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8th International Conference on
Sustainable Solid Waste Management

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The Significance of Chemical Use and Transfer to Recycling and Recovery Systems

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UN Sustainable Development Goal 12:

Ensure sustainable consumption and production patterns

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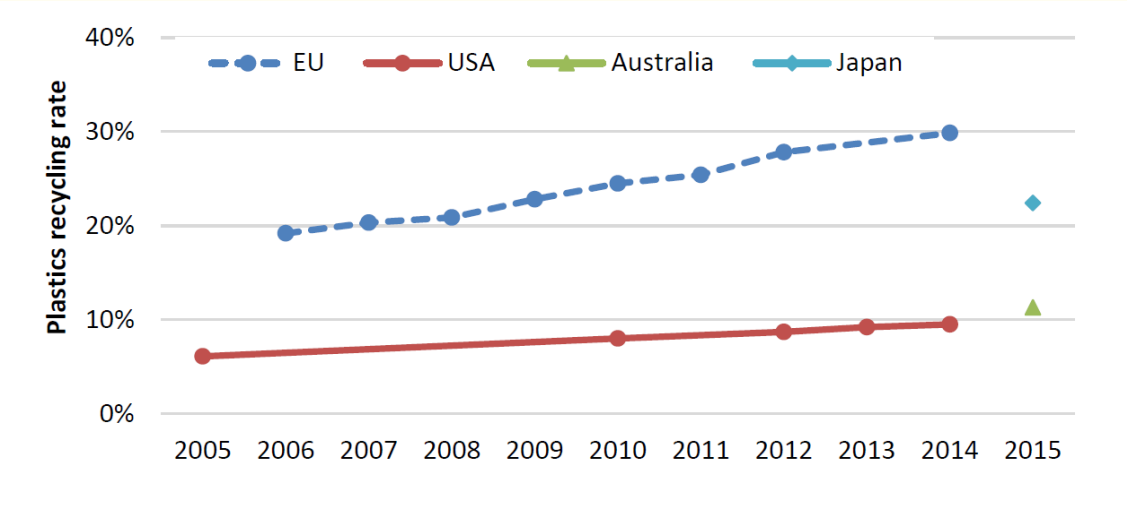
Plastics Recycling



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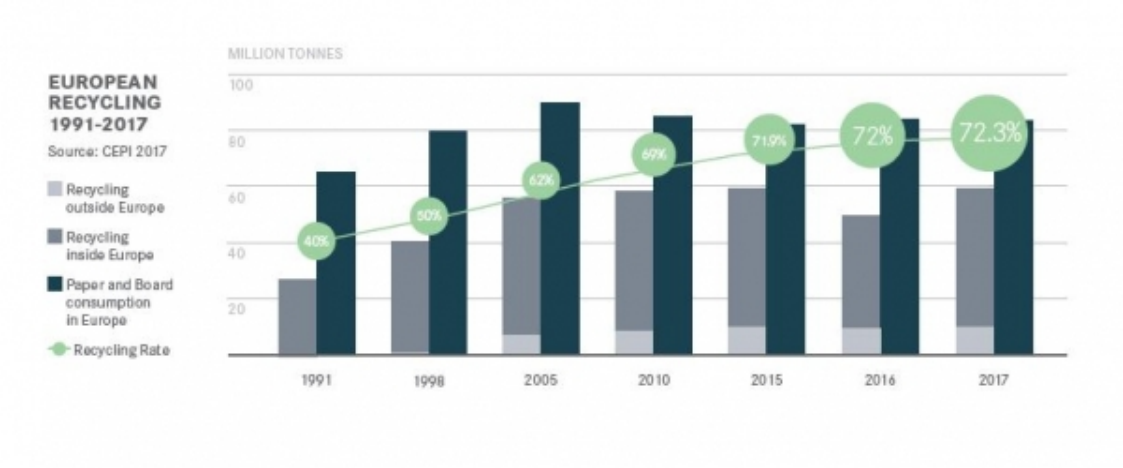
Paper Recycling



