	Tracing and tagging (5)
Leather (4)	Water and effluent treatment
Lubricants and greases (2)	Wire and cable insulation, gaskets and hoses
Medical utensils (14)	

Figure 1: Industrial Markets of PFAS (Glüge 2020)

[1] *Hammel et al., (2022). iScience 25, 104020, April 15, The Author(s). https://doi.org/10.1016/j.isci.2022.104020*
[2] *Glüge J. et al. (2020); An overview of the uses of per- and polyfluoroalkyl substances (PFAS), Environ. Sci.: Processes Impacts, https://pubs.rsc.org/en/content/articlelanding/2020/em/d0em00291g*
[3] *BUILDING A BETTER WORLD, Eliminating Unnecessary PFAS in Building Materials www.greensciencepolicy.org*

Even Sustainable Developments Goals (SDGs) are involved with PFAS applications, (Figure 2), such as the propellors of windmills and the fluoropolymer coatings on solar panels and leak these toxic - forever-chemical - substances into the soil, air, and water during production, as well as use. If PFAS ends up as waste, humans will be directly exposed to these highly toxic for-ever chemicals.

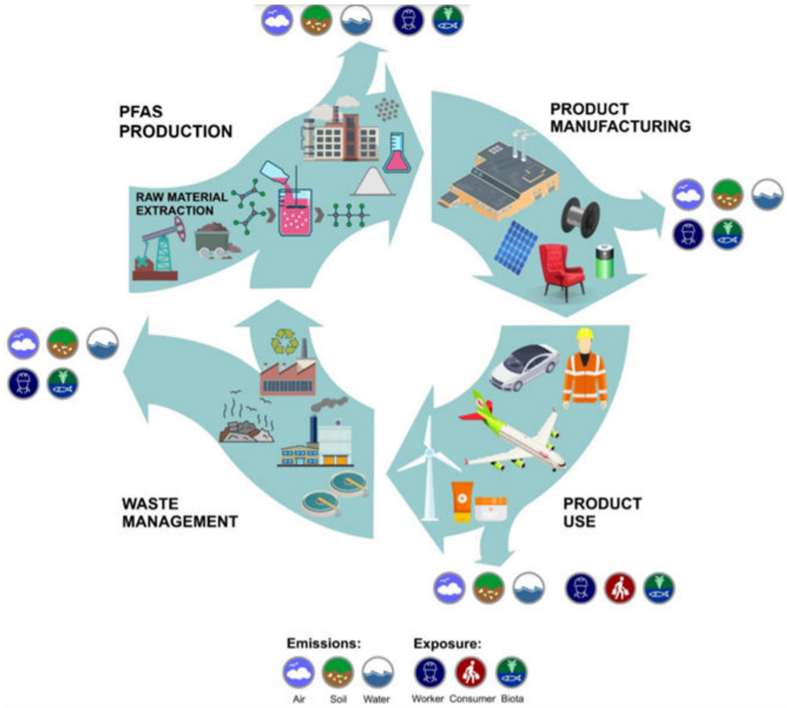


Figure 2: Overview figure of EU Commission Staff Working document on PFAS, October 2020.

Figure 3 shows an overview of PFAS exposure pathways to the human population and the environment, (Sunderland et al. 2019).[4] PFAS are man-made substances that do not naturally occur in the environment. Due to emissions, leakage, wear of materials, incidents, etc., PFAS substances end up in the environment and are found, among other chemical substances in, soil, dredging spoil and surface water.[5]

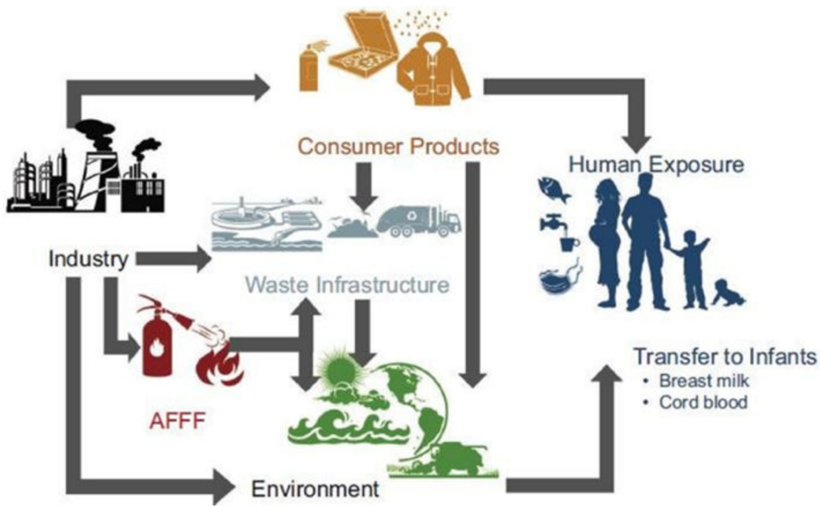


Figure 3: PFAS exposure pathways to the human population and the environment (Sunderland et al. 2019).

[4] *Sunderland EM. (2019). Journal of Exposure Science & Environmental Epidemiology (2019) 29:131–147*

[5] *https://www.rivm.nl/en/pfas*

Health risks associated with PFAS

The European Food Safety Authority (EFSA) concluded that both PFOS and PFOA are associated with reduced antibody response to vaccination. EFSA also concluded that parts of the European population exceed the tolerable weekly intake (TWI) of PFAS.[6] PFAS are associated with adverse human health effects on thyroid function, metabolism (including overweight/obesity), diabetes, insulin resistance, high cholesterol, foetal development, and the immune system.[7] The risk of immunotoxicity for humans and wildlife can therefore not be disregarded.[8] An increase in cardiovascular disease has been found in relation to PFAS exposure. Several studies point to changes in lipid and glucose metabolism and increased blood pressure as possible links to cardiovascular thromboembolic events.[9] Children have a greater risk of exposure because PFAS are transferred through the placenta and postnatal sources of human milk and house dust.[10]

A substantial impact on male infertility can be found with a reduction in semen quality, testicular volume, and even penis length.[11] Other adverse effects commonly reported in experimental animals exposed to PFOA include carcinogenicity, hepatomegaly and hepatocyte proliferation, hormone disruption, and a myriad of developmental effects, including neonatal mortality.[12] A list of health risks associated with PFAS:

- Alter cholesterol levels
- Disrupt thyroid function
- Harm to liver and kidney function
- Alter immune response
- Raise the risk of ulcerative colitis
- Harm reproductive health
- Increase the risk of birth defects
- Decrease infant birth weights
- Cause tumours and cancer
- Link to Alzheimer's disease [13]

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[6] *https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf*

7 Young, A.S. et al. (2021). Env. Health Perspect. 129 (4), 047010-1 to 047010-13.

8 Corsini, E., et al., Perfluorinated compounds: Emerging POPs with potential immunotoxicity. Toxicol. Lett. (2014)

9 Meneguzzi A, et al. (2021) Exposure to Perfluoroalkyl Chemicals and Cardiovascular Disease: Experimental and Epidemiological Evidence. Front. Endocrinol. 12:706352.

10 Wang et al (2019). Inactivation of common airborne antigens by perfluoroalkyl chemicals modulates early life allergic asthma. PNAS 2021 Vol. 118 No. 24 e20119571

[11] *Di Nisio A. et al. (2018). Endocrine disruption of androgenic activity by perfluoroalkyl substances: clinical and experimental evidence, The Journal of Clinical Endocrinology & Metabolism; Copyright 2018 DOI: 10.1210/jc.2018-01855*

[12] *DeWitt, Jamie. (2015). Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances. 10.1007/978-3-319-15518-0.*

[13] *Zhang, Qian et al. "Developmental perfluorooctane sulfonate exposure results in tau hyperphosphorylation and β-amyloid aggregation in adult rats: Incidence for link to Alzheimer's disease."* Toxicology *347-349 (2016): 40-6*

Short-chain PFAS

Short-chain PFAS are introduced on the market as alternatives for PFOA and PFOS. Animal experiments show fast elimination of these short-chain PFAS. Long-chain PFAS are perfluoroalkyl sulfonic acids (PFOS) containing ≥ 6 carbons, and perfluoroalkyl carboxylic acids (PFOA) with ≥ 7 carbons. Short-chain PFAS have fewer carbons such as perfluorobutanesulfonic acid (PFBS) and perfluorobutanoic acid (PFBA) having a 4-carbon fluorocarbon chain.

However, the elimination of PFAS in humans takes far more time, several months before a reduction of 50% of these chemicals in the blood is reached.[14] Table 1 shows the recently re-evaluated relative potency factor (RPF) assessed from sub-chronic repeated toxicity studies.[15] These substitutes (like ”Gen-X” and PFBS) turn out to be more toxic than PFOA in such a manner that ‘regrettable substitutes’ can rightly be termed, see Figure 4. The relative potency Hexafluoropropylene Oxide (HFPO/” Gen-X”) Dimer Acid, so Gen-X chemicals set in the research of Bil et al. (2022) on factor 9, because of its long elimination time in human serum. However, no consensus has yet been reached in establishing an RPF.

Compound	Internal RPF
PFBS	0.2
PFHxS	0.6
PFOS	3
PFBA	2
PFHxA	10
PFOA	1
PFNA	5
PFDoDA	10
HFPO-DA	9

Table 1: Relative potency factors (RPFs) for PFAS (Bil W. (2022).

Figure 4: Structure formula of PFDoDA (Pubchem).

Short-chain PFAS are associated with the following toxicity threats:[16]

- Developmental toxicity (PFBA, PFBS)
- Endocrine toxicity (PFHxA, PFBA, PFBS)
- Hematotoxicity (PFBS)
- Immunotoxicity (PFBS)
- Neurodevelopmental toxicity (PFBS)
- Reproductive toxicity (PFBA, PFBS)
- Respiratory toxicity (PFHxA)
- Ocular toxicity (PFBS)

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[14] *PFAS with shorter carbon-chain length [e.g., perfluorooctanoic acid (PFBA), perfluorooctanoic acid (PFHxA), perfluorobutane sulfonic acid (PFBS), 6:2 fluorotelomer carboxylic acid (6:2 FTSA), 6:2 fluorotelomer carboxylic acid (6:2 FTCA)] and substances with other functional groups, like perfluoro ether sulfonic and carboxylic acids [e.g., hexafluoropropylene oxide-dimer acid (**HFPO-DA or GenX**), hexafluoropropylene oxide-trimer acid (HFPO-TA), 6:2 chlorinated poly-fluoroalkyl ether sulfonic acid (6:2 Cl-PFESA), ammonium 4,8-dioxa-3H-perfluorononanoate (ADONA), and Nafion by-product 2 (BP2)].*

[15] *Bil W. (2022). Internal Relative Potency Factors for the Risk Assessment of Mixtures of Per- and Polyfluoroalkyl Substances (PFAS) in Human Biomonitoring, Environmental Health Perspectives 077005-1 130(7) July 2022*

[16] *DTSC (2019). Product-chemical profile for textile treatments containing PFAS: discussion draft, november 2019 • discussion draft, https://dtsc.ca.gov.*

Thyroid hormone suppression

One of the main endpoints for the effects of PFAS are the suppressions of the hormonal activity of the thyroid. The thyroid, an endocrine gland in vertebrates, is located at the front of the neck, below the Adam's apple and produces the hormones T4 (3,5,3′,5′-tetraiodo-L-thyronine) and T3 (3,5,3′-triiodo-L-thyronine, see Figure 5. These hormones are important for brain development in mammals, during embryonic and foetal stages, regulating processes of neuronal proliferation, migration and differentiation, neurite outgrowth, synaptic plasticity, dendritic branching, and myelination. After birth, thyroid hormones are crucial for normal brain function throughout the entire life.[17]

PFAS are ubiquitous and, when assimilated, difficult to be eliminated, persisting for years both in humans and animals. The thyroid gland appears to be an important key organ in health problems associated with PFAS contamination. Interference with the thyroid gland, especially its competition with the T4 molecule, is the basis of a bioassay, FITC-T4, used to measure the toxicity of a PFAS mixture. This method of FITC-T4 bioassay is used in this research as well.

