IPCP Webinar Series: POPs in plastic and monitoring approaches

Part I: Understanding POPs in plastics; 24/25 April 2023

Understanding Brominated POPs – PBDEs, HBCD, HBB – in Plastic

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IPCP International Panel on Chemical Pollution

UN environment programme

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19 new POPs listed in the Stockholm Convention since 2009

Chemical	Pesticides	Industrial chemicals	Unintentional production	Annex
Chlordecone	+			A
α- and β- hexachlorocyclohexane	+		By-product of lindane	A
Lindane (gamma HCH)	+			A
Endosulfan, Dicofol	+			A
Pentachlorophenol (PCP)	+	+		A
Commercial PentaBDE		+		A
Commercial OctaBDE (hexa/hepta)		+		A
DecaBDE		+		A
Hexabromobiphenyl (HBB)		+		A
Hexabromocyclododecane (HBCD)		+		A
Perfluorooctane sulfonic acid (PFOS), its salts and PFOSF	+	+		B
PFOA and related compounds		+		A
PFHxS and related compounds		+		A
Short Chain Chlorinated Paraffins		+		A
Hexachlorobutadiene (HCBD)		+	+	A/C
Pentachlorobenzene (PeCBz)		+	+	A/C
Polychlorinated Naphtalene (PCN)				

POPRC: Chlorpyrífos, MCCP, LC-PFAA. **COP:** Methoxychlor; UV328, Dechlorane Plus

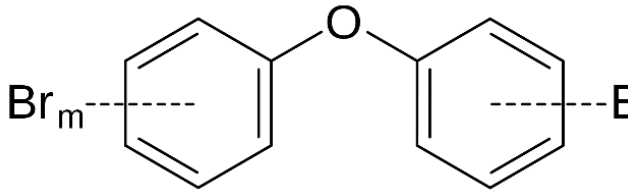
Nine of the new listed POPs are additives in plastic or have other links to plastic.

Five brominated flame retardants were listed in the SC since 2009.

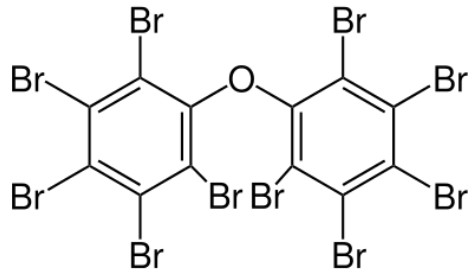
DecaBDE and HBCD received exemptions for continued production.

Polybrominated diphenyl ethers (PBDEs)

- Polybrominated diphenyl ethers (PBDEs) have been widely used as additive flame retardants since 1970s in plastics and synthetic fibers in electronics, vehicles and buildings.
- PBDEs were produced at three different degrees of bromination:
  - commercial Pentabromodiphenyl ether (c-PentaBDE) (stop 2004),
  - commercial Octabromodiphenyl ether (c-OctaBDE) (stop 2004)
  - commercial Decabromodiphenyl ether (c-DecaBDE) (still produced)



Decabromodiphenyl ether



- Proposal: 2013, Norway
- Risk profile: UNEP/POPS/POPRC.10/10/Add.2
- Risk management evaluation: UNEP/POPS/POPRC.11/10/Add.1

Production: Approx. 1,600,000 t **with ongoing production in China (<10.000 t).**
Past and current use: As a BFR used in electrical and electronic equipment in housings of computers and TV sets, in the transportation and aeronautic sectors and in construction and building, such as wires and cables, pipes and carpets, textiles, mainly for public buildings and transport and in domestic furniture textiles; in the adhesive layer of reflective tapes on work wear which are used as fire fighter uniforms & oil platforms.
Alternatives: Available but not for all countries.