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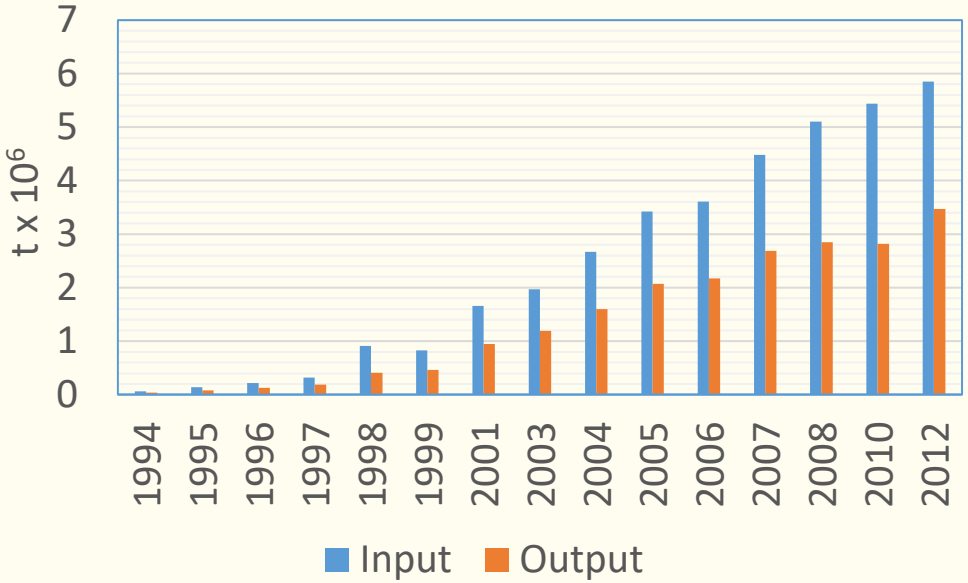
Growth in UK Composting Industry



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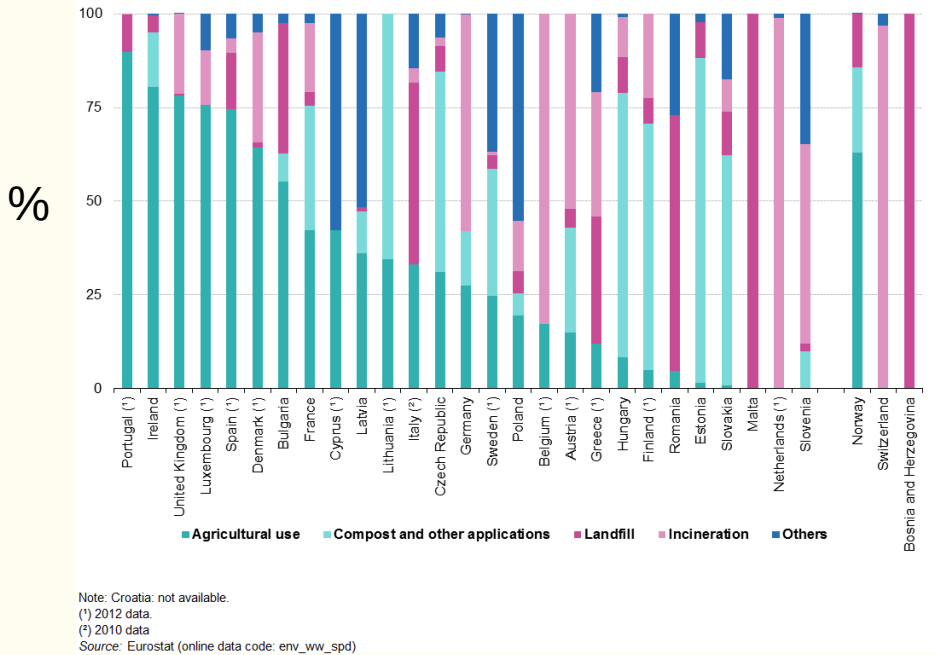
Sewage Sludge Management



Note: Croatia: not available.
(1) 2012 data.
(2) 2010 data
Source: Eurostat (online data code: env_ww_spd)