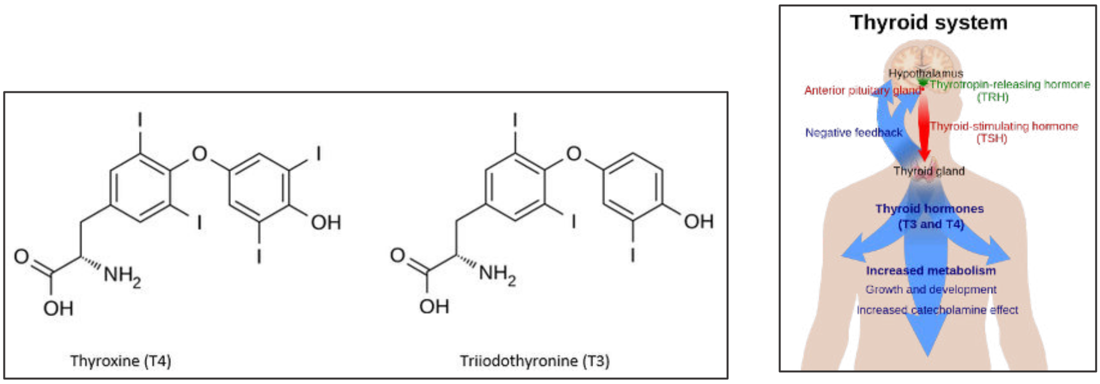

Figure 5: Thyroxine (T4), Triiodothyronine (T3) and Thyroid system, https://en.wikipedia.org/wiki/Thyroid_hormones

[17] *Talhada D, et al (2019) Thyroid Hormones in the Brain and Their Impact in Recovery Mechanisms After Stroke. Front. Neurol. 10:1103*

FITC-T4 assay

Chemical analytical techniques for the determination of PFAS, are liquid chromatography-tandem mass spectrometry (LC-MS/MS) and gas chromatography-mass spectrometry (GC-MS). However, only a tiny fraction of the real PFAS burden of the estimated > 10,000 substances, can be determined and assessed. The most equipped laboratories, now, can only identify around 50 PFAS substances. The pool of "known unknown" and "unknown unknown" PFAS is very large and immeasurably deep.[18] The lack of analytical standards, and secret patented chemical formulations by the industry-targeted quantitative measurements of unknown PFAS is hard to accomplish.[19] Other methods are the total oxidizable precursor (TOP) assay, the extractable organic fluorine (EOF) and bioassays.[20] The mass balance between TOP and target PFAS analyses shows a great portion of unknown PFAS precursor and/or fluorinated compounds. In this study, a FITC-T4 bioassay method is applied.

FITC-T4 is the acronym for Fluorescein IsoThioCyanate (FITC) and L-thyroxine, a hormone-containing 4 iodine elements (T4). The thyroid hormone homeostasis can be disrupted by chemicals at different points of interaction in the thyroid pathway, including during the transport of the hormone through the blood. **PFAS** bind potently to the thyroid transport protein transthyretin (TTR) thereby competing with the natural hormone thyroxine (T4)**.** The measurement is based on the difference between the bound and non-bound hormone thyroxine (T4). Bound FITC-T4 will result in a higher fluorescence than non-bound. Theoretical also other substances than PFAS can interfere with T4. So, the results can be higher, but the toxicity for T4 remains. The analysis results of the FITC-T4 will be expressed in **µg PFOA equivalent/g product**.[21,] The result doesn't implicate all can be related to PFAS, also other substances, brominated bisphenols, can have a competitive effect on T4. So, the FITC-T4 is not specific to PFAS, but also to other toxic substances, like tetrabromo-bisphenol-A (TBBPA), phthalates, and PBDEs.[22] All these substances have a serious toxic interaction with the thyroid system, which can be measured by this bioassay.

The FITC-T4 bioassay method is by our knowledge, for the first time applied on face masks and by BioDetection Systems, Amsterdam, the Netherlands, accredited under RvA L401.[23]

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[18] *Wang, Z.Y., DeWitt, J.C., Higgins, C.P., Cousins, I.T., 2017. A never-ending story of per- and polyfluoroalkyl substances (PFASs)? Environ. Sci. Technol. 51, 2508- 2518.*
[19] *Van Leeuwen SPJ, Kärrman A, Van Bavel B, De Boer J and Lindstrom G, 2006. Struggle for quality in determination of perfluorinated contaminants in environmental and human samples. Environmental Science and Technology, 40, 7854–7860.*
[20] *Zhu, H., & Kannan, K. (2020). Total oxidizable precursor assay in the determination of perfluoroalkyl acids in textiles collected from the United States. Environmental Pollution, 114940.*
21 Smith, D.S., (1977). FEBS Lett. 77, 25-27.
[22] *Hamers T. (2020). Transthyretin-Binding Activity of Complex Mixtures Representing the Composition of Thyroid-Hormone Disrupting Contaminants in House Dust and Human Serum, Environmental Health Perspectives 017015-1 128(1)*
[23] *Behnisch P.A. et al. (2021). Developing potency factors for thyroid hormone disruption by PFASs using TTR-TRβ CALUX® bioassay and assessment of PFASs mixtures in technical products, Environment International 157, 106791*

Samples

Three (3) different types of face mask samples were purchased in February 2022 in public shops for this first pilot study.

Sample 1: **Single-use mouth-face mask - M-01**

Tradename DR. Family, Filtering half mask, filtering facepiece (FFP) and not re-usable marked as NR (FFP2 NR), Figure 6. The connotation '2' means a filter efficiency of at least 94% of airborne particles. Bought in a box of 20 pieces. Dimensions: 160 x 105 mm. Exist in five (5) layers, material: 40% non-woven fabric, melt-blown[24] fabric 30%, hot air cotton 30%. Produced in China. Bought in a (Do-it-Yourself) DIY shop, Harlingen, the Netherlands. "Protection against droplets and aerosols" as mentioned on the box and in each single package. Dimensions 222 x 114 mm.

Figure 6: Sample 1, Mouth-face mask M-01 "DR. Family".

Sample 2: **Single-use mouth-face mask - M-02**

'Promasque', stay safe, colour black, FFP2, high-filtration respirator. Connoted as non-medical, certified EN 149:2001+A1:2009. Regulation EU 2016/425. Produced in Baoding City, China, a high-filtration respirator, bought in a DIY store. FFP2 stands. Dimensions 191 x 114 mm, Figure 7.

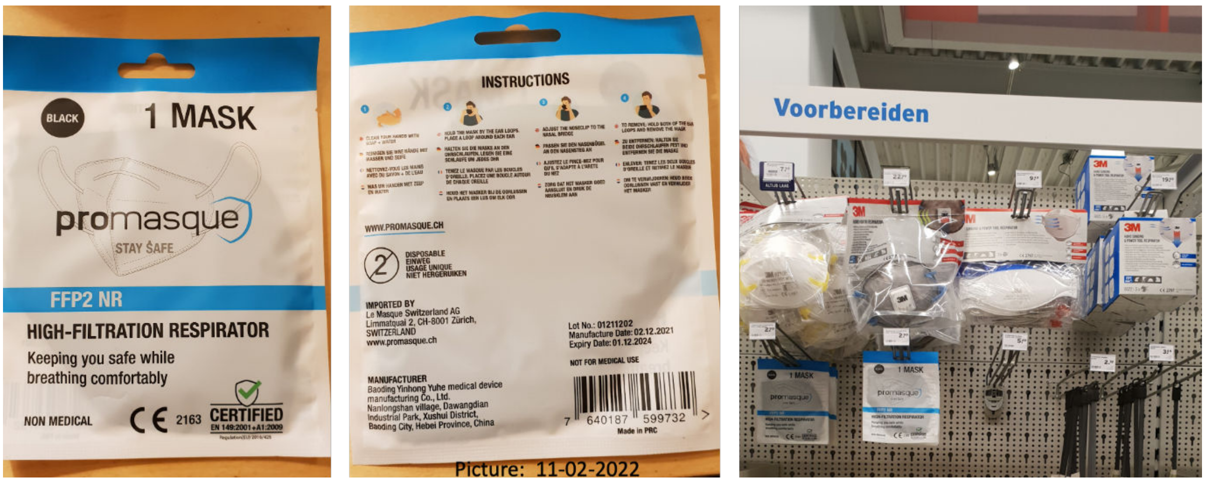


Figure 7: Sample 2, M-02 mouth-face mask 'Promasque'.

[24] *Melt blowing is a conventional fabrication method of micro- and nanofibers where a polymer melt is extruded through small nozzles surrounded by high-speed blowing gas. The randomly deposited fibres form a nonwoven sheet product applicable for filtration. This is most of the time indicated as "non-woven polypropylene (PP).*

Sample 3: Single-use mouth-face mask - M-03

Trade name *BruMed*, surgical Face masks, produced in Shenzen, China. Bought in a box of 50 pieces. Material is polypropylene (PP) non-woven (2x), and melt blown. Dimensions 178 x 98 mm. Weight 3 grams, EEC Class 1, Splash resistant, Figure 8.

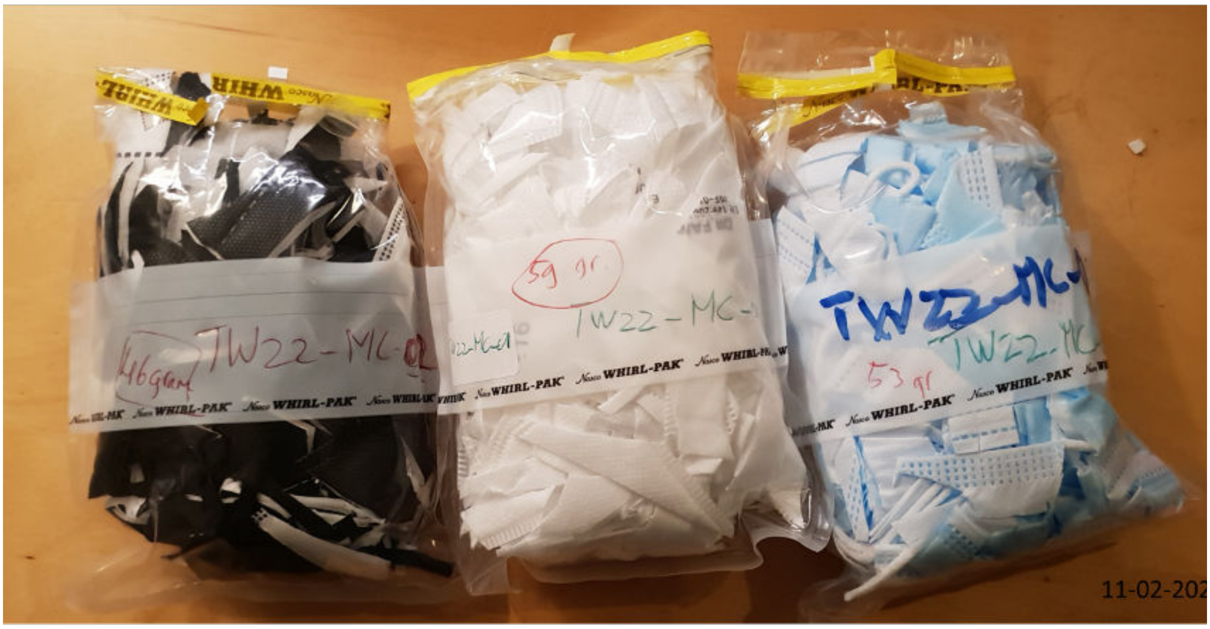
A random box of this brand is bought at a gasoline tank station. These face masks are commonly seen and sold in ordinary drugstores, and other shops in the Netherlands and are freely available for visitors of public places, healthcare as pharmacies, hospitals, dentists, and nursing homes, wearing face masks is mandatory conforming with governmental policies. The elastic straps are made of elastane a synthetic fabric made from polyurethane (PUR).

Figure 8: Sample 3, M-03 mouth-face mask "BruMed".

Sample preparation

Ten (10) masks and their straps per sample (M-01, M-02, M-03) are cut into pieces of 2-3 cm. In total 59, 46, and 53 grams of each face mask sample (n=3), were collected in HDPE bags and sent to the laboratory, Figure 9.

1. For each sample preparation in the lab three-five (3-to-5) gram sample material was used and extracted three (3)-times with 10 ml methanol. After each extraction time, the sample was centrifuged, and the methanol fractions were collected.
2. The collected sample extracts were extracted with hexane to separate the fat fraction from the PFAS fraction.
3. The methanol fraction was evaporated to 1 ml final volume and added to a WAX SPE (Weak Anion-eXchange Solid Phase Extraction) sorbent.



M-02: TW22-MC-02 | **M-01**: TW22-MC-01 | **M-03**: TW22-MC-03

Figure 9: Sample preparation of M-01, M-02, M-03 for analyses 3 type of face masks.

Analyse results of PFAS in face masks

The lab analysis of the three (3) mouth-face mask samples (M-01, M-02, M-03) with the method FITC-T4 bioassay show detectable levels of PFAS in these facemasks, Figure 10. The results are expressed as micrograms PFOA equivalence per gram product/textile, (µg PFOA eq./g product/textile). The result values of this pilot study show 7300 – 31000 ng PFOA eq./g product or as expressed in micrograms (µg): 7.3 – 31 µg PFOA eq./g product/textile. Expressed in PFAS load per square metre 331 – 1424 µg PFOA eq./m^2.