→ Listed in: Annex A (**Decision SC-8/10**)

→ Production: Production allowed for exempted uses

→ Use: A range of exempted uses

→ Status: Several countries have registered exemptions

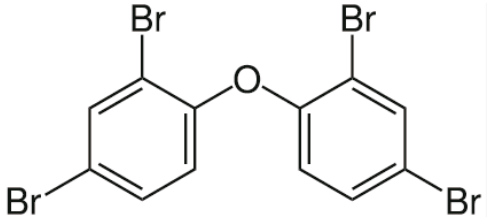
DecaBDE exemptions listed in the Convention

Following exemptions in accordance with Part IX of this Annex:

- **Textiles** that require **anti-flammable characteristics**, **excluding clothing & toys**;
- **Additives in plastic housings** and parts used for heating home appliances, irons, fans, immersion heaters that contain or are in direct contact with electrical parts or are required to comply with fire retardancy standards, at concentrations lower than 10% by weight of the part;
- **Polyurethane foam for building insulation**;
- **Parts for use in vehicles** specified in paragraph 2 of Part IX;
- **Aircraft** for which type approval has been applied for before December 2018 and has been received before December 2022 and **spare parts for those aircraft**.

Tetrabromodiphenyl ether and pentabromodiphenyl ether of c-PentaBDE

- **Proposal:** 2005, Norway (original proposal commercial PentaBDE)
- **Risk profile:** UNEP/POPS/POPRC.2/17/Add.1
- **Risk management evaluation:** UNEP/POPS/POPRC.3/20/Add.1



Production: Approx. 175,000 t c-PentaBDE 1970s to 2004 (90% in US). Ceased in Europe/Japan (in 1990s), in US/China (2004/2003).

Past use: **Most commonly as additive flame retardant in PUR foam; also in textiles and printed circuit boards**.

Currently: **In vehicles & furniture produced before 2005 (mainly US).**

Alternatives: Alternatives guidance FR alternatives to c- PBDE (POPRC 2008)
Profiles of Chemical FR Alternatives for PUR foam (USEPA 2005)

→ **Listed 2009 in Annex A (Elimination)**

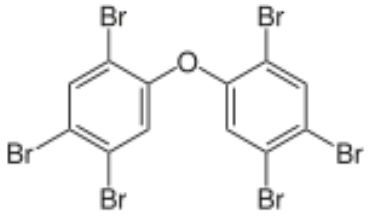
→ Production: **Total ban - No exemption**

→ Use: **Ban of use in new products**

→ Exemption for recycling of articles: May allow recycling of articles that (may) contain the chemicals, and the use and final disposal of articles manufactured from recycled materials that (may) contain the chemicals

Tetrabromodiphenyl ether and pentabromodiphenyl ether of c-OctaBDE

- Proposal: 2006, EU; original proposal c-OctaBDE
- Risk profile: UNEP/POPS/POPRC.3/20/Add.6
- Risk management evaluation: UNEP/POPS/POPRC.4/15/Add.1



Production: Approximately 130,000 t 1970s to 2004 (stop).

Past use: Most commonly used as a additive flame retardant in acrylonitrilebutadiene styrene (ABS) plastic. Other use: high impact polystyrene (HIPS), polybutylene terephthalate (PBT) and polyamide polymers.

Currently: Present in EEE older than 2004 and WEEE plastic & recycling

Alternatives: Available and already used since two decades.

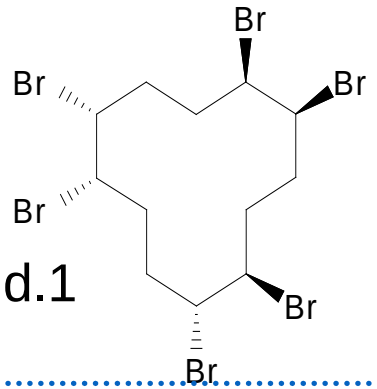
→ Listed in Annex A (Elimination)

→ Production: **Total ban - No exemption**

→ Use: **Total ban of use in new products and articles**

→ Exemption for recycling of articles: May allow recycling of articles that (may) contain the chemicals, and the use and final disposal of articles manufactured from recycled materials that (may) contain the chemicals

Hexabromocyclododecane



- Proposal: Norway 2009
- Risk profile: UNEP/POPS/POPRC.6/13/Add.2
- Risk management Evaluation UNEP/POPS/POPRC.7/19/Add.1

Production: Stopped 12/2021(last production was in China) within a GEF project

Major use: Flame retardant in expanded and extruded polystyrene (EPS/XPS) in insulation in construction (>90% of all historic use).

