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Organic Micropollutants:

Their control, occurrence and consequences for recycling systems

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- ~180 million unique chemicals in CAS database
- >100,000 unique substances are registered for industrial use on the EC Inventory of chemicals
- Potential environmental and health concerns:
 - Toxic, mutagenic, carcinogenic, endocrine disruption, developmental toxins, ecotoxic, antibiotic resistance



Imperial College Per- and Polyfluoroalkyl Substances PFAS London 'Forever Chemicals'

- Invented in 1930s and used widely in consumer products from the1950s
- C-F strongest bond in organic chemistry
- Non-degradable and highly persistent
- Polar and non-polar structure: "amphiphilic" = soluble in water – <u>very unusual for a POP</u>
- Bioaccumulative
- Adverse reproductive, developmental and immunological effects in animals and humans
- Found in every environmental compartment
- >4,700 commercially available PFAS



Structures of PFHxS, perfluorohexane sulfonic acid; PFOS, perfluorooctane sulfonic acid; PFOA, perfluorooctanoic acid; FOSA, perfluorooctane sulfonamide

Uses of PFAS



industry/Application	1173 1960	0303
Aviation and	Polymer	Mechanical components (PFA tubing, piping, seals, cables
Aerospace		and insulators)
	Nonpolymer	Hydraulic fluid additives to prevent evaporation, fires and
		corrosion
Automobile	Polymer	Mechanical components (wiring, cable, bearing, lubricants,
		polymer coating on carpets)
	Nonpolymer	Surface treatment for carpets, leather and exterior surfaces
Herbicides and	Polymer	Not reported
Pesticides	Nonpolymer	Active ingredients such as short-chain sulfonamides in plant
		growth regulators and sulfluramid in ant and termite baits.
Building and	Polymer	Fluoropolymer membranes and coatings on roofing, stones,
construction		concretes; adhesives and additives in paints
	Nonpolymer	Additives in paints, coatings and surface treatments
Cosmetics and	Polymer	Dental floss and micro powders in creams and lotions
Personal care	Nonpolymer	Shampoos, nail polish, eye makeup and dental cleaners
products		
Electronics	Polymer	Insulators, solder sleeves, printed circuit boards, transducers
	Nonpolymer	Flame retardants for polycarbonate resin
Food Processing	Polymer	Fluoropolymer fabrication materials
	Nonpolymer	Coatings on food packaging
Metal Plating	Polymer	Not reported
	Nonpolymer	Wetting agent, mist suppression for harmful vapors
Mining	Polymer	Not reported
	Nonpolymer	Surfactants used in oil mining flotation
Textiles (upholstery,	Polymer	Fluoropolymers used in the construction of outdoor gear,
leather and apparel)		clothing and housewares, stain release finishing
	Nonpolymer	Chromium treatment for leather, coatings for oil and water
		repellent and stain release finishes
Household products	Polymer	Nonstick coatings on utensils
	Nonpolymer	Floor finishes and polishes, cleaning agents

lleas

Industry/Application DEAs Type

Stockholm Convention

Listed PFOS, its salts and PFOSF in Annex B (restriction)

2009

Water Framework Directive (EU)

Listed of PFOS as a priority hazardous substance and specified limit concentrations in different water bodies

Stockholm Convention

POPs Regulation

Listed PFOA, its salts and PFOA-related compounds in Annex A (elimination) Limited the maximum conc. of PFOS and gave specific exemptions

Stockholm Convention

202

Listed PFHxS, its salts and PFHxS-related compounds in Annex A (elimination)

2023

REACH (EU)

202⁻

Limited the maximum conc. of C9-C14 PFCAs and gave specific exemptions

POPs Regulation

2020

2019

Limited the maximum conc. of PFOA in different condition and gave specific exemptions

Analysis of the most appropriate regulatory management options on PFASs (UK)