Sample 1: Single-use mouth-face mask - M-01: **8.4** µg PFOA eq./g product/textile
331.0 µg PFOA eq./m^2

Sample 2: Single-use mouth-face mask - M-02: **31.0** µg PFOA eq./g product/textile
1424.0 µg PFOA eq./m^2

Sample 3: Single-use mouth-face mask - M-03: **7.3** µg PFOA eq./g product/textile
417.0 µg PFOA eq./m^2

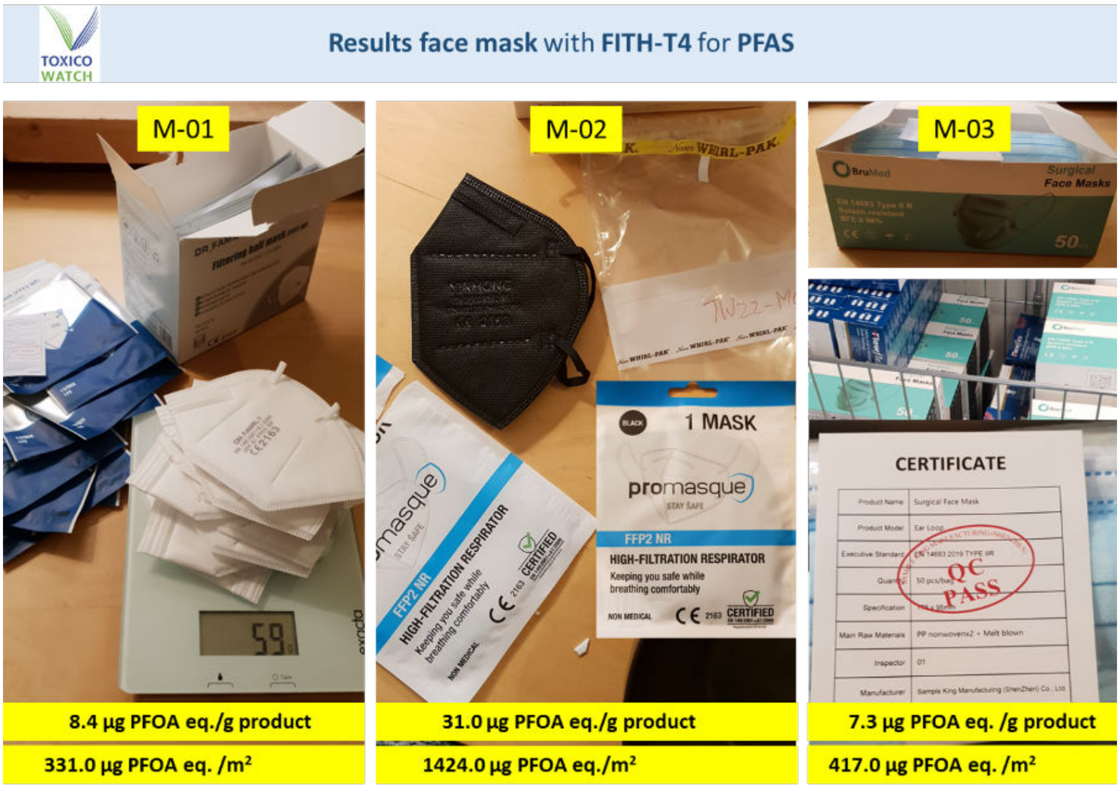


Figure 10: PFAS Results analysis FITC-T4 mouth-face masks, 2022.

In 2017 the EU set a maximum residue level of 1 µg PFOA/m^2 in textiles.[25] The PFAS in **the analysed face masks** expressed as PFOA equivalencies with the FITC-T4 analysis (µg PFOA equivalent/m^2) **exceed the EU limit with a factor of 331 - 1424.** In the next chapters, the relation to the safety limit of the Tolerable Weekly Intake (TWI) of PFAS set by the European Food Safety Authority (EFSA) will be discussed.

[25] *COMMISSION REGULATION (EU) 2017/1000, https://eur-lex.europa.eu/legal content/EN/TXT/PDF/?uri=CELEX:32017R1000&from=EN*

Regulation of chemicals

Regulation of chemicals results often in a backlash of risks, as the industry responds with substitutes often to be regrettable. The same applies to the European and global approaches to other hazardous chemicals. Bisphenol A (BPA) is restricted by several EU regulations and directives, although a long list of exemptions, like i.e., reusable plastics, medical devices, etc. The result of BPA being restricted is the rapid invention of many new alternatives by the industry. The question is: *are these new "BPA-free" alternatives less toxic for human health and the environment? A* dramatic new development can be observed in the fluorochemicals market, where the ban on PFOA and PFOS has led to an explosion of new substances, which cannot be controlled at this moment. Since laboratories can only analyse 50-100 fluorinated substances out of the 10,000. Regulation is failing utterly, partly because of the industry's reluctance to release information and partly because of the lagging development of analytical potential for PFAS. This is reflected in the scant research available on the health risks for people wearing face masks added with PFAS.

The investigative documentary film "The devil We know" painfully outlines the intertwined world between industrial/financial interests, governmental policy, and human interests.[26] Already since the 1950s research documents (from the industry) have shown the evidence of highly toxic risks of fluorinated compounds on living organisms. The industry of fluorochemicals defends the production and application of PFAS with arguments that "*not all the PFAS are the same*" and "*that one should not group them all together by the entire class*".[27] Already in 2014 the scientific community urged to ban PFAS as one class (Madrid Statement). The whole family of PFAS should not be used due to its extremely toxic risks to human and environmental health, which will last for decades if not longer because it will pass forward a huge threat to the next generations.[28]

In 2019 a 'global' ban on the production and use of perfluorooctanoic acid (PFOA) entered into force for more than 160 countries (except Japan, the U.S., Israel, China, and India). Exemptions to this 'global' ban are the application in medical textiles. No information has been provided by the EU to explain the need for this exemption. Also, the World Health Organisation (WHO) flaws established risk assessment guidelines for PFAS, disregarding the precautionary principle, and leaving people unprotected.[29] The Dutch government has together with Norway, Denmark and Sweden submitted a proposal to review the entire group of PFAS Regrettable substances by 2025. However, this proposal will only be applicable to non-essential use of PFAS, leaving the loophole open for the definition of essential use. Besides that, loophole in regulation, how will the enforcement control PFAS as laboratory tools are not equipped for analyses for the total group of > 10,000 PFAS substances?

The lack of research articles concerning chemicals and PFAS in face masks is alarming and should get more attention. Critique on the efficiency of face masks was for a long time not appreciated and social and scientific platforms used censorship of articles which did not conform with their policy guidelines. A dismissing of the article of Rancourt [30] from ResearchGate is a given example in the article of Y. Shir-Raz et al. (2022) on how censorship can work. [31] But above all the application of chemicals such as PFAS should be regulated based on the precautionary principle, to protect human health.

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[26] *The Devil We Know, 2018 investigative documentary film by director Stephanie Soechtig https://www.youtube.com/watch?v=NJFbsWX4MJM*

[27] *https://cen.acs.org/materials/coatings/PFAS-paper-food-packaging/99/i36*

[28] *Environ. Sci. Technol. Lett. 2020, 7, 532–543*

[29] *WHO (2022). https://www.ewg.org/news-insights/news/2022/10/flawed-who-report-forever-chemicals-fails-human-health-ewg-scientists*

[30] *Rancourt D.G. (2019). COVID censorship at ResearchGate: Things scientists cannot say, Ontario C.L.A.*

[31] *Shir-Raz Y. et al. (2022). Censorship and Suppression of Covid-19 Heterodoxy: Tactics and Counter-Tactics, Minerva https://doi.org/10.1007/s11024-022-09479-4*

Safety limits for PFAS advise of EFSA

In 2008, the European Food Safety Authority (EFSA) set the Tolerable Weekly Intake (TWI) for PFOA at 10500 ng /kg body weight per week, Figure 11. In 2020 the EFSA re-evaluated the health-based limit for PFAS with a Tolerable Weekly Intake (TWI) set at 4.4 nanograms (ng) per kilogram (kg) of body weight (**4,4 ng PFAS/kg bw/week**).[32] A laboratory can identify only as many as 50-100 different PFAS substances, while there are probably >10,000 PFAS substances. This EFSA limit is based on 4 substances: PFOA, perfluoronanic acid (PFNA, C9), perfluorhexane sulfonic acid (PFHxS, C6) and perfluorooctane sulfonic acid (PFOS)[33] and taken as equally toxic.[34] In a recent study by the Dutch National Institute for Public Health and the Environment (RIVM), substitutes for PFOA and PFOS[35] are found to be more toxic, highlighting the potential potency of organofluorine substances in general. In the 12 years, since the first publication of safety limits in 2008 by the EFSA, PFOA has been found to be 2000 times more harmful to human health in 2020. Taking into account that as all the substitutes for PFOA are toxic, and most of them even more toxic than the original 'parent' substances, precaution is very much needed.

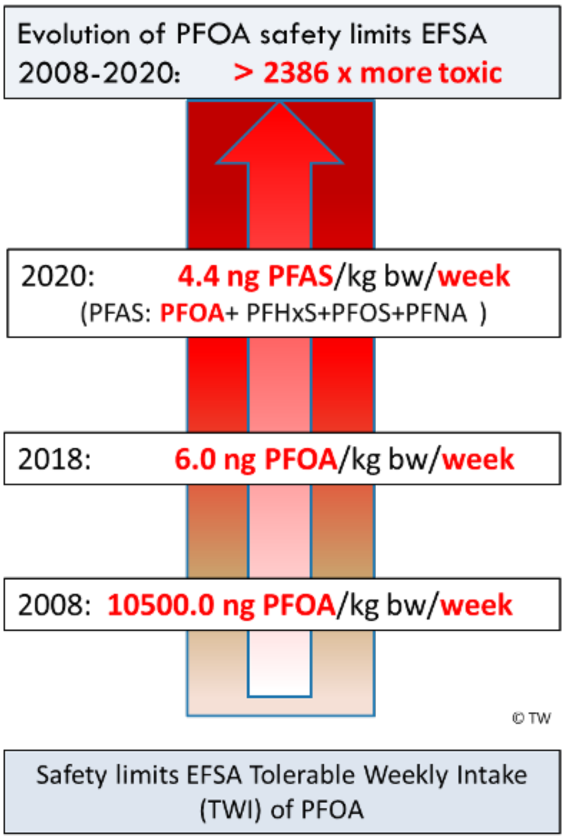

Figure 11: PFOA: In 12 years of evaluation determining the toxicity of PFOA, it is found to have been enhanced by a factor > 2000.

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[32] *EFSA, 2018. Risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food 16(12), 05194.*

[33] *Schrenk D et al. (2020). Scientific Opinion on the risk to human health related to the presence of perfluoroalkyl substances in food. EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain), EFSA Journal 2020;18(9):6223, 391 pp*

[34] *RIVM-briefrapport 2022-0010 P.E. Boon | J.D. te Biesebeek*

[35] *Bil W. et al (2022). Internal Relative Potency Factors for the Risk Assessment of Mixtures of Per- and Polyfluoroalkyl Substances (PFAS) in Human Biomonitoring, Environmental Health Perspectives, 130(7) July 2022*

The synthetical 'textile' of face masks

Disposable face masks (single-use face masks) are produced from polymers such as polypropylene, polyurethane, polyacrylonitrile, polystyrene, polycarbonate, polyethene, or polyester and consist of three - five layers; an inner layer (soft fibres), middle layer (melt-blown filter), and an outer layer (nonwoven fibres, which are water-resistant and usually coloured). The middle layer is the main filtering layer of the mask with micro- and nanofibers.

Three main categories of face masks can be distinguished:

- Filtering facepiece (FFP 2) masks protect the wearer from (aerosol) particles, promoted for protection against airborne viruses. These masks fall under the European Regulation for Personal Protective Equipment.
- Medical/surgical mouth masks for healthcare workers for the protection of themselves and patients, but also available for public use. These masks fall under the European Regulation for Medical Devices (BS-EN-14683).
- Non-medical face masks for the protection of droplets, aerosols, and dust are often made by people at home from (organic) textiles, like (dyed) cotton, or from (dyed) synthetical textiles. This category is not standardised.