Past use (~2013): Flame retardant in textiles and high impact polystyrene (HIPS) in electronics

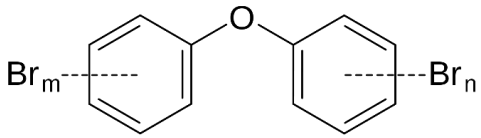
Alternatives: Available

→Listed in: **Annex A (Elimination) (2013 Decision SC-6/13;)**

→Production: **As allowed for the parties listed in the Register. All registrations for exemption have expired except China (stop 12/2021).**

→Use: **Exemptions for EPS/XPS in buildings in accordance with the provisions of Part VII of this Annex.**

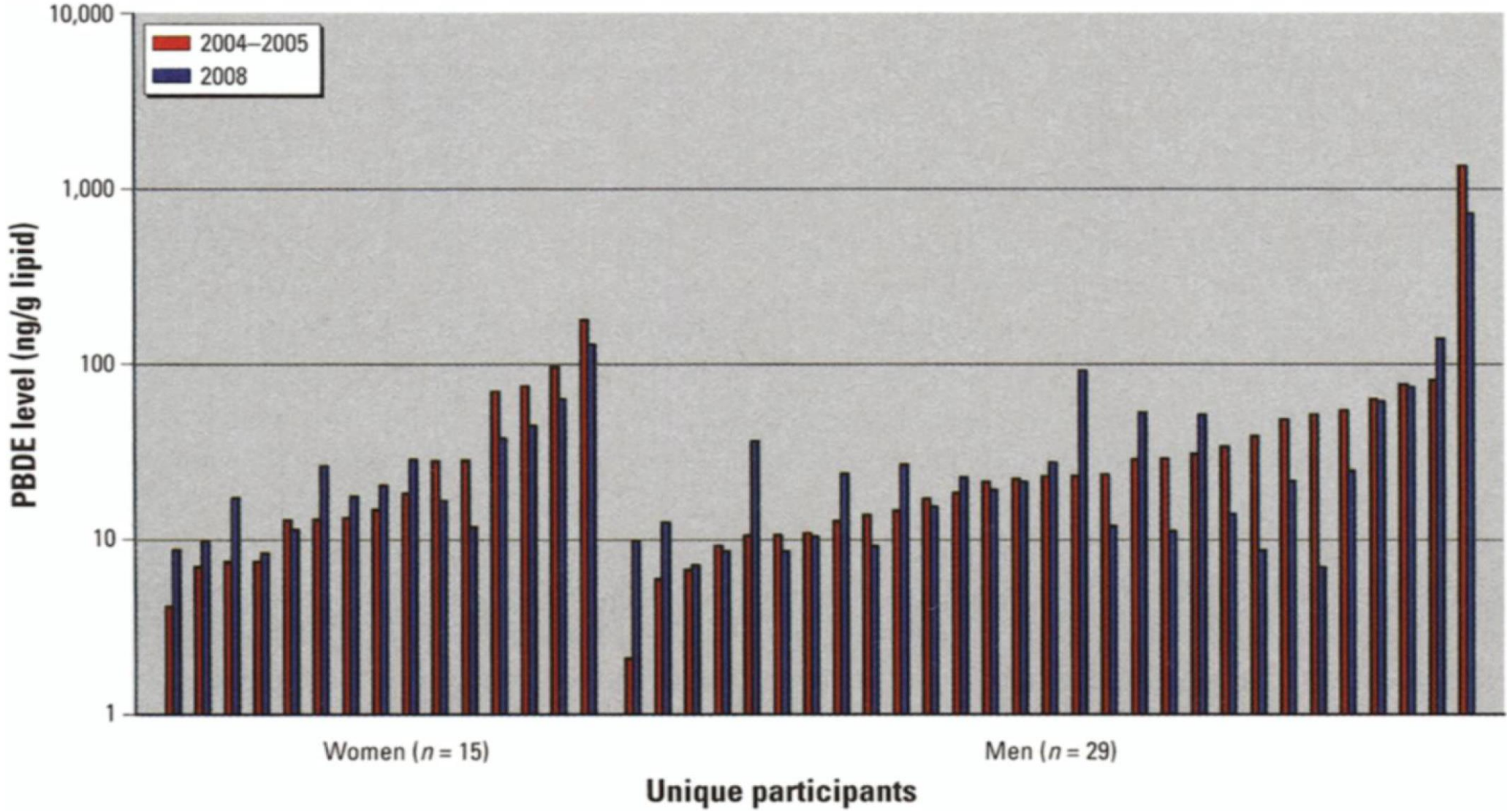
Effect of PBDEs on human health



- Many adverse effects have been associated with human exposure to PBDEs, including **endocrine disruption, reproductive effects, diabetes,** and **effects on fetal/child neurodevelopment**. (Birnbaum & Staskal (2004) EHP;112, 9-17;.Lim et al. (2008) Diabetes Care;31, 1802-1807).
- PBDE exposure adversely affects the developing nervous system in children. **c-PentaBDE is associated** with substantial **neurodevelopmental deficits**. **Children with higher PBDEs showed 5 to 8 points lower IQ** scores. (Herbstman et al. (2010) Environ Health Perspect 118, 712-719).