Gave information on annual use and emission of PFASs within UK 6 kinds of PFASs were identified as SVHCs on the UK REACH candidate list and it is required to notify the Agency if any is present above 0.1% by weight and the quantity exceeds 1 tonne/y

Restriction proposal on PFASs (EU)

Gave information on annual use and emission of PFASs within EU Full ban on all the PFASs or ban with use-specific derogations Gave Information on hazards, exposures, risk and alternatives

Imperial College PFAS Production Continues Globally





Imperial College Some of the Main Sources and Uses of PFAS in Different Sectors in Britain

Industrial Sector	t/y
F-gases (refrigeration and air-conditioning, aerosols, solvents, firefighting fluids, high voltage switch gear, medical equipment and products – eg inhalers and scanners)	50,000
Textiles, upholstery, leather and carpets	4,000 - 14,000
Medical devices and medicines	5,000
Electronics (semi-conductors and batteries)	2,000
Construction	2,000
Fire-fighting foams	2,000
Food packaging	Not reported

Imperial College London Food Packaging: Recycling Targets and PFAS Content



Total Organic Fluorine content in takeaway food packaging from UK high street retailers

Content above 20mg/kg dw indicates intentional PFAS treatment



ltem	Range (mg/kg dw)	Mean (mg/kg dw)
Bakery bags	290 - 1000	670
Takeaway bags	470 - 990	660
Takeaway boxes	700 - 1200	880



Wastewater Treatment and Sewage Sludge Management



Biosolids Recycling Benefits

Organic matter

Land Application is the Best Practicable Environmental Option

C sequestration





Transfer Pathways and End-points for Risk Assessment



Schowanek et al (2004) A risk-based methodology for deriving quality standards for organic contaminants in sewage sludge for use in agriculture—Conceptual Framework. *Regulatory Toxicology and Pharmacology* 40 (2004) 227–251

Imperial College The Potential Transfer of Organic Contaminants to Food by London Agricultural Use of Biosolids and Other Recycled Wastes

- Dairy ingestion trials under controlled conditions – wastes spread to land
- Crop trials controlled growth chamber studies with barley and carrots; field investigation with winter wheat







Imperial College London Perfluorooctanesulphonic Acid (PFOS) in Milk



= FSA 2012 Total Diet Study (TDS) value for milk (0.05 μg kg⁻¹ whole weight) (Fera 2012)

- PFOS was 40-120 times greater in milk from the biosolids treatment at week 4 compared to the control and 24 times greater than the TDS value
- Concentrations rapidly fell to background after biosolids removal from the diet and no transfer was detected with soil incorporation
- No immediate impacts on the human diet, there is time to take effective action on source control

Contaminants Impact Recycling in Favour of Incineration

- Expensive and complex
- Not feasible in many regions
- Old solution to new challenges
- Destroys resources
- Inflexible and reduces future opportunities
- Low sustainability EU: recycling or recovering preferred options
- Surely we can do better!





biopolymers from W

Imperial College PFAS Supply Chain and Regulatory Focal Points



¹ HSE reports 2,600 - 36,700 t/y PFAS are currently manufactured or imported into GB (excludes content in products) https://www.hse.gov.uk/reach/rmoa.htm?utm_source=press.hse.gov.uk&utm_medium=referral&utm_campaign=corporate-push

Source Control

- Experience with legacy chemicals demonstrates source control is effective in protecting vulnerable recycling systems
- The case of dioxins in sewage sludge

Contemporary analysis: ~8 ng Dioxin TEQ kg⁻¹ DS



Year

Actions and Consequences:

- Environmental measures focused on bioresources/recycled materials could limit recycling for less sustainable practices (incineration)
- Move focus of control measures to point of use (eg food packaging)
- Greater awareness, understanding and labelling of products containing PFAS
- Bioresources and recycling industries need to be more aware and proactive about contaminants in waste streams and recycled products
- Enforcement of monitoring and control systems on imported products
- Effective source controls are critical to support vulnerable recycling systems
- An important topic that should receive greater attention at the ICSSWM