FFP2 and medical face masks must meet certain requirements such as water, alcohol, oil and dirt repellence and splash resistance. Fluorinated chemicals are used for this purpose, but the exact composition or quantities are not known. It should be recommended to place it on the mark if certain textile is treated with fluorochemicals, so consumers have the possibility to choose. **Baths of 6% and 12%,** grams of fluorinated chemicals per litre are applicated. The lowest add-on level of the repellent finish is 6% of the cover fabric to obtain the repellent property. The question is: *What is the leakage potential of fluorinated chemicals out of the mask into the human body?* **As PFAS absorbed into microfibers, as particulate dust, or as volatile substances.**

Viruses may be able to penetrate or spread through the mask in the form of liquid diffusion by a capillary effect, particularly since the expired air will most likely wet the mask. The high moisture content and high temperature in the expired air can cause water vapour to condense in the mask due to the temperature difference between the outside air and the mask or the space between the mask and skin. The droplets that are expelled when speaking will accelerate the wetting process. **During repeated breathing actions**, **a mask also becomes a collector of bacteria and viruses**, particularly when its outer surface is exposed to contaminated droplets. This process is typical in porous materials such as nonwoven textile materials. As viruses and bacteria can stay on the surface and in the masks for a significantly long period during the wearing time, it is obviously dangerous and undesirable if they can live and stay active in the warm and humid microenvironment in the masks. That is a reason the protective performance of face masks is enhanced by making them become water-repellent and be able to inactivate bacteria and viruses. This can be performed by nano-functional treatment (NFT) a process to coat the fibres in the facemasks by using nanomaterials.[36,37,38]

Another worrying aspect is the application of chemicals in face masks to protect the skin against the harm of ultraviolet radiation. One of these chemicals is UV-328, which was just proposed to be banned in the Stockholm Convention, because of its toxicity.[39]

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[36] *Li et al (2006). In Vivo Protective Performance of N95 Respirator and Surgical Facemask, AMERICAN JOURNAL OF INDUSTRIAL MEDICINE 49:1056–1065 (2006)*

[37] *Jyothirmai B. and K. Vagdevi (2022). Materials Today: Proceedings 64 (2022) 835–840*

[38] *Awodele MK et al (2018). Graphene and its Health Effect Review Article. Int J Nanotechnol Nanomed, 2018, Volume 3 | Issue 2 | 2 of 5*

[39] *Doyon VC, Khosravi-Hafshejani T, Richer V. An Added Benefit of Masks During the COVID-19 Pandemic: Ultraviolet Protection. Journal of Cutaneous Medicine and Surgery. 2022;26(1):63-70. doi:10.1177/12034754211034478*

Microplastics /microfibres

"It should be noted here that there are several research gaps and a lack of thorough investigation on the fate of fibres with various treatments and finishing. Most textile products are coated with various chemicals and auxiliaries to render new functionality (e.g., water repellence, antimicrobial finishes) or dyed with various synthetic colourants including reactive dyes."
Periyasamy A.P., Tehrani-Bagha A., (2022)

The production and consumption of medical textiles have increasingly grown since the governments declared corona pandemic crisis and as a result, the mandated mouth-nose coverage by face masks. With this global commitment, the huge increase in microplastics from these face masks is a new source of environmental pollution, both during use and as waste. Microplastics originating from textiles typically have a fibre shape and are therefore often referred to as microfibres.[40] Fibre fragments are defined as polymeric fibrous materials with a regular or irregular shape with dimensions between 1 µm to 5 mm. Fibre fragments can cross the dermal barrier (skin) and cause toxicity, and health risks to humans when exposed to it. Microfibers are released into the air directly because of wearing clothes.[41] Loosening fibre fragments can be ingested and substantially threaten metabolic activities. An additional property of fibre fragments is the transportation of toxic chemicals.[42]

The mechanical structure of fibres deteriorates over time due to various factors including sunlight exposure, by wearing the textile, and washing. The exposure of fabrics to sunlight with a wide spectrum of wavelengths covering UV, visible, and IR regions can increase the heat and accelerate the oxidation of fibres and their gradual degradation. Other than that, fibres deteriorate due to mechanical stress, abrasion, and friction during wearing the textile, sweating, and exposure to gases like CO2.

There are different factors on the microfiber generation with known well-controlled melt-blown nonwoven manufacturing process variables. Nonwovens are used in medical face masks and have thinner fibres from the high airflow rate, which made them vulnerable to microfiber generation. The number of free fibres depends on the technology of bonding such as hydroentangling, thermal bonding, and needle-punching. The shedding of nonwoven medical textile is found to be 44,700 – 170,000 microfibers per gram textile with a length of 0.05 – 7.05 mm.[43] The wearing of disposable masks changes the structure, and chemical composition and decreased the mechanical strength. New face masks already release 483,888 plastic particles, and 1,566,560 particles can be released if the mask is aging.[44]

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[40] Jönsson C. et al (2018) Microplastics Shedding from Textiles—Developing Analytical Method for Measurement of Shed Material Representing Release during Domestic Washing. Sustainability 2018, 10, 2457; doi:10.3390/su10072457
[41] Environ. Sci. Technol. 2020, 54, 3288–3296
[42] Mato, Y. et al (2001). Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment. Environ. Sci. Technol. 2001, 35, 318–324
[43] Kwon et al (2021). Microfiber shedding from nonwoven materials including wipes and meltblown nonwovens in air and water environments, https://doi.org/10.1007/s11356-022-20053-z
[44] Wang Z. et (2021). Journal of Hazardous Materials 417 (2021) 126036

Face masks and chemicals

Most textile products are coated with various chemicals and auxiliaries to render new functionality (e.g., water repellence, antimicrobial finishes) or dyed with various synthetic colourants including reactive dyes. Chemicals used in face masks are besides long- and short-chain PFAS, heavy metals, formaldehyde, and Bisphenol-A and because synthetic textiles are extremely fire-prone, fire retardants, are added (figure 12).[45,46] There is an urgent need for measuring all the parameters involved in wearing synthetic veils full of toxic chemicals.

Potentially more than 8,000 chemical substances are used in the textile industry. The Swedish Chemicals Agency assessed 750 substances to be hazardous for human health, including PFOS, PFOA, PFHxS, hexabromobiphenyl (HBB), tetra- and pentabromodiphenyl ether (commercial (c)-pentaBDE), hexa- and heptabromdiphenyl ether (c-octaBDE), decaBDE, hexabromocyclododecane (HBCD), and short-chain chlorinated paraffin (SCCPs).[47,48] Fluorochemicals (fluorocarbons) provide effective repellence against both aqueous and oil-based substances. More than 90% of the overall PFAS concentrations in these textiles are fluorotelomer alcohols (4:2, 6:2; 8:2 and 10:2 FTOH). The vast majority of PFAS are therefore either non-degradable or ultimately transform into stable terminal transformation products (which are still PFAS). The fluorotelomer alcohols (FTOH) are a source of PFOA and PFOS, which are extremely resistant to environmental and metabolic degradation. A recent study by Muensterman (2022) indicates that wearing masks treated with high levels of PFAS for extended periods of time can be a notable source of exposure and have the potential to pose a health risk. [49]

Figure 12: Flame retardants in textile fabrics, https://greensciencepolicy.org/harmful-chemicals/flame-retardants/

The paradigm in managing the corona epidemic and other pandemics is focused single-mindedly on virology, toxicology is put aside. However, in- and outdoor environments contain a myriad of toxic stressors attacking and degrading the immune system. A more holistic approach which embraces the toxicology perspective, alongside the virological perspective would be more effective in managing the consequences of a pandemic. The topic of this report is the face mask, mandated during the Corona pandemic. Starting with a shortage in supply, the industry has met the worldwide demand with enormous production of single-use face masks and with that, contributing on large scale to toxic plastic pollution.

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[45] Periyasamy A.P., Tehrani-Bagha A., (2022) A review on microplastic emission from textile materials and its reduction techniques, Polymer Degradation and Stability 199 (2022) 109901
[46] Poulsen et al (2021). Survey and risk assessment of chemicals in textile face masks, Danish EPA
[47] A Review of PFAS as a Chemical Class in the Textile Sector, Natural Resources Defense Council (NRDC)
[48] POPs Review Committee of the Stockholm Convention, United Nations Environment Programme. Risk profiles, accessed December 4, 2020, on c-pentaBDE (UNEP/POPS/POPRC.2/17/Add.1), HBB (UNEP/POPS/POPRC.2/17/Add.3), PFOS (UNEP/POPS/ POPRC.2/17/Add.5), c-octaBDE (UNEP/POPS/POPRC.3/20/Add.6), HBCDD (UNEP/POPS/POPRC.6/13/Add.2), decaBDE (UNEP/ POPS/POPRC.10/10/Add.2), SCCPs (UNEP/POPS/POPRC.11/10/Add.2), PFOA (UNEP/POPS/POPRC.12/11/Add.2), PFHxS (UNEP/ POPS/POPRC.14/6/Add.1), http://chm.pops.int/tabid/243
[49] Muensterman et al. (2022) Per- and Polyfluoroalkyl Substances (PFAS) in Facemasks: Potential Source of Human Exposure to PFAS with Implications for Disposal to Landfills. Environ. Sci. Technol. Lett. 2022, 9, 4, 320–326

Other chemicals

There is a necessity for assessing a mixture risk assessment (MRA) and managing for the types and levels of additives in face masks. Substances that are commonly found in medical devices are phthalates and Bisphenol A (BPA). These substances have been the subject of intense political debate in recent years due to their widespread use in consumer products and the risks they pose to human health and the environment.

Phthalates

Phthalates are used as plasticisers to soften polyvinyl chloride (PVC) and are applied in an enormous variety of consumer products, such as cosmetics, food packages, medicinal products, toys, footwear, textiles, etc. The presence of hazardous compounds as phthalic acid esters in face masks poses a serious human health concern. Several phthalates have endocrine-disrupting properties and are classified in the European Union as reproductive toxicants, category 1B ("May damage fertility and/or the unborn child"). They are identified as Substances of Very High Concern (SVHC) (ECHA, 2022).

It has been shown in animal studies that beyond the group of phthalates, other anti-androgenic substances also disrupt male reproductive tract development in a dose-additive manner, and thus contribute to the cumulative human health risk. The actual risk to reproductive health from a mixed exposure to anti-androgenic chemicals is higher than from similar chemical classes. In a study by Xie (2020) phthalates from face masks were investigated as a novel source of phthalate exposure.[50] Estimated daily intakes (EDIs) of phthalates from face masks were calculated with a median value of 33.9 ng/kg-bw/day. The EDIs of the phthalates from masks for toddlers were approximately 4–5 times higher than those for adults. The phthalates are usually applied as additives and they are not chemically bonded to the materials, therefore they can be easily released into the environment and enter the human body, through dermal absorption, as well as ingestion and further exert a series of adverse effects.

Animal studies have revealed that phthalate exposure was reported to affect fetal growth and had reproductive toxicity. Butyl benzyl phthalate (BBP) and diisononyl phthalate (DINP) were proved to affect testosterone and semen parameters. Bis(2-ethylhexyl) phthalate (DEHP) was found to be associated with penile birth defects and other effects related to androgen disruption.

In research by Lange (2022) about 63% of the risk from combined phthalate exposure would have gone unnoticed in a single substance evaluation. This demonstrates the urgent need to incorporate a mixture of risk assessments into current regulatory practice on a regular basis.[51] There is still information lacking regarding the emerging alternative plasticizer 1,2-cyclohexanedioic acid diisononyl ester (DINCH) and its potential effects on the immune system. It is suspected to have adverse effects on humans by affecting macrophages in the human body by inducing cellular stress and might accelerate inflammation-related diseases.

All by all, one can observe an under-reported role of toxic substances exposures in the COVID-19 pandemic in. general, but specific in the mandating of possibly toxic face masks. [52]

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[50] *Xie H. et al (2020). Face mask—A potential source of phthalate exposure for human, J. of Haz Materials 422 (2022) 126848*
[51] *Lange R., et al. (2022). Cumulative risk assessment of five phthalates in European children and adolescents. International Journal of Hygiene and Environmental Health*
[52] *Kostoff RN, et al (2020). The under-reported role of toxic substance exposures in the COVID-19 pandemic. Food Chem Toxicol. 2020 Nov; 145:111687. doi: 10.1016/j.fct.2020.111687*

Bisphenol A (BPA)

In 2017, the European Chemical Agency (ECHA) added Bisphenol A (BPA) to the Candidate List of Substances of Very High Concern (SVHC). Based on research that early exposure to BPA is associated with an increased risk of altered cognitive function i.e. learning, memory) and behaviour (i.e. hyperactivity), metabolic disorders and risk of cancer development in later life. Restrictions on the use of BPA in consumer goods have led to the replacement of numerous BPA analogues.[53] More than 200 BPAs have been identified, still under investigation but it is becoming clear that the substitute/alternative of BPA carries greater risks than the parent component of Bisphenol A.[54]

Bisphenol A (BPA) is widely applicated in clothes and is also found in the surgical face mask.[55] In general, laundry cannot remove BPA efficiently but cause cross-contamination in clothes. Children with a higher ratio of body skin area to body weight might face greater exposure risk, especially for BPA released from sweaty clothes. Human exposure to BPA via dermal contact with clothes is an important uptake, especially in the sweating scenes. An estimated dermal exposure dose of 52.1 ng/kg bw/d was obtained for BPA exposure in children from the highly polluted sweaty clothes (with BPA concentration of 199 ng/g). This is a high exposure risk for the human body, and the contribution of the dermal exposure dose of BPA cannot be neglected.[56]

BPA is for the industry one of the most thoroughly tested chemicals in use today and has a safety track record of more than 50 years.[57] In science is BPA associated with many health damage effects in humans, including reproductive effects (erectile dysfunction, miscarriage), cardiovascular diseases, thyroid, immune and metabolic diseases (diabetes), childhood obesity as well as general/abdominal obesity and hypertension, neurodevelopment impairments, respiratory conditions and behaviour alterations (anxiousness, hyperactivity, depression). BPA has recently also been suggested to be an emerging threat to male infertility. Particularly worrying is the fact that exposure to phthalates and Bisphenol A can lead to cumulative adverse effects on future generations such as neural and immune disorders, infertility, and late-onset complex diseases (cancers and diabetes).