- In **Dutch children**, **prenatal exposure** to **pentaBDE** and HBCDs was associated with significant adverse effects on **motor, cognitive,** and **behavioral outcomes** (Roze et al. (2009) Environ Health Perspect 117:1953-8).
- Health cost in the US for PBDEs (c-PentaBDE) due to **IQ points loss** & **intellectual disability** were estimated to **266B US$/a** (Attina et al. (2016) The Lancet 80, 345-350) and in EU to 9B Euro/a (Trasande, et al. (2015). J Clin Endocrinol Metab, 100(4), 1245–1255.
- DecaBDE has lower toxicity but degrade to the lower brominated more toxic PBDEs and has strong potential to form PBDD/PBDF (Shaw et al. Rev. Environ. Health 25(4), 261-305. http://greensciencepolicy.org/wp-content/uploads/2013/11/Review-of-Env-Health-2542010-SHAW-BLUM-.pdf).

PBDE levels in blood of Wisconsin/US cohort

PBDE levels in blood of individuals in Wisconsin cohort show two order of magnitude (100 times) differences between individuals. Specific exposure by PentaBDE treated pillow, vehicle, furniture.



Imm et al (2009), EHP. 117(8) 1890-1895 https://ehp.niehs.nih.gov/doi/10.1289/ehp.0900839