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- Over 178 million unique chemicals in CAS database
- 106,213 unique substances are registered for industrial use on the EC Inventory of chemicals
- Environmental and health concerns:
  - Toxic, mutagenic, carcinogenic, endocrine disruption, developmental toxins, ecotoxic, antibiotic resistance

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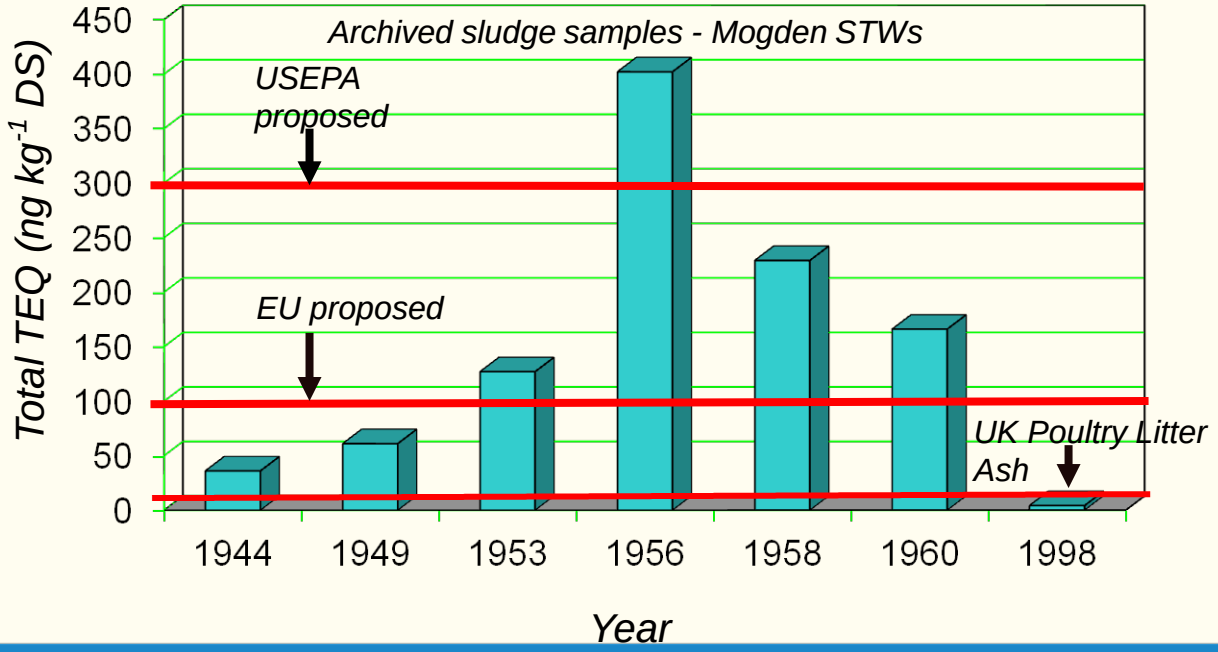
Sewage Sludge Quality - Dioxin

Contemporary analysis: ~8 ng Dioxin TEQ kg^{-1} DS



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Organic Contaminants in Biosolids and CLO

	Biosolids	CLO	Reference
PCDD/Fs & non-ortho PCBs (ng TEQ kg^{-1} DS)	14.6-20.4	18.9-12.0	20[a]
Ortho PCBs (SUM µg kg^{-1} DS)	29.4-73	25.4-29.6	220[b]
PBDD/Fs & non-ortho PBBs (ng TEQ kg^{-1} DS)	40.3-77.9	18-32.2	20[a]
Ortho PBBs (SUM µg kg^{-1} DS)	0.05-0.06	0.1-0.4	220[b]
PXDD/Fs (ng TEQ kg^{-1} DS)	0.20-0.27	0.18-0.29	20[a]
PXBs (ng TEQ kg^{-1} DS)	0.02	0.014-0.02	20[a]
PAHs (PAH16 µg kg^{-1} DS)	1125-2144	2481-3792	4000[c]
PBDEs (SUM µg kg^{-1} DS) (including BDE 209)	4303-6781	1717-1761	1400[b]
Deca-BDE 209 (µg kg^{-1} DS)	4200-6690	1650-1720	1000[b]
HBCDs (µg kg^{-1} DS)	5.5-390	3-836	200[d]
PBCD (µg kg^{-1} DS)	7.0	13-351	0.20[e]
TBBPA (µg kg^{-1} DS)	33-45.2	100-517	280[b]
PCNs (ng kg^{-1} DS)	541-743	680-1980	44000[b]
PFOS (µg kg^{-1} DS)	60.9-204	8.9-35.4	200[b]
PCAs (short and medium chain) (µg kg^{-1} DS)	6425-140700	1100-59500	959000[b]