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[53] *bisphenol AF, bisphenol AP, bisphenol B, bisphenol BP, bisphenol C (BPC), bisphenol E, bisphenol F (BPF), bisphenol G, bisphenol M (BPM), bisphenol P, bisphenol PH, bisphenol S (BPS), bisphenol TMC, and bisphenol Z*

[54] *Lucarini et al. (2020), Exposure to New Emerging Bisphenols Among Young Children in Switzerland. International Journal of Environmental Research and Public Health 17(13):4793*

[55] *Poulsen et al (2021). Survey and risk assessment of chemicals in textile face masks, Danish EPA*

[56] *Wang L. et al (2019). Widespread Occurrence of Bisphenol A in Daily Clothes and Its High Exposure Risk in Humans, Environmental Science & Technology 2019 53 (12), 7095-7102*

[57] *https://www.americanchemistry.com/chemistry-in-america/chemistries/bisphenol-a Exposures*

Bacterial contamination of face masks

During the current COVID-19 pandemic, the use of face masks has become increasingly recommended and even made mandatory by governmental health policies in community settings. Improper use of face masks can lead to a higher risk of infection and the spreading of viral and bacterial pathogens. Bacteria, and specifically pathobionts, accumulate on both surgical and more so on cotton face masks after 4 hours of wearing. The accumulation of pathobionts on the masks due to human saliva and exhaled breath represents a possible underestimated biosafety concern. Most colonies were identified as Bacillus or Staphylococcus species. Among the Bacillus species, *Bacillus thuringiensis* and *Bacillus cereus* were most represented. Among the *Staphylococcus species*, mostly detected are *Staphylococcus epidermidis*, as well as *Staphylococcus aureus*, *Staphylococcus warneri*, and *Staphylococcus caprae*, which are known species of healthy human skin and nasal microbiome.

Of the isolated colonies, almost half of these have full antimicrobial resistance. "*The accumulation of antibiotic-resistant strains on the face masks as antibiotic-resistant strains are a worldwide problem, and it is believed that by 2050 more people will die from an antibiotic-resistant bacterial infection than from cancer*." As referred by the WHO.[58]

The skin microbiome profiles are somewhat more influenced by mask-wearing than the nasal microbiome profiles. Microorganisms present on the skin and in the upper respiratory tract could be transferred to the face mask while wearing it. For optimal growth, bacterial cells need a surface to grow on, warmth, moisture, and nutrients, which is the environment created on the face mask due to exhaled air and water vapor. Growth of these microorganisms will also increase the number of bacteria that are inhaled or could be transferred to the skin. The disturbance in the skin and nasal microbiome due to for instance the overgrowth of certain pathobionts, which are associated with an increased risk of inflammation and infections. In In several studies, the use of face masks has been associated with acne linked to an accumulation of *Staphylococcus aureus.*

"*Face masks should be better evaluated to weigh the risks of disease transmission rate against other biosafety risks such as bacterial overgrowth, especially in vulnerable populations*" according to Delanghe. [59] This would be especially the case for i.e., for people in elderly nursing homes.

Fomites consist of both porous and nonporous surfaces or objects that can become contaminated with pathogenic microorganisms and serve as vehicles in transmission. Face masks, the inner and outside layers can serve as a fomite, a carrier of virus and bacteria load if proper handling is not applied. Shortcomings of protecting face shields push the industry into finding other means of controlling viruses and bacteria. This involves also techniques with downsides, as hardly regulated nanoparticles and toxic for-ever chemicals as PFAS.

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[58] *World Health Organization. Antimicrobial Resistance: Global Report on Surveillance. Geneva: World Health Organization (2014)*

[59] *Delanghe L, Cauwenberghs E, Spacova I, De Boeck I, Van Beeck W, Pepermans K, Claes I, Vandenheuvel D, Verhoeven V and Lebeer S (2021) Cotton and Surgical Face Masks in Community Settings: Bacterial Contamination and Face Mask Hygiene. Front. Med. 8:732047*.

Nanoparticles (NP) - Graphene

The protective performance of face masks is enhanced by making them capable to inactivate bacteria and viruses with **nano-functional treatment (NFT)**. A process to coat fibres in the facemasks with nanomaterials.[60,61,62] Face masks with anti-micro biotic treatment have also appeared on the market. This can be achieved in different ways. One such method is the application of nanoparticles. Nanoparticles (NP) or nanomaterials are defined as materials that usually have sizes ranging from several to hundreds of nanometres and are 1-10 nm thick.

Under this definition falls **graphene-family nanomaterials (GFNs),** Graphene and its derivatives include monolayer graphene, few-layer graphene (FLG), graphene oxide (GO), reduced graphene oxide (rGO), graphene nanosheets (GNS), and graphene nanoribbons. Due to their exceptional physical and chemical properties, graphene materials have been widely used in various fields, including energy storage; nano electronic devices; batteries; and biomedical applications, such as antibacterial, biosensors, cell imaging, drug delivery, and tissue engineering.

Also, silver nanoparticles (AgNPs) have the potential to deactivate microorganisms. However, Ag-loaded fabrics generally wear off with time due to the detachment of active Ag from the material or often result in agglomeration of the NPs.

Metallic Cu, copper nanoparticles (CuNPs), copper (II) oxide (CuO), copper(I) oxide (Cu2O), and copper iodide (CuI) are found to be effective in inactivating several types of viruses. Apart from metal and metal oxides or their combinations, tungsten oxide, magnesium peroxide, and Zinc oxide (ZnO) are also antimicrobial and used on face masks, filters, gloves, and other medical appliances. However, the stability and effectiveness of these compounds need to be evaluated to establish their practical utility.

Nanoparticles present possible dangers, both medically and environmentally. Most of these are due to the high surface-to-volume ratio, which can make the particles **very reactive or catalytic**. They are also thought to aggregate on phospholipid bilayers and pass-through cell membranes in organisms, and their interactions with biological systems are relatively unknown. Sales of antimicrobial masks, without adequate quality control, in online and offline shopping platforms is a cause of concern. Extensive research is needed to develop a robust protocol and validating standards about the use of antimicrobial agents, antimicrobial loading, and testing the antibacterial and antiviral activity of antimicrobial face mask. The performance of antimicrobial face masks should be evaluated for both antibacterial and antiviral activities, to establish the claim of “antimicrobial face mask” on more substantial grounds for developing a protective face mask. There should be a thorough evaluation of the biotoxicity and ecotoxicity associated with the antimicrobial agents and the antimicrobial face masks. The risk of unknown toxicity calls for proper assessment of, skin compatibility, and stability of the antimicrobial coatings. [63]

[60] *Li et al (2006). In Vivo Protective Performance of N95 Respirator and Surgical Facemask, AMERICAN JOURNAL OF INDUSTRIAL MEDICINE 49:1056–1065 (2006)*

[61] *B. Jyothirmai and K. Vagdevi (2022). Materials Today: Proceedings 64 (2022) 835–840*

[62] *Awodele MK et al (2018). Graphene and its Health Effect Review Article. Int J Nanotechnol Nanomed, 2018, Volume 3 | Issue 2 | 2 of 5*

[63] *Pullangott G. et al. (2021). A comprehensive review on antimicrobial face masks: an emerging weapon in fighting pandemics RSC Adv., 2021, 11, 6544*

Natural antimicrobial agents

Face masks with a natural antimicrobial treatment have also appeared on the market. A few examples:

Several antimicrobial compounds extracted from medicinal plants are found to be effective against bacteria and viruses. Unlike chemical polymeric or nano-based materials, the natural compounds do not produce toxic effects. Extracts of diverse vegetation (*Punica granatum*, *Allium sativum*, *Strobilanthes cusia*, *Aloe barbadensis*) have antimicrobial properties. Also, the combination of eugenol, eugenol acetate, carvacrol, thymol, and vanillin, *Melaleuca alternifolia*, *ginkgo biloba* leaf extract, and *ginkgo biloba* extract in combination with *Sumac* (*Anacardiaceae* family) have been studied for their antiviral properties. These compounds are found to be potential agents that could be applied to face masks, air-filters with plastic and nonwoven polymer fabrics. Antimicrobial studies with mangosteen show significant reductions in *Staphylococcus aureus* and *Mycobacterium tuberculosis*.[64]

In another study, the oil of a Vietnamese medicinal plant, Folium *Plectranthii amboinicii*, and sustainable filter paper were used to develop a seven-layer antimicrobial face mask. Also, the wearing of the mask resulted in clearer nasal passageways, fewer throat symptoms, and fewer respiratory symptoms. The antibacterial effect of *Plectranthii amboinicii* is accounted due to terpinen-4-ol and carvacrol, which inhibits bacterial proliferation. [65]

[64] *P. Ekabutr, P. Chuysinuan, S. Suksamrarn, W. Sukhumsirichart, P. Hongmanee and P. Supaphol, Development of antituberculosis melt-blown polypropylene filters coated with mangosteen extracts for medical face mask applications, Polym. Bull., 2019, 76, 1985–2004.*

[65] *Pullangott G. et al. (2021). A comprehensive review on antimicrobial face masks: an emerging weapon in fighting pandemics RSC Adv., 2021, 11, 6544*

Migration of PFAS

The use of medical textiles undergoes reduced repellence during their lifetime.

- Evaporation of volatile PFAS as a residual from the fabric.
- Loss of particles and fibre fragments containing fluorinated polymers by physical abrasion, the process of wearing down.
- Breaking of the carbon-oxygen bond of the fluorinated side chain.

Toxic chemicals, like PFAS, can be released from products to dust by physical abrasion or potentially gradually break down over time, releasing fluorinated side chains. Generally, waterproof breathable fabrics have a water-repellent (hydrophobic) finish, such as fluoropolymers, fluorochemicals, silicones and waxes applied to the outer layer. It is important that this finish does not adversely affect breathability or any other desirable properties of the fabric, such as handle and comfort.

Migration of PFAS from the textile into the air happens to find its way by aerosols, or as particulate dust depending on the physical properties of the substances. Semi-volatile organic compounds (SVOCs) will tend to partition between the vapour phase and suspended particulate, dust, depending on the part of their octanol/air partition coefficients. Some PFAS such as Fluorotelomer alcohols (FTOH) and Perfluorooctane sulfonamido ethanol (FOSE) are relatively volatile and are found in the vapour phase. PFOA and PFOS are found at high concentrations in the dust. FTOH have been detected in textiles and are sufficiently volatile to contribute to total human exposure to PFAS, as they may become part of the migrating dust or degrade to PFAS in human fluids (blood, lymph), mucosa (nose, inhalation pathway) or in human tissue by the dermal uptake (skin).

For textile finishing the most used impregnating agents are fluorotelomers with an alcohol functional group (FTOH). Values of these impregnating agents are as high as 50,000 µg/L. Products are sold under brand names such as Scotchguard®, Teflon® fabric protector, Nanotex® and Unidyne®. The impregnates are applied to the fabric as a thin layer using a spray which forms a thin polymer structure of both polyfluoro-alkylated and non-fluoro side chains on the surface. Median concentrations FTOH are about 700 mg/kg. Kotthoff (2015) stressed the importance of screening and monitoring of consumer products for PFAS loads and the necessity to regulate the use of PFAS. [66]

PFAS in textiles and other coated fabrics can be released during cleaning/washing and by wearing the textile fabric. To have an idea of degradation potential: PFAS in carpets degrades by 95% at the end of the life cycle. Calculations by the industry in the Netherlands, show that of the 10 tonnes of fluorinated organic polymers applied, 9.5 tonnes of PFAS will be released into the environment, due to the wear of carpet protection polymers.[67] Treatment of products with PFAS results in increased durability, leading to longer service life compared to similar non-treated products. This will likely prolong the emission of PFAS by indoor dust in households and possible human and environmental exposure. When such products are finally disposed of, waste landfills and waste incinerators will have to deal with compounds of enhanced chemical stability (classified as 'forever-chemicals') which will lead to harmful toxic emissions to water, soil, and air and with that PFAS contamination of the environment.