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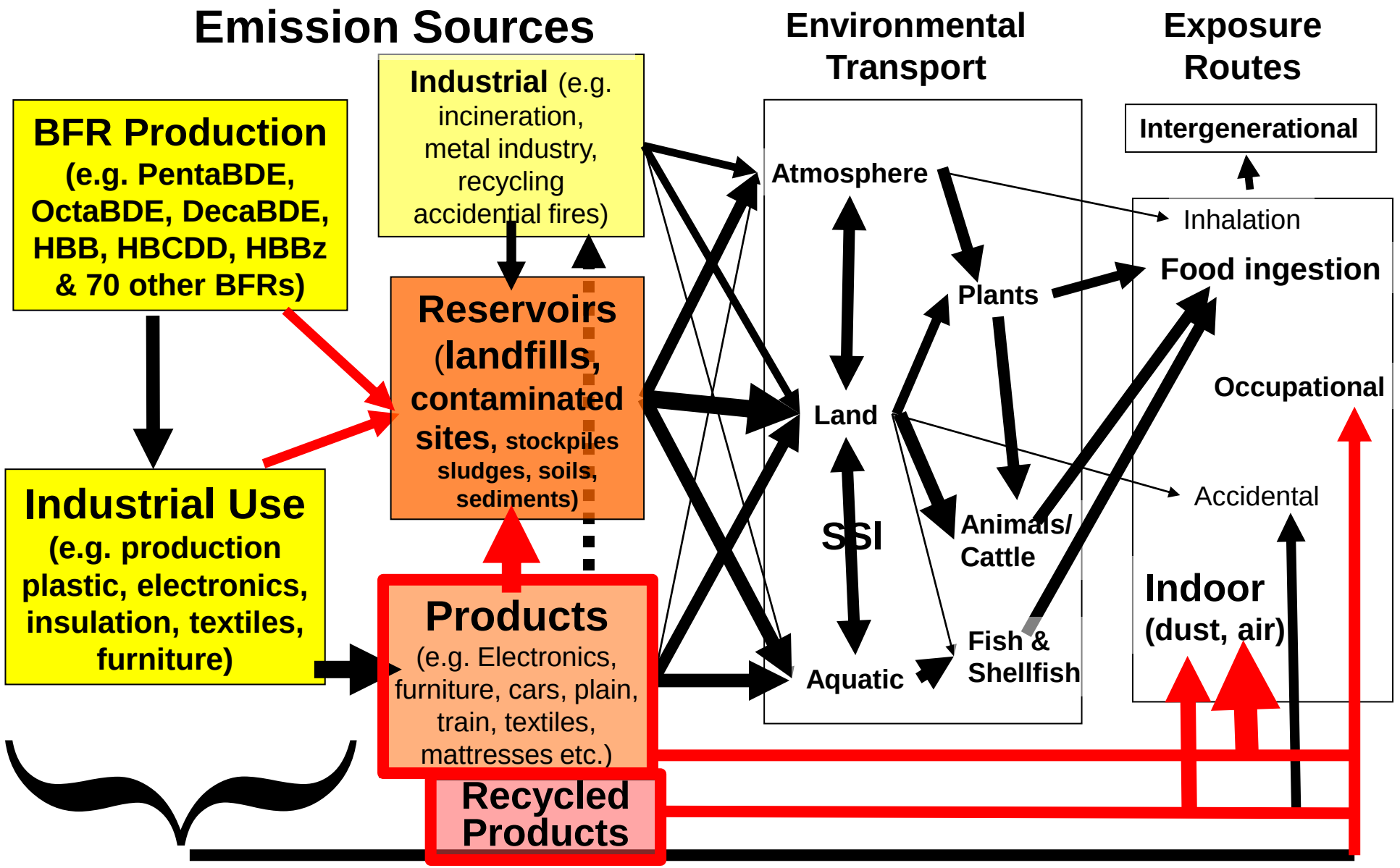