CLO=compost like output; [a]Equivalent to the maximum limit of 20 ng WHO-2005 TEQ kg^{-1} DS for a batch of PLA destined for land application stipulated in the end-of-waste criteria for PLA (WRAP, 2012a); [b]Mean concentration in sewage sludge (Smith, 2009a); [c]Swiss guide limit value for the USEPA 16 priority PAHs in compost (Saveyn and Eder, 2014); [d]Mean concentration from a survey of Chinese sewage sludge (Xiang *et al*., 2015); [e]Mean concentration from a survey of Chinese sewage sludge (Zeng *et al*., 2014)

RIGBY, H., DOWDING, A., FERNANDES, A., HUMPHRIES, D., JONES, N.R., LAKE, I., PETCH, R.G., REYNOLDS, C.K., ROSE, M. AND SMITH, S.R. (2021) Concentrations of organic contaminants in industrial and municipal bioresources recycled in agriculture in the UK. *Science of the Total Environment* 765, 142787.

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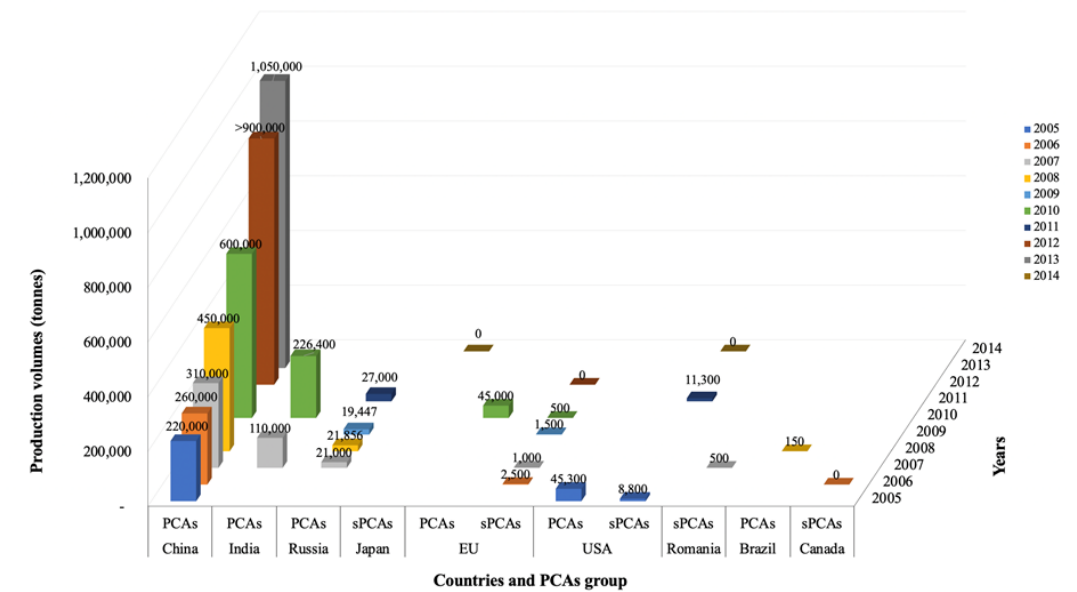
With greater source control in Europe and US, production of hazardous chemicals moves to less well regulated regions, eg polychlorinated alkanes:



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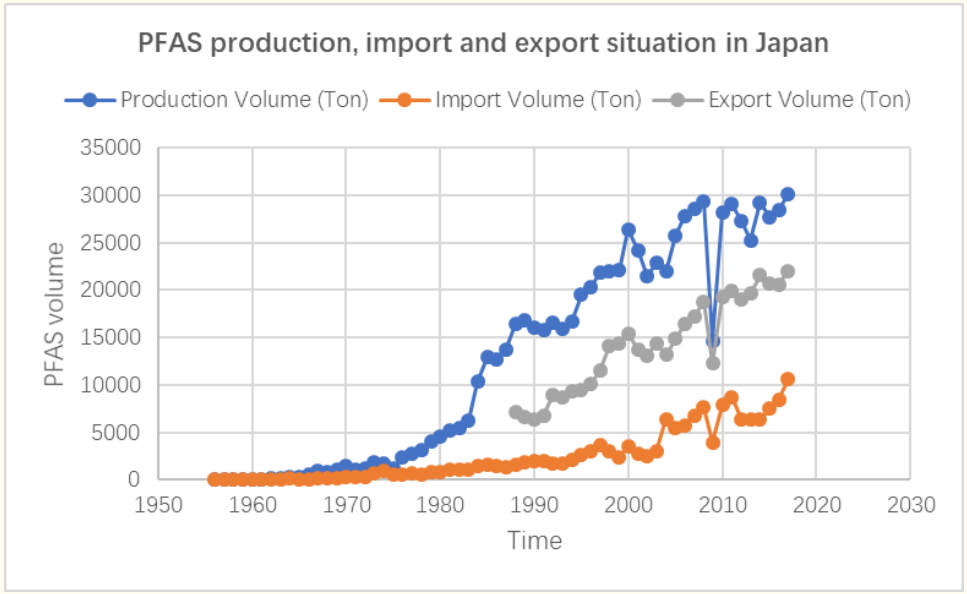
Per- and Polyfluoroalkyl Substances (PFAS)



> 4,700 PFAS exist, PFOS and PFOA are the main forms found in environmental media

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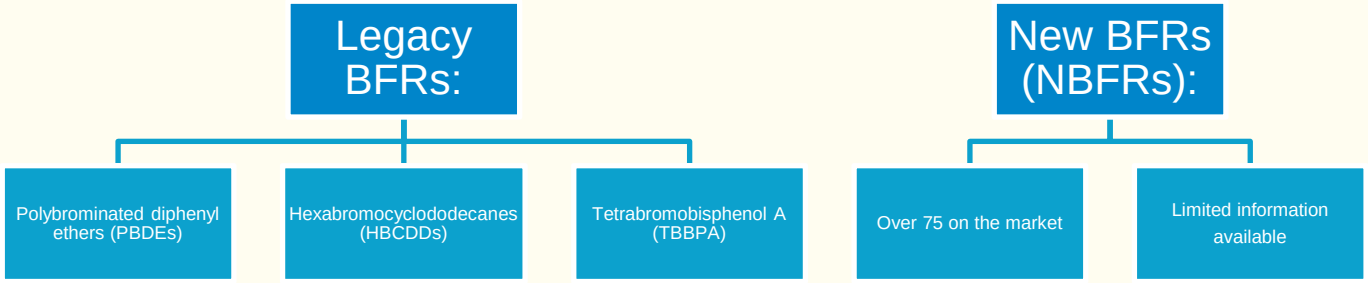
Brominated Flame Retardants (BFRs)



- Used to reduce the flammability of treated materials
- Act by interrupting the radical gas phase during combustion
- Most cost-effective way of passing flammability tests (Fire Safety Regulations)

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Sources of BFRs and Recycling of Flame Retarded Material

- Furniture: sofas, mattresses
- Textiles
- Carpets
- Curtains
- Wallpaper
- Coatings
- Polystyrene Insulation
- Children’s Products and Clothing: toys, changing pads, cribs, child seats
- Food Contact Materials
- Building Materials
- Hard Plastics in Electronics
- Car Interiors

