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, ecotox, antibiotic resistance
Invented in 1930s and used widely in consumer products from the 1950s

C-F strongest bond in organic chemistry

Non-degradable and highly persistent

Polar and non-polar structure: “amphiphilic” = soluble in water – *very unusual for a POP*

Bioaccumulative

Adverse reproductive, developmental and immunological effects in animals and humans

Found in every environmental compartment

>4,700 commercially available PFAS

**Per- and Polyfluoroalkyl Substances PFAS**

‘Forever Chemicals’

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

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

Water Framework Directive (EU)
Listed of PFOS as a priority hazardous substance and specified limit concentrations in different water bodies

Stockholm Convention
Listed PFOA, its salts and PFOA-related compounds in Annex A (elimination)

POPs Regulation
Limited the maximum conc. of PFOS 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
PFAS Production Continues Globally
### Some of the Main Sources and Uses of PFAS in Different Sectors in Britain

<table>
<thead>
<tr>
<th>Industrial Sector</th>
<th>t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-gases (refrigeration and air-conditioning, aerosols, solvents, firefighting fluids, high voltage switch gear, medical equipment and products – eg inhalers and scanners)</td>
<td>50,000</td>
</tr>
<tr>
<td>Textiles, upholstery, leather and carpets</td>
<td>4,000 – 14,000</td>
</tr>
<tr>
<td>Medical devices and medicines</td>
<td>5,000</td>
</tr>
<tr>
<td>Electronics (semi-conductors and batteries)</td>
<td>2,000</td>
</tr>
<tr>
<td>Construction</td>
<td>2,000</td>
</tr>
<tr>
<td>Fire-fighting foams</td>
<td>2,000</td>
</tr>
<tr>
<td><strong>Food packaging</strong></td>
<td>Not reported</td>
</tr>
</tbody>
</table>
Food Packaging: Recycling Targets and PFAS Content

- Waste packaging is ~25% of total household waste in the UK.
- Of which, 70% is food and drink packaging.
- Under the UK resources and waste strategy, England needs to recycle 50% of plastic packaging by 2025, and 55% by 2030.
- The overall recycling target for all packaging has been set at 70% by 2030.

![Image of pizza in a cardboard box]

### Total Organic Fluorine Content in Takeaway Food Packaging from UK High Street Retailers

Content above 20mg/kg dw indicates intentional PFAS treatment.

<table>
<thead>
<tr>
<th>Item</th>
<th>Range (mg/kg dw)</th>
<th>Mean (mg/kg dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakery bags</td>
<td>290 - 1000</td>
<td>670</td>
</tr>
<tr>
<td>Takeaway bags</td>
<td>470 - 990</td>
<td>660</td>
</tr>
<tr>
<td>Takeaway boxes</td>
<td>700 - 1200</td>
<td>880</td>
</tr>
</tbody>
</table>

https://chemtrust.org/pfas-food-packaging-faq/

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

• 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
Perfluorooctanesulphonic Acid (PFOS) in Milk

- 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.

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

For sustainable food production

Recycle nutrients

Resource recovery

Eg biopolymers from WW1
PFAS Supply Chain and Regulatory Focal Points

1 National/European production of PFAS

International production of PFAS

Limits on manufacture, marketing and use

No transparent controls on PFAS in imported products
- 160,000 t/y could be imported to EEA from 3rd countries
- Illegal imports ~33% of the legal F-carbon market

Ban or restrictions: Move from recycling to incineration

PFAS found in recycled wastes

PFAS added to composite materials

Commodity products

1 HSE reports 2,600 - 36,700 t/y PFAS are currently manufactured or imported into GB (excludes content in products)

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
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