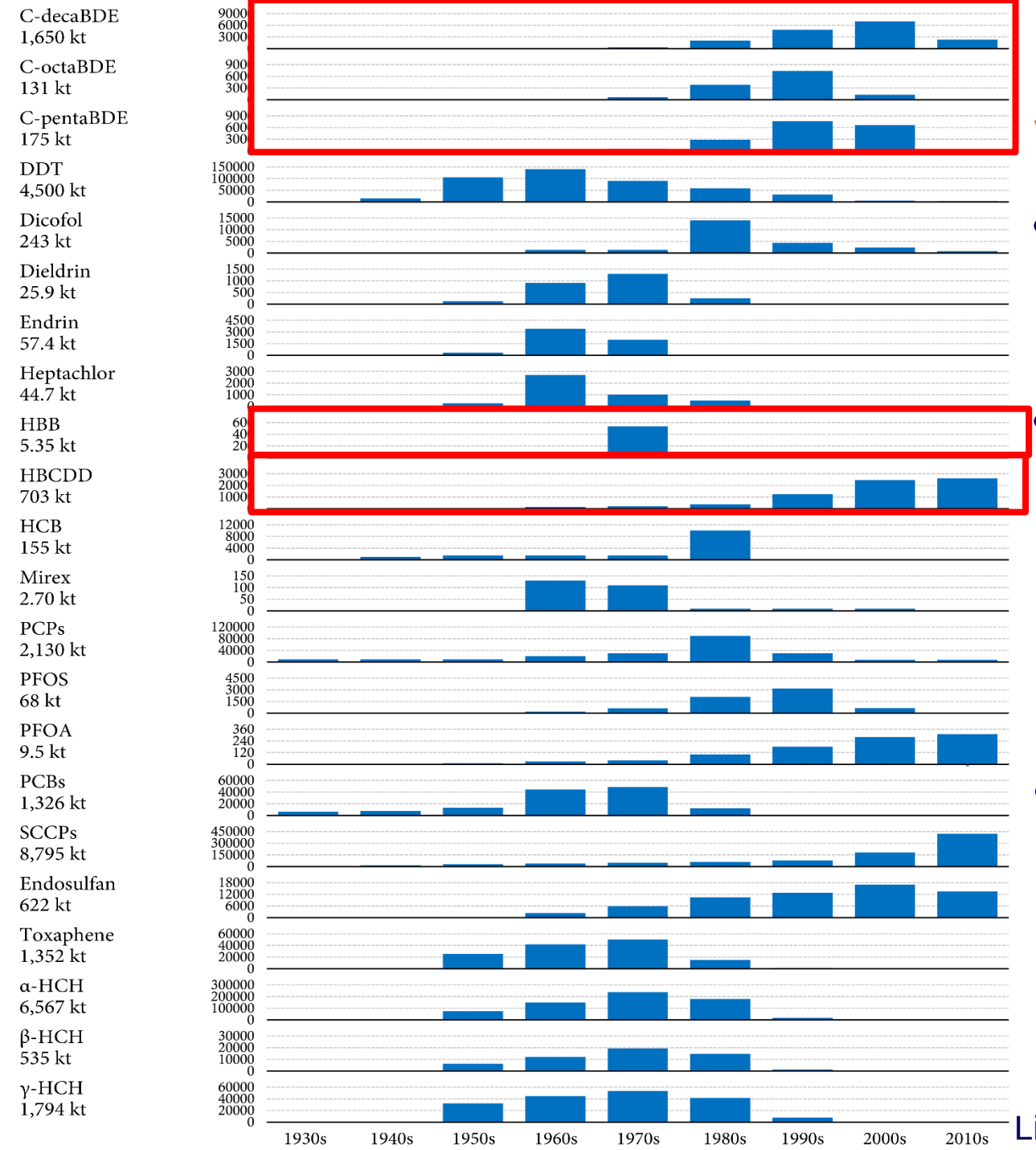
Life-Cycle PBDEs/BFRs