[66] *Kotthoff, M., Müller, J., Jürling, H. et al. Perfluoroalkyl and polyfluoroalkyl substances in consumer products. Environ Sci Pollut Res* ***22****, 14546–14559 (2015).*

[67] *Hekster F.M. Perfluoroalkylated substances, Aquatic environmental assessment Report RIKZ/2002.043, University of Amsterdam*

Multiple pathways of human exposure to PFAS

The multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFAS) can and will all contribute to the migration of toxic PFAS into the human body, where it persists, bioaccumulates and accelerates its toxic properties.

Mouth - Oral uptake

The ubiquitous presence of PFOA in indoor environments and exposure to humans is of concern, due to the long half-time duration in humans. Several endocrine-related effects have been shown following exposure to dust-associated PFOA, and important target tissues are the mammary gland, thyroid, and adipose tissue.[68] Non-dietary ingestion of microplastics or microfibres contaminated with PFAS substances dissolved in mucus coming from the mouth or from the nasal cavity has been shown to be an important exposure. PFOA is readily bioavailable and has a rapid systemic distribution following inhalation or oral exposure to house dust coated with PFOA. Dust particles with a smaller size fraction have a higher PFAS load. The exposure to PFAS from dust via ingestion is far more extensive than via inhalation. [69] No publications could be found on the migration of PFAS-contaminated microfibers from face masks into the gastrointestinal tract, Figure 13.

The exposure of consumers to non-volatile PFAS present in textiles occur via ingestion of particles. Despite the ban on the use of PFOS and PFOA, these substances are still found at high levels through the phenomenon of biodegradation of precursors to PFOS and PFOA.[70] The absorption of PFOA following oral exposure in animal studies showed that virtually all of it was absorbed over the gastrointestinal tract.

Figure 13: PFAS oral uptake and the ingestion pathway.

The major route of exposure to PFAS in humans comes from the ingestion of contaminated food and drinking water. Researchers collected residential indoor and personal air, house dust (i.e., floor dust, elevated surface dust at higher than 0.5 m above the floor, and vacuum cleaner bag dust), as well biological samples (serum, plasma, whole blood). Based on these results, the uptake of 13 different PFAS was modelled. Detailed information about dietary habits, a variety of personal characteristics and personal behaviors, and house characteristics of the participant were collected through questionnaires, as well as a food diary.[71]

The study indicates, PFAS levels are high in most people. In particular, the observation that the average intake of PFAS is still below the TWI already appears to be invalidated by the TWI re-set by the EFSA In 2020. However, the TWI in 2020 has already been superseded by recent studies on the relative potency of PFOA substitutes (GEN-X), which are found to be much more toxic than the parent component of PFOA (Bil et al, 2022).

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[68] DeWitt, Jamie. (2015). Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances. 10.1007/978-3-319-15518-0.
[69] Gustafsson Å. et al. (2021) Bioavailability of inhaled or ingested PFOA adsorbed to house dust, Environmental Science and Pollution Research https://doi.org/10.1007/s11356-022-20829-3
[70] Eriksson, U., Kärrman, A., 2015. World-wide indoor exposure to polyfluoroalkyl phos- phate esters (PAPs) and other PFASs in household dust. Environ. Sci. Technol. 49 (24), 14503–14511.
[71] Poothong, S., Papadopoulou, E., Padilla-Śanchez, J.A., Thomsen, C., Haug, L.S., 2020. Multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFASs): from external exposure to human blood. Environ. Int. 134, 105244

Pulmonary uptake

Perfluoroalkylated substances (PFAS), such as PFOS and PFOA, are well absorbed orally but poorly eliminated. Particulate matter (PM) is an air pollutant and is associated with respiratory diseases such as asthma, chronic obstructive pulmonary disease, and even cancer. PM is classified as coarse (PM_{10}), fine ($PM_{2.5}$) and very fine ($PM_{1.0}$). Dust particles are associated with PFAS. The highest PFAS content is found in the smallest particles, $PM_{2.5}$ and $PM_{1.0}$. [72] Surgical face masks are not able to filter $PM_{2.5}$ and $PM_{1.0}$, while the N95 (FFP2) masks filter these particles with an efficiency of 50-70%, but breathability is decreased.

Multiple- Path Particle Dosimetry (MPPD) Model can be used for quantifying PM deposition in relation to body orientation, breathing scenario, tidal volume, pause fraction, inspiration fraction, and breathing frequency are specified in the MPPD for quantifying PM depositions.[73] However, no studies are found to have detailed information about the leakage of dust particles from face masks, Figure 14.

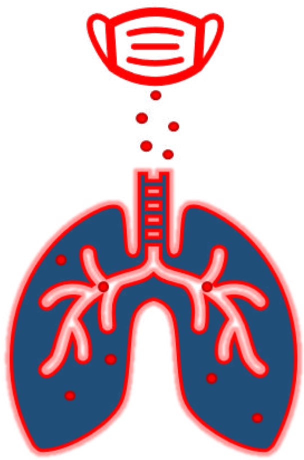

Figure 14: PFAS in lungs (pulmonary uptake) by inhalation.

Size-segregated PM (PM_{10}, $PM_{2.5}$, and $PM_{1.0}$) deposition in human lungs, fine particles ($PM_{2.5}$ and $PM_{1.0}$) are highly deposited in the pulmonary regions. These fractions will not be filtered by surgical face masks and will have a contribution to the PFAS load inhaled. Inhalation of dust resulted in an exposure to PFOA between 0.2 pg/kg bw and 1.9 pg/kg bw per day in children for the median, which is the worst exposure intake respectively. The bioavailability from oral exposure is 93% and for inhalation of the dust, a bioavailability factor of 75% is modelled.[74] As PFOS and PFOA have low volatility, the exposure through the air is mainly due to the inhalation of volatile PFOS and PFOA precursors such as fluorotelomers phosphate monoester (8:2 monoPAP) and 8:2 fluorotelomer phosphate diester (8:2 diPAP), which formulas are frequently applicated in medical textiles.[75]

[72] *Gustafsson Å. et al. Estimated daily intake of per- and polyfluoroalkyl substances related to different particle size fractions of house dust. Chemosphere 303 (2022) 135061*
[73] *N. Manojkumar et al., Ecotoxicology and Environmental Safety 168 (2019) 241–248*
[74] *DeWitt, Jamie. (2015). Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances. 10.1007/978-3-319-15518-0.*
[75] *Lassen C. et al (2015). Polyfluoroalkyl substances (PFASs) in textiles for children, The Danish Environmental Protection Agency*

There are studies of the intake of dust without face masks mentioning conclusions already worrying. Surgical face masks cannot filter dust particles, so these will enter the lungs. But more worrying is the fact that the 'lazy' melt form of the inner layer of the face masks releases of microparticles. The shedding of nonwoven medical textile is found to be 44,700 – 170,000 microfibers per gram textile with a length of 0.05 – 7.05 mm.[76] The physicochemical features of disposable masks change under UV weathering by the transformation of chain structure and chemical composition and decreased mechanical strength. Around 483,888 plastic particles can be released from one virgin disposable face mask, and 1,566,560 particles from a weathered mask.[77]

Dust particles are associated with PFAS. So hypothetically the intake of PFAS entering the human body will be increased by dust intake by wearing a face mask. A surgical face mask does not filter the fine and very fine particles of $PM_{2.5}$ and $PM_{1.0}$. Another intake of PFAS takes place with volatile PFAS. More than 90% of the overall PFAS concentrations in medical textiles are fluorotelomer alcohols (4:2, 6:2; 8:2 and 10:2 FTOH). These volatile PFAS, applicated as substitutes for PFOA, will degrade to persistent PFOA when it comes into the body.

As PFOS and PFOA have low volatility, the exposure through the air is mainly due to the inhalation of volatile PFOS and PFOA precursors such as fluorotelomers, which formulas are frequently applied in medical textiles. [78] Wang (2021) demonstrates that early life exposure of mice to a PFAS blunts airway antigen bioactivity to modulate pulmonary inflammatory responses, which may adversely affect early pulmonary health.[79] A fact showing that early/previous exposure can cause health effects later in time due to the persistent feature of these fluorinated chemicals.

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[76] *Kwon et al (2021). Microfiber shedding from nonwoven materials including wipes and meltblown nonwovens in air and water environments, https://doi.org/10.1007/s11356-022-20053-z*
[77] *Wang Z. et (2021). Journal of Hazardous Materials 417 (2021) 126036*
[78] *Lassen C. et al (2015). Polyfluoroalkyl substances (PFASs) in textiles for children, The Danish Environmental Protection Agency*
[79] *Wang M, et al (2021). Inactivation of common airborne antigens by perfluoroalkyl chemicals modulates early life allergic asthma. Proc Natl Acad Sci U S A. 2021 Jun 15;118(24): e2011957118.*

Skin - Dermal uptake

PFAS have been identified in a wide range of products, such as cosmetics and fabrics, Figure 15. Waterproof, sweatproof, and long-wearing cosmetics are found to have PFAS, which will penetrate the body and stay for a long time because of their persistency and bioaccumulation properties. An important step in PFAS regulation is the "No PFAS in Cosmetics Act" in California.[80] Also structurally related brominated and chlorinated chemicals are dermally bioavailable and can result in significant contributions to the body burdens of these hazardous chemicals. Dermal uptake experiments are urgently required to address this crucial research gap. [81]

Understanding of dermal absorption of PFAS remains incomplete and experimental data is scarce. As knowledge and understanding of the health impact of PFAS increases, it is important to fill the knowledge gaps that exist regarding this pathway to a total understanding of human exposure to PFAS. Experiments with the use of 3D-Human Skin Equivalent (3D-HSE) models are promising helpful tools to overcome the ethical issues of the use of laboratory animals in toxicological studies.[82] These studies mimic real-life exposure scenarios with sweat/sebum mixtures that mimic skin fluids, to test dermal uptake from PFAS-containing materials.

Figure 15: PFAS dermal uptake by, contaminated textile on skin.

The question in this research is how much PFAS can be released while wearing a face mask, which is difficult to be answered. Comparative studies with other halogenated studies because fluorinated substances like PFAS have very specific properties, but typically there are applications of PFAS to obtain high efficiency of trans-membrane transport, even in formulations of liposomes.

The penetration of PFOA through the human skin epidermis after 24 hours of exposure was found to be 48% and 69% for the epidermis and full-thickness skin samples respectively. Varying the pH, which is obviously the case in sweat, PFOA uptake is elevated dramatically.[83] Human exposure occurs by contacting the materials with artificial saliva and simulated sweat aqueous solutions. In migration tests to artificial saliva, the $\sum_{31}$PFAS determined in the artificial saliva migration tests ranged between 0.50 and 7.8 ng per gram. Short-chain PFCAs desorb more than long-chain PFCAs from the fabric into the artificial saliva, because short-chain PFASs are more water-soluble. The ∑31PFAS in the artificial sweat migration tests ranged from 0.04 to 100 ng g^{-1} and is measured in time cycles of 30 minutes.

Research showed that migration of PFAS from textiles could be a significant direct and indirect source of PFOS and PFOA exposure for both humans and the environment.[84] Indirect sources are there where fluorinated compounds, like fluorotelomer alcohols (FTOHs) are being degraded to PFOA and PFOS.[85]

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[80] *https://www.collins.senate.gov/imo/media/doc/No%20PFAS%20in%20Cosmetics%20Act_0.pdf*

[81] *Whitehead H.D. et al. (2021). Fluorinated Compounds in North American Cosmetics. Environ. Sci. Technol. Lett. 2021, 8, 538−544*

[82] *O. Ragnarsdo´ttir et al. Dermal uptake: An important pathway of human exposure to perfluoroalkyl substances? Environmental Pollution 307 (2022) 119478*

[83] *Franko, J., et al (2012). Dermal penetration potential of perfluorooctanoic acid (PFOA) in human and mouse skin. J. Toxicol. Environ. Health, Part A 75, 50–62*

[84] *Supreeyasunthorn P. et al (2016). Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) contamination from textiles, JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH, PART A 2016, VOL. 0, NO. 0, 1–6*

[85] *Veen, Van der I., et al (2020). The effect of weathering on per- and polyfluoroalkyl substances (PFASs) from durable water repellent (DWR) clothing. Chemosphere 249, 126100.*

Recently, while there have been alarming reports of PFAS in clothing, and school uniforms and leaking from children's car seats, there have been no publications of leaking chemicals such as PFAS and brominated flame retardants from these synthetic non-woven plastic textile masks worn directly on the skin.