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PCBs in Recycled Paper Products

ng TEQ kg^{-1} DS	Non-ortho-PCBs
Biosolids	0.7 – 1.7
CLO	0.7 – 0.8
MBMA	0.08 – 1.7
PLA	0.06 – 1.0
PSA	0.03
Virgin wood	0.04
RWW	0.05 – 0.4
Cardboard	0.45
Paper Sludge	**1.4 – 1.9**

- Restrictions first introduced in EU by Council Directive 76/769/EEC of 27 July 1976
- Legacy use of Aroclor 1242 in carbonless copy paper
- Paper recyclable up to 7 times therefore remains in the system at low levels for very long time
- Spokane City in Washington State recently led and won a major national lawsuit in the US against Monsanto for $550 million relating to water and environmental contamination with PCBs

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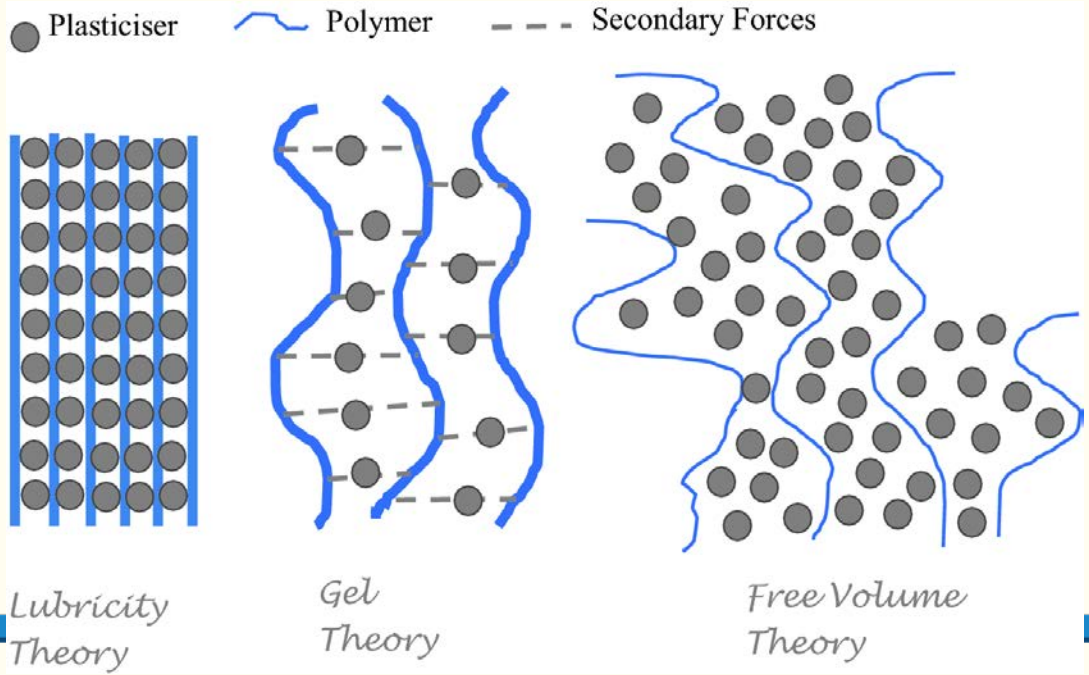
Major contaminant types are not chemically combined with the matrix eg flame retardents and plasticisers



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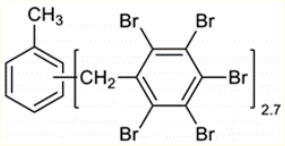
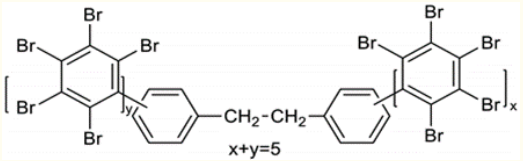
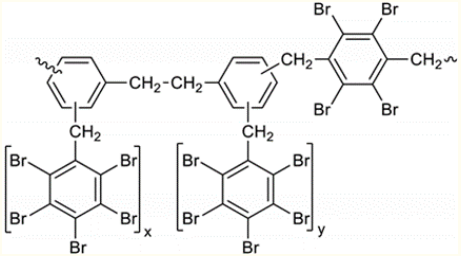
Emerging FRs and QSAR Analysis