Some POP-BFRs were used in high volumes - ongoing use of DecaBDE



- The high **volume POPs additive DecaBDE is still produced (<10,000 t/a) and HBCD has been produced untill recently (HBCD stop 12/2021).**
- **1.9 MT PBDE have been produced**. With an **additive amount of 10%, ~19 MT POP plastics**.
- **0.7 MT HBCD** has been produced until 2021. 90% used in EPS/XPS at ca. 1.5% resulting in **42 MT** of EPS/XPS largely still present as insulation foam.
- **0.005 MT HBB** has been produced 1970-1976 (US). These products have largely been disposed in past 50 years and maybe some classic cars still in use.

Li et al. (2023). Environmental Science: Advances.

Major uses of commercial PBDE mixtures

- Uses of c-DecaBDE and c-OctaBDE (hexaBDE and heptaBDE) in all major uses (electronics, construction, transport and textiles)
- Major use of c-PentaBDE in foams in furniture, construction & transport (also a major use of treated textile/foam in transport).
- **The long service life in construction will make this sector more relevant for PBDE management in future.**
  - Please note that more than 90% of c-PentaBDE were used in USA.

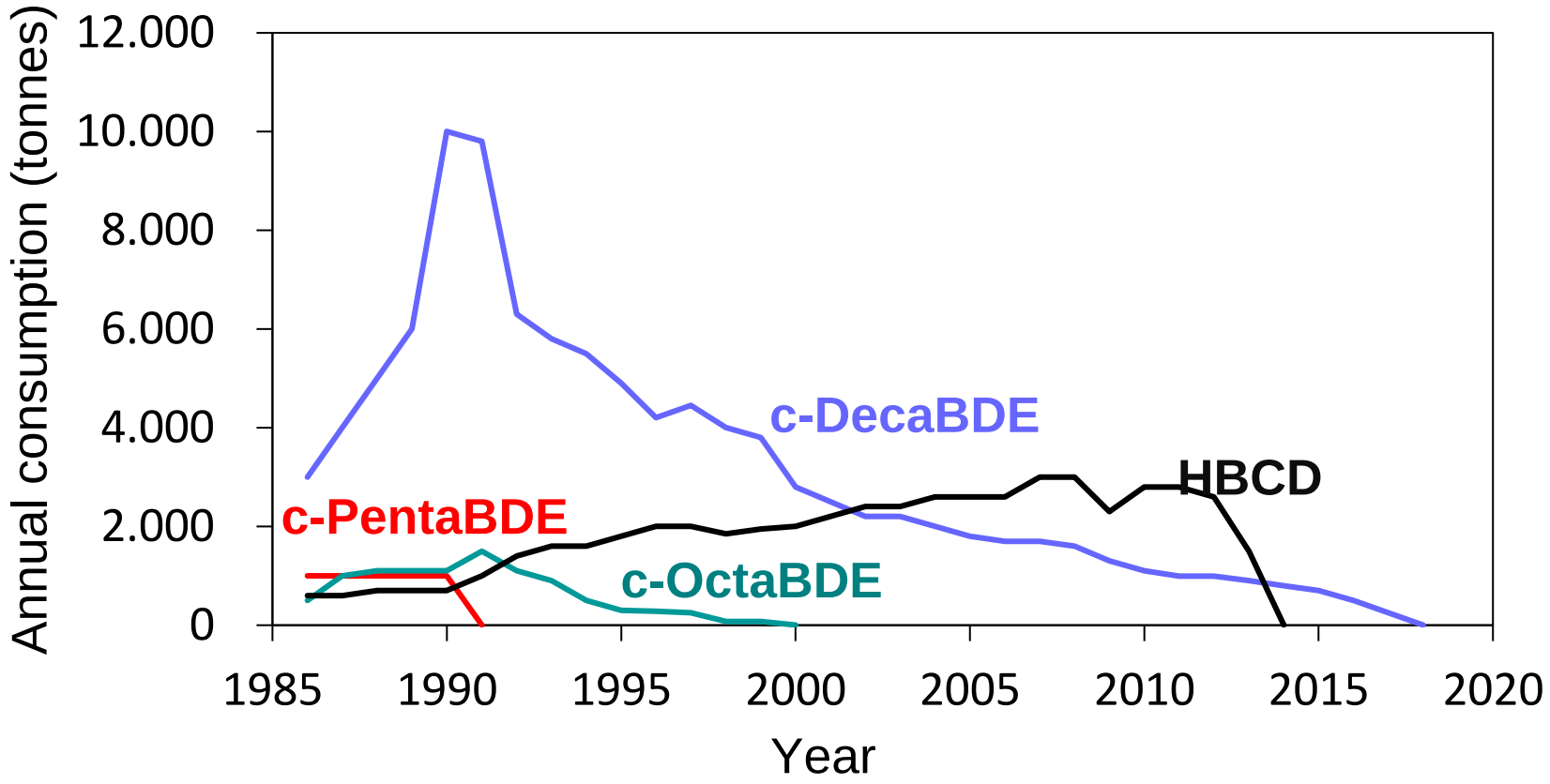
Applications (AP)	Commercial **PentaBDE**	Commercial **OctaBDE**	Commercial **DecaBDE**	**Average lifespan**	**HBCD**
AP1: electronics	10%	40%	30%	7	<3%
AP2: foam and carpet	50%	15%	25%	10	
AP3: construction	20%	25%	20%	32	**90%**
AP4: transportation	15%	15%	15%	15	<3%
AP5: textile	5%	5%	15%	10	<8%

Abassi et al. (2019) Environ. Sci. Technol. 2019, 53, 6330−6340; based on UNEP PBDE inventory guidance 2012. And US EPA alternative assessment for the flame retardant DecaBDE.

Production/use history of POP-BFRs (Japan)

Japan has an inventory of the former use amount and time trend of PBDEs.