The exposure of consumers to non-volatile PFASs present in textiles occurs via ingestion and dermal absorption. Although there is potential for absorption of this chemical into, and penetration through the skin, this exposure route has not been thoroughly investigated and has long been underestimated.[86] Recent studies show dermal absorption of non-volatile PFAS is of significant order even more than with ingestion. [87,88] PFOA has an estimated hydrolytic half-life of more than 97 years. In humans, PFOA has a half-life of approximately 4.5 years.[89]

Recent studies highlight the use of PFAS in various consumer products that come in prolonged contact with human skin. This includes anything from cosmetics to water-repellent clothing.[90] However, the extent of dermal absorption upon skin contact with face masks and its significance as a pathway of human exposure to PFAS is currently unknown. The limited understanding of the dermal exposure route may constitute a serious knowledge gap, especially considering the use of PFAS at relatively high concentrations in face masks contacting human skin for prolonged periods.

What is the influence of PFAS-containing cosmetics, which will be stressed by using a face mask? Coloured lipsticks, mascaras, and foundations advertised as "long-lasting" or "wear-resistant" had particularly high PFAS levels. One of PFAS is fluorotelomer alcohols, which can break down in our bodies into the compounds PFOA and PFOS, compounds that are prohibited from being produced in the European Union and the U.S. because of long-known health risks. Which does not mean that it will not be a commercial product on the EU market. Dermal uptake of PFAS via face mask is evident. The amount of PFAS can be through multiple use, and continuous repetitions are greater than even oral ingestion of PFAS-associated dust.

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[86] *D. Trudel et al., Estimating consumer exposure to PFOS and PFOA. Risk Anal. 28, 251–269 (2008).*
[87] *CEC. 2017. Furthering the Understanding of the Migration of Chemicals from Consumer Products – A Study of Per- and Polyfluoroalkyl Substances (PFASs) in Clothing, Apparel, and Children's Items. Montreal, Canada: Commission for Environmental Cooperation. 201 pp.*
[88] *Franko, J., et al. (2012). Dermal penetration potential of perfluorooctanoic acid (PFOA) in human and mouse skin. J. Toxicol. Environ. Health, Part A 75, 50–62. https://doi.org/10.1080/ 15287394.2011.615108*
[89] *DeWitt, Jamie. (2015). Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances. 10.1007/978-3-319-15518-0.*
[90] *Glüge et al., 2020; An overview of the uses of per- and polyfluoroalkyl substances (PFAS), Environ. Sci.: Processes Impacts*

Nose – Intranasal, inhalation and mucosal uptake

Another pathway of xenobiotics, like PFAS, into the human body, is the nasal pathway, Figure 16. There is a great interest in pharmaceutical research in the intranasal pathway for drug delivery. Fluorinated glucocorticoids are being applicated intranasal.[91] AstraZeneca has tried to make needle-free vaccines with the intranasal application, but trials failed, and the research has stopped.[92]

The mucus layer and cell membrane inside the nose are two major barriers against drug delivery. In a study with mice intranasally treated with PFOS and challenged with a dose of *P. aeruginosa*, a reduction of the numbers of eosinophils, neutrophils, and lymphocytes was observed.[93] Interesting is the fluorination augment for its significant ability of nanoparticles (cylindrical polymer brushes, CPBs) crossing the blood-brain-barrier (BBB). Fluorination of polypeptides shows a promising potential for integrating fluorinated compounds for transmembrane transport.[94] The mucosa, or mucous membrane, is a tissue that delineates the nasal cavity, and most drugs are cleared by the mucociliary system. Fluorination of substances gives promising results in higher efficiency of passage and resists metabolic breakdown.[95] With high humidity in the nasal cavity, the contribution of PFAS-containing water droplets and dust particles on the mucosa can be significant.

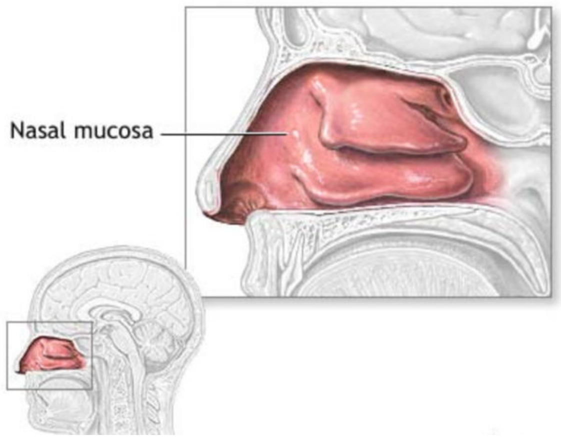

Figure 16: Mucous area of the nose, intranasal pathway

Nasal mucus is responsible for several physiological functions, such as humidification and warming of the inhaled air. Mucous membranes are usually moist tissues that are bathed by secretions. Despite tremendous advancement in the characterization of nasal enzyme expression, knowledge of the role of the nasal mucosa in the metabolism of xenobiotics is still inadequate, primarily due to the limited availability of in vitro models for nasal metabolism screening studies. Nasal secretions originate mostly from submucosal glands and goblet cells. The nasal respiratory mucosa consists of epithelium, basement membrane, and lamina propria. Many of the epithelial cells are covered on their apical surface with fine projections of microvilli, which enhance the respiratory surface area.

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91 *https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2020180279*
92 *Madhavan, 2022. https://doi.org/10.1016/j. ebiom.2022.104298*
93 *Wang et al, 2021. PNAS 2021 Vol. 118 No. 24 e2011957118*
94 *Wang Z. et al (2018). The fluorination effect of fluoroamphiphiles in cytosolic protein delivery, nature comm. 9:1377*
95 *J. Rohrer J. et al (2018), Advanced formulations for Intranasal Delivery of Biologics, International Journal of Pharmaceutics*

Brain - Cerebral uptake

PFAS have the potential to pass through the nasal cavity, through the mucosa to the brain, Figure 17. Intensive research is now on the use of the nasal route for the administration of drugs to the brain due to its reliability, safety, non-invasiveness, and suitability. This pathway should be more efficient because it passes the first-pass metabolism.[96] The application of fluorinated compounds in drug formulation is an intensive research field in pharmaceuticals, especially applied to transmembrane transport.

The brain is protected by many complex barriers before exogenous chemicals can pass through and enter the central nervous system. PFAS are found to have the ability to pass through the **life-protecting membrane** like the placenta, testicular membrane and also the blood-brain-barrier (BBB). For the transmembrane transport of PFAS into the brain, several potential mechanisms are proposed.[97] Some of these possibilities are already postulated by the author in a study from 1981.[98] Especially, the disruption of tight junctions in the blood-brain barrier as a pathological mechanism for xenobiotics to enter the brain. PFAS can also be transported through the membrane by special proteins located at the BBB.[99] Active PFAS uptake may also occur by a class of proteins that actively shuttle molecules with specific biochemical properties across the BBB.

Figure 17: PFAS passing through Blood-Brain-Barrier (BBB).

Finally, the BBB passes small molecular weight molecules more easily through passive diffusion than large molecular weight molecules. Given that PFAS can cross the BBB and access the brain parenchyma, it is of the utmost importance for neurobiological, endocrine, and behavioural consequences to understand the consequences of exposure for brain function. PFAS can induce neurobehavioral effects, particularly in developmentally exposed animals, leading to persistent aberrations in spontaneous behaviour as well as deficits in learning and spatial memory functions. The accumulation and distribution of PFAS in the brain may lead to toxic effects in the central nervous system, including PFAS-induced behavioural and cognitive disorders.[100,101] It would be impossible to thoroughly assess the neurotoxicological differences between PFAS compounds on an individual basis. Therefore, the grouping of PFAS compounds by chemical class is a necessary step towards understanding PFAS behaviour in humans and wildlife more integral to the whole. [102,103] Kawabata (2017) demonstrated that PFDoA passes through the blood-brain barrier and accumulates in the brain. In animal experiments with adult rats, cognitive deficit is found to be associated with PFDoA levels in the brain.[104]

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[96] *Rohrer J, Lupo N, Bernkop-Schnürch A. Advanced formulations for intranasal delivery of biologics. Int J Pharm. 2018 Dec 20;553(1-2):8-20. doi: 10.1016/j.ijpharm.2018.10.029. Epub 2018 Oct 11. PMID: 30316796.*

[97] *Piekarski, D., Diaz, K., & McNerney, M. (2020). Perfluoroalkyl chemicals in neurological health and disease: Human concerns and animal models. NeuroToxicology, 77, 155–168.*

[98] *Arkenbout A. (1981). Membrane dynamics in relation to transmembrane transport of xenobiotics. UU, NL*

[99] *Ndemazie N.B. et al. (2021). Multi-disciplinary Approach for Drug and Gene Delivery Systems to the Brain. AAPS PharmSciTech (2022) 23:11*

[100] *Cao Y, Ng C. Absorption, distribution, and toxicity of per- and polyfluoroalkyl substances (PFAS) in the brain: a review. Environ Sci Process Impacts. 2021 Nov 17;23(11):1623-1640. doi: 10.1039/d1em00228g. PMID: 34533150.*

[101] *Starnes H.M., et al (2022). A Critical Review and Meta-Analysis of Impacts of Per- and Polyfluorinated Substances on the Brain and Behavior, Frontiers in Toxicology vol. 4*

[102] *Cousins et al., (2020). Environ. Sci.: Processes Impacts, 2020, 22, 2307*

[103] *Kwiatkowski C.F. (2020). Scientific Basis for Managing PFAS as a Chemical Class. ES&T Letters, 7, 532–543*

[104] *Kawabata K. (2018). Perfluorododecanoic Acid Induces Cognitive Deficit in Adult Rats TOXICOLOGICAL SCIENCES, 2017*

Ocular uptake

Figure 18: Ocular pathway

Animal experiments show evidence that emerging pollutants like flame retardants, polychlorinated bi- phenyls (PCBs) and perfluorobutane sulfonate (PFBS) can induce visual dysfunctions in animals. Zeeshan (2020) studied the role of PFAS as an ocular toxicant in Shenyang, China, because of the occurrence of a large population of ocular diseases and near the largest fluoropolymer manufacturing facilities in China. Association is found between serum levels of perfluoroalkyl substances (PFAS) and increased impairment in the eye, one of the most sensitive and exposed organs.[105]

As an alternative to perfluorooctane sulfonate (PFOS), increasing usage of perfluorobutane sulfonate (PFBS) has led to its ubiquitous presence in the environment. Perfluorobutanesulfonic acid (PFBS) is a chemical compound having a four-carbon fluorocarbon chain and a sulfonic acid functional group. This PFAS is used in textiles, as an alternative to PFOS.[106,107] PFBS is also shown to potentially disrupt the thyroid endocrine system. Considering the regulation of thyroid hormones in visual development, PFBS is likely to adversely affect the development and function of visual systems, which a sensitive target of environmental pollutants. Accumulation of PFBS and the resulting defects of visual systems further highlight the eye as a sensitive target organ of environmental pollutants. The susceptibility and sex-specific responses of visual systems to environmental pollutants warrant more work for a comprehensive risk assessment.[108] The mechanism(s) for the observed effects of PFAS on eye disease remain(s) largely unknown, oxidative stress is hypothesised as the primary mechanism via which PFAS exert its detrimental effect on eyes.

[105] *Zeeshan M et al (2020). Incidence of ocular conditions associated with perfluoroalkyl substances exposure: Isomers of C8 Health Project in China, Environment Int.,Vol. 137,2020,105555*
[106] *Hanssen, L.; Herzke, D. (2015) Investigation of outdoor textiles and gear with respect to determine the content of ionic perfluorinated substances (PFASs). Evaluation of results, Norwegian Environment Agency/NILU*
[107] *Poulsen et al (2021). Survey and risk assessment of chemicals in textile face masks, Danish EPA*
[108] *Chen L. et al, (2018) Accumulation of perfluorobutane sulfonate (PFBS) and impairment of visual function in the eyes of marine medaka after a life-cycle exposure, Aquatic Toxicology, Volume 201, Pages 1-10,*

Bioaccumulation of PFAS

The study of toxicokinetic, observed in laboratory animals, is important for extrapolating health effects and effect levels to humans for purposes of establishing health-based criteria. However, there are appreciable differences in PFAS elimination rates across species the elimination half-life for PFOS is estimated to be 3.3–5.4 years in humans, 110–200 days in monkeys, and only 24–83 days in rats.[109] These interspecies differences were the reasons for re-evaluating EU safety limits like TWI for POPs like dioxins and PFAS.

With respect to the bioaccumulation effect, perfluorononanoic acid (PFNA), a perfluoroalkyl substance (PFAS), structurally related to perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) has long-lasting effects on the immune system after a single high dose exposure to PFNA.[110]

Most experimental studies focus on short-term, very high-dose PFAS exposures to single compounds, while the most realistic exposures for humans and wildlife are mixtures of exposures that are more chronic and lower doses in nature.[111] PFAS have a high potency to accumulate, even small amounts can lead to this accumulation over time. Small concentrations can lead to high exposure and this characteristic is an important argument in the risk assessment of PFAS. Low-dose continuous administration can lead to a high level of bioaccumulation of persistent forever chemicals in all parts of our body with risks and short- and long-term effects.