New BFRs in development:

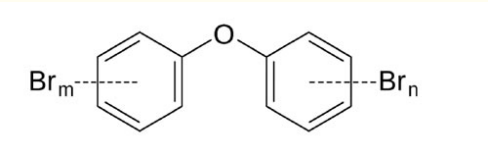






- As substances are banned manufacturers increase halogenation/aromaticity
- High log Kow
- Strong adsorption and transfer to sludge in WWT
- Negligible leaching
- High aquatic toxicity
- Potentially highly bioaccumulative
- Persistent

Polybrominated diphenyl ether (PBDE) structure:



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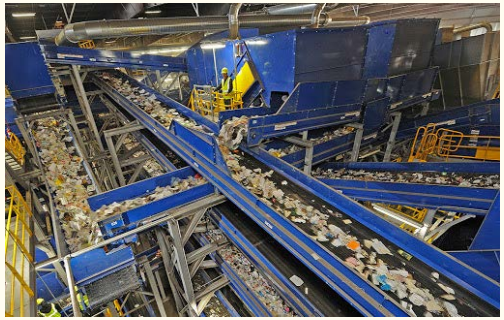

PTEs in Solid Waste Fractions

- Lead (Pb)
- WEEE remains important source, particularly PCBs
- Lead still apparent in solder
- Various types of batteries
- Glass packaging (e.g. beverage bottles)
- Ceramics (e.g. colourful foodware)
- Paints and house dust
- Plastics
- Cadmium (Cd)
- Various types of plastics
- Contemporary consumer plastics
- Glass including enamels of bottles
- Ceramic materials
- NiCd batteries (largely legacy) but also in other batteries

EU legislation and directives restrict the use of PTEs (e.g., RoHS, 494/2011 consumer products, 94/62/EC packaging and 2006/66/EC batteries), but they are still present in significant concentrations in consumer goods

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PTEs in Mechanically-sorted MSW Compost

- Historical (Smith, 2009) and contemporary data were benchmarked against PAS100
- Pb and Cd have source controls
- Increase in compliance for some metals (eg Pb, Zn, Cr), but not others (eg Cd)
- The extensive use of heavy metals in consumer products continues to challenge the composition of mechanically-sorted MSW composts

		Pb	Cd	Zn	Cu	Ni	Cr
PAS100 mg/kg DM		200	1.5	400	200	50	100
Smith 2009	n	22	22	22	17	22	20
	%>PAS 100	***73***	***64***	73	68	50	35
Singh Gill 2021	n	26	24	27	26	26	22
	%>PAS 100	***42***	***63***	59	62	54	23
n, number of studies							

SMITH, S.R. (2009) A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environment International* 35, 142-156.

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How do toxic chemicals enter the EU economy?

- More than 90% of all chemicals in consumer products non-compliant with REACH come from outside of the EU (CEFIC, 2020)
- Legacy contamination within recycling systems
- Leach out of manufactured products and transfer to environmental media
- Emerging chemicals and production of persistent, bioaccumulative and potentially biologically active chemicals not yet subject to source control regulations

https://cefic.org/app/uploads/2020/09/Cefic-Input-Paper-Chemical-Strategy-for-Sustainability-CSS.pdf

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Actions:

- Emphasis on source control – *ALL* halogenated compounds are a priority
- Enforcement of monitoring and control systems on imported products
- Monitoring and source control of legacy chemicals in recycling systems
- Smarter chemicals that are not bioaccumulative or toxic and that are chemically bound to stay where they are intended
- Recycling systems critical to SDG12: Responsible Consumption & Production (Circular Economy) are vulnerable to multiple routes of chemical contamination and it is vital source control measures are implemented and effective
- An important topic that should receive greater attention at the ICSSWM