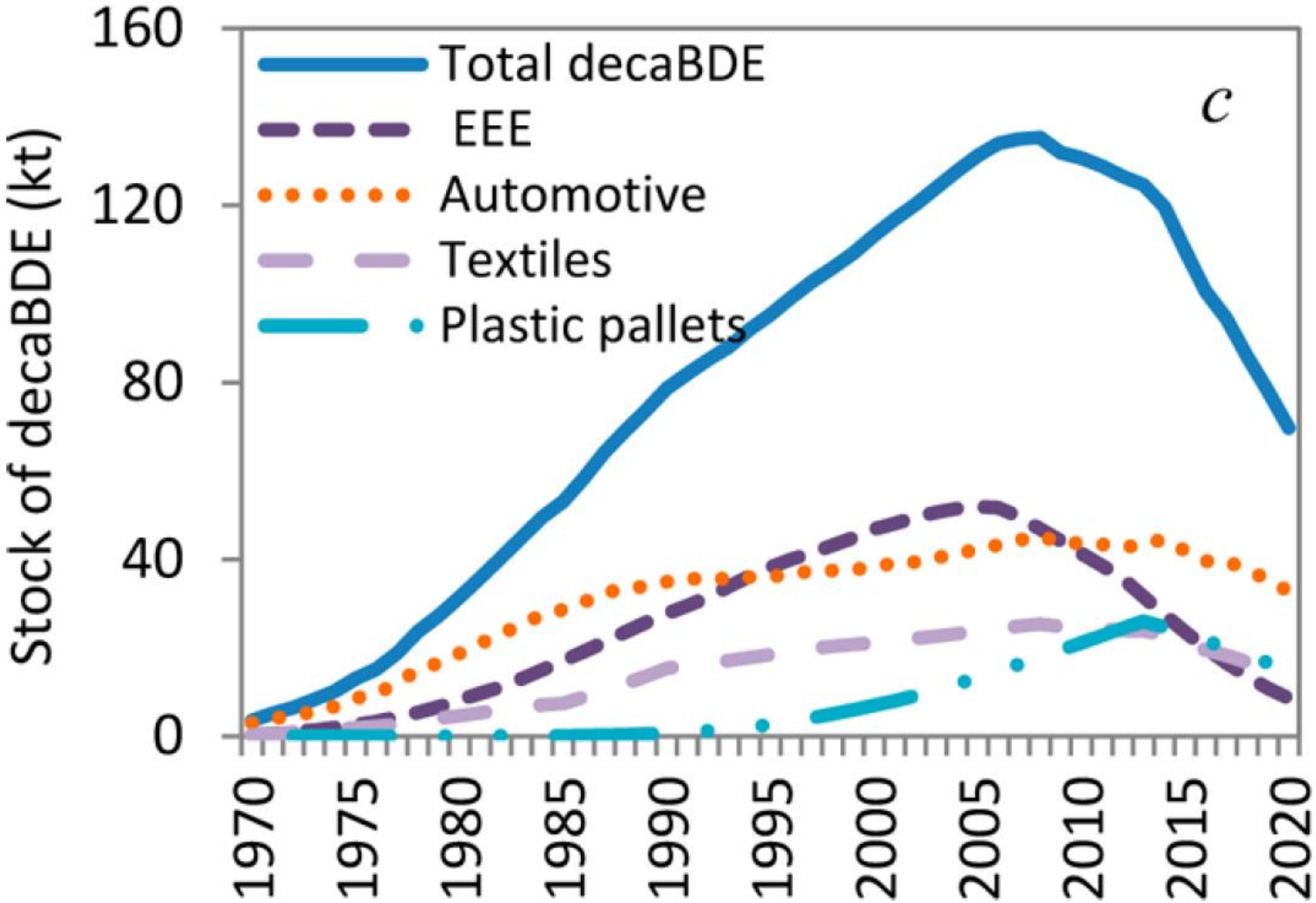
- The use of DecaBDE and HBCD in vehicles in Japan were voluntarily ceased by the end of 2016 and 2010, respectively.
- The timing and use of PBDEs is different in other countries. E.g. the US has used PentaBDE & OctaBDE until 2004. Chinese HBCD production and use stopped 11/2021.



Kajiwara N (2020) Presentation Stockholm Convention workshop, N

Time trend DecaBDE in in-use products US & Canada