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[109] Pizzurro D.M. et al. (2019). Interspecies differences in perfluoroalkyl substances (PFAS) toxicokinetics and application to health-based criteria, Regulatory Toxicology and Pharmacology,Vol. 106

[110] Rockwell CE, Turley AE, Cheng X, Fields PE, Klaassen CD. Persistent alterations in immune cell populations and function from a single dose of perfluorononanoic acid (PFNA) in C57Bl/6 mice. Food Chem Toxicol. 2017 Feb; 100:24-33

[111] Piekarski, D., Diaz, K., & McNerney, M. (2020). Perfluoroalkyl chemicals in neurological health and disease: Human concerns and animal models. NeuroToxicology, 77, 155–168.

Face masks and waste

The last chapter is saved for the aspect when the face mask is used and will dispose of as waste. The statement of the "Covid-19 pandemic" by governments has resulted in an unprecedented rise in the global production of face masks which are produced by using polymeric materials. China increased its daily production of medical face masks to 14.8 million, and over 600 million orders of face masks per month were in demand in April 2020 (METI, 2020).[112] "*Generated millions of tons of plastic waste are being littered into the environment because of improper disposal and mismanagement*", according to Du. H (2022). Plastic waste can release microplastics (MPs) with the help of physical, chemical, and biological processes, which is placing a huge microplastic contamination burden on the ecosystem. "*Microplastic pollution linked to face masks should be a focus worldwide*", Du, H (2022). The rapid growth of face mask production and consumption is worrying, and the waste of face masks will result in worse microplastic pollution worldwide. It is urgent to understand the potential environmental risks and the significant contribution of face masks of it, which needed further study.[113]

Worldwide 79% of the disposed of face masks will be landfilled.[114] *Are waste incinerators capable to destroy PFAS completely?* Figure 19 shows the results of PFAS analyses with the FITC-T4 bioassay on sediment, mosses, and pine needles. The figure is expressed in micrograms (µg) per gram sample and shows how widespread PFAS is in our environment.

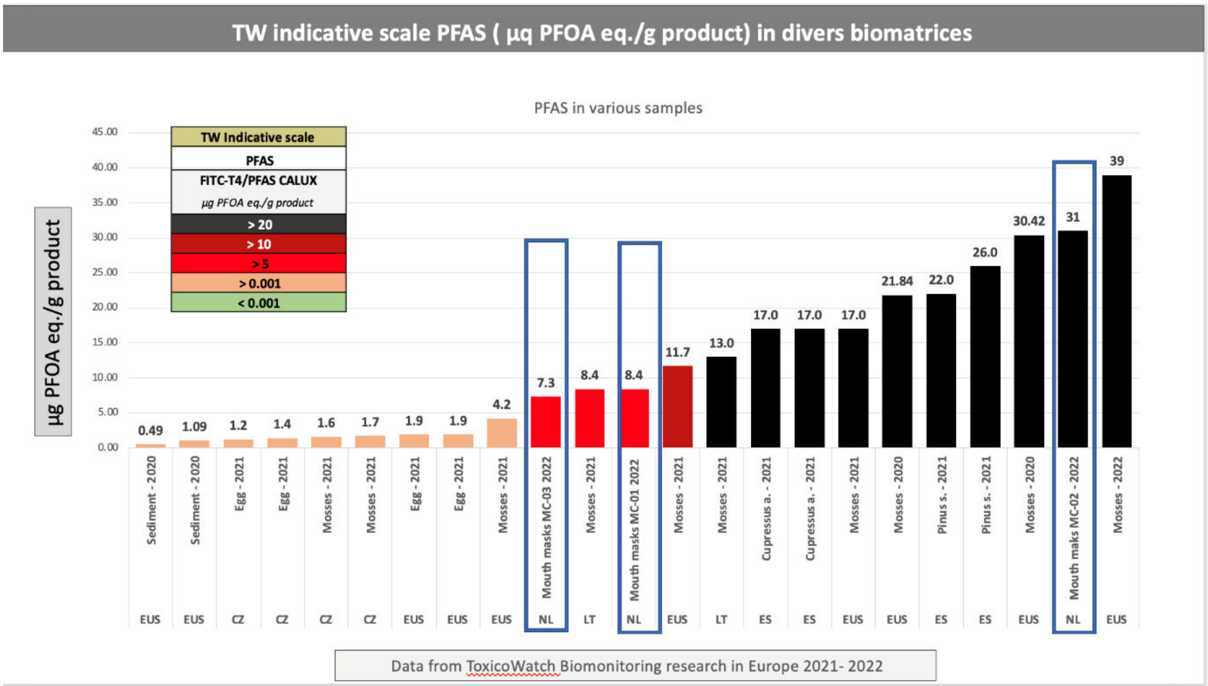

Figure 19: TW indicative scale PFAS (ug PFOA eq./g product) in divers biomatrices on TW data biomonitoring 2021-2022.

[112] *Science of the Total Environment 737 (2020) 140279*
[113] *Shen, Maocai et al. "Neglected microplastics pollution in global COVID-19: Disposable surgical masks." The Science of the Total Environment 790 (2021): 148130 - 148130.*
[114] *Du H. et al, (2022). Environmental risks of polymer materials from disposable face masks linked to the COVID-19 pandemic, Science of The Total Environment,Volume 815,152980*

Conclusion

The answer to the initial question for this research, ***Is PFAS added to face masks***? is confirmed by bioassay FITC-T4 analyse. and literature review. However, the FITC-T4 is not specific to PFAS, also other toxic substances, such as bisphenol and phthalates also react at this bioassay. From a toxicological view, the total toxic effect is important. The literature review shows PFAS may enter the human body through various pathways:

- Mouth (swallowing, oral uptake of microplastics)
- Lungs (pulmonary uptake)
- Skin (dermal uptake)
- Nose (intranasal, inhalation and mucosal uptake)
- Brain (cerebral uptake, blood-brain-barrier)
- Eyes (Ocular uptake)

The PFAS in the analysed face masks expressed as PFOA equivalencies with the FITC-T4 analysis (µg PFOA equivalent/m2) exceeding the EU PFOA safety threshold for textiles with a factor of 331 - 1424. The corresponding values are 7.3 – 31 µg PFOA equivalent/gram product/textile. Chemical analysis unfortunately lacks efficiency, is only congener specific and cannot assess the total toxicities of mixtures. With this report, ToxicoWatch wants to advocate the use of bioassay FITC-T4 as a valuable method especially for measuring a mixture of toxic chemicals.

A list of health risks associated with PFAS: Altered cholesterol levels, disrupt thyroid function, harmed liver, and kidney function, alter immune response, raise the risk of ulcerative colitis, harmed reproductive health, increase risk of birth defects, decrease infant birth weights, cause tumours and cancer, and link to Alzheimer disease.

Besides long- and short-chain PFAS chemicals used in face masks, the added heavy metals, formaldehyde, and Bisphenol-A are also of concern. Another point to highlight for health risk is fire/flame retardants since synthetic textiles are extremely fire-prone chemicals used to prevent fire. This understanding raises an urgent need for assessing all the parameters involved in wearing synthetic masks full of toxic chemicals, as well as, phthalates, nanoparticles (graphene) and microplastics.

On the question ***What are the risks for human health if PFAS is added to face masks?*** The added toxic chemicals will be released from the face mask as volatile gas, particles, or microplastics/microfibers. If PFAS interacts with the skin, the uptake can be in the same order as oral uptake. When fluorinated toxic chemicals enter the nasal cavity, an uptake is possible into the blood circulation. More worrisome is the evidence for efficient passage through the blood-brain barrier to enter every part of the brain. Also, the placenta barrier to the foetus is found to be vulnerable to PFAS transport.

In recent years there has been a tsunami of scientific publications, which are hugely fragmented, and an overall picture of the risks posed by PFAS to human and environmental health is still barely comprehensible. A well-balanced answer as to whether inhaling microfibers, metal nanoparticles such as graphene oxide, alongside other chemicals such as bisphenol, phthalates, and brominated flame retardants together with PFAS, is healthy and safe in face masks, can still not be given and therefore needs much more research.

The risks of PFAS to human health are too serious to ignore. PFAS pollution starts with the production, continues when the fluorinated products are used or worn, and in the end, it is a problem as waste. The list of disorders and diseases associated with PFAS is growing, like thyroid disorders, where the bioassay of FITC-T4 analysed method for this research is based on. Further highlighting is the upcoming reproductive disorders for men and women, impaired immune response, and all kinds of neurological disorders.

This pilot research started with questions and ended with questions: *Why is the precautionary principle ignored in the application of highly toxic forever chemicals in face masks? Why is so little research been published on the potential contamination of PFAS in face masks?* And besides that; *Why are chemicals of concern, like bisphenols, phthalates, brominated flame retardants and even nanoparticles used in the face mask, without proper regulation based on scientific assessments?*

PFAS are known for decades and are one of the most toxically threatening chemicals ever invented and found up until now, in every compartment of life. Chemical pollution disrupts the balance of human health and ecosystems, and PFAS are the ultimate example of it. On top of this worldwide chemical tragedy, face masks have been made mandatory for a period by governmental policies for what is called health protection, enlarging the problem of PFAS pollution. Most people are already confronted with exceeding the safety limits of PFAS, and maybe also for bisphenol and phthalates. In Figure 20 the line of safety is symbolically drawn to the lips. This a wake-up call to reconsider the application of toxic substances, about which we still know little, both from an analytical and toxicological point of view. **PFAS should never have been produced in the first place and certainly not applicated in face masks**.

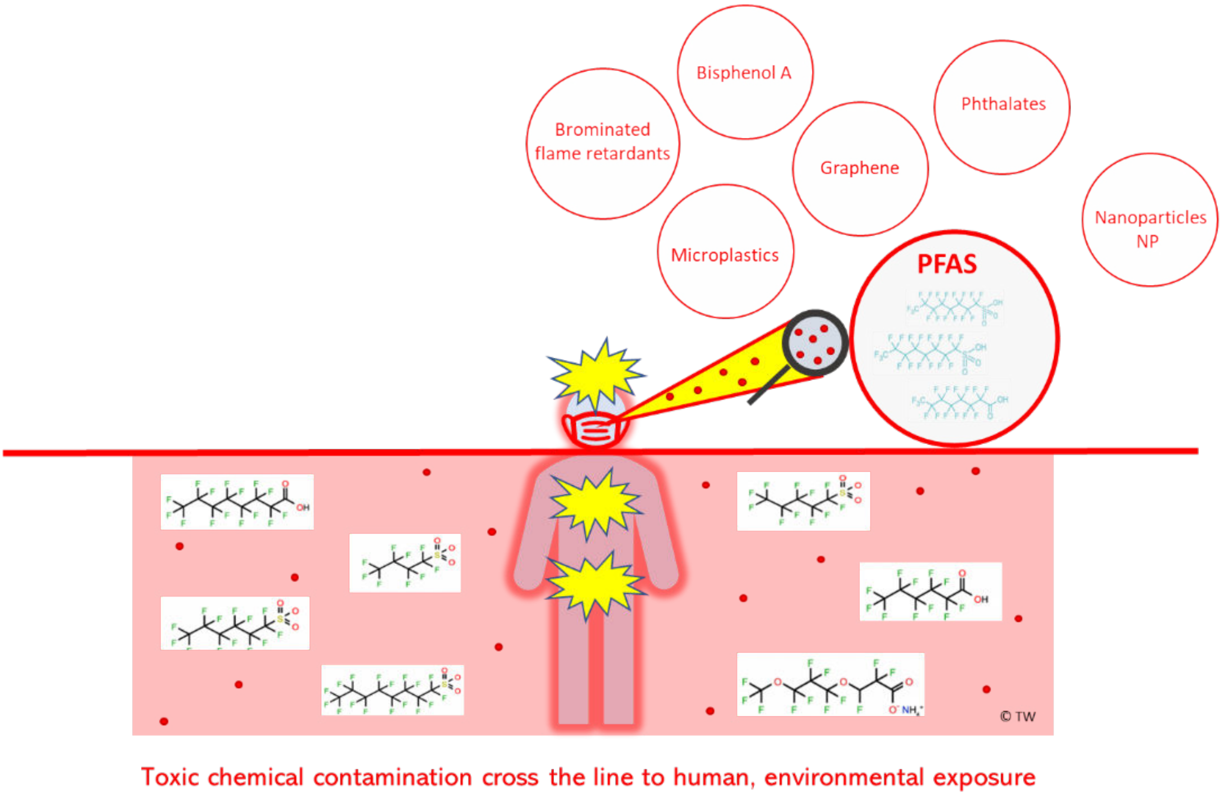

Figure 20: PFAS pollution already crosses the line to human exposure. Remedy of face masks is worse than its malady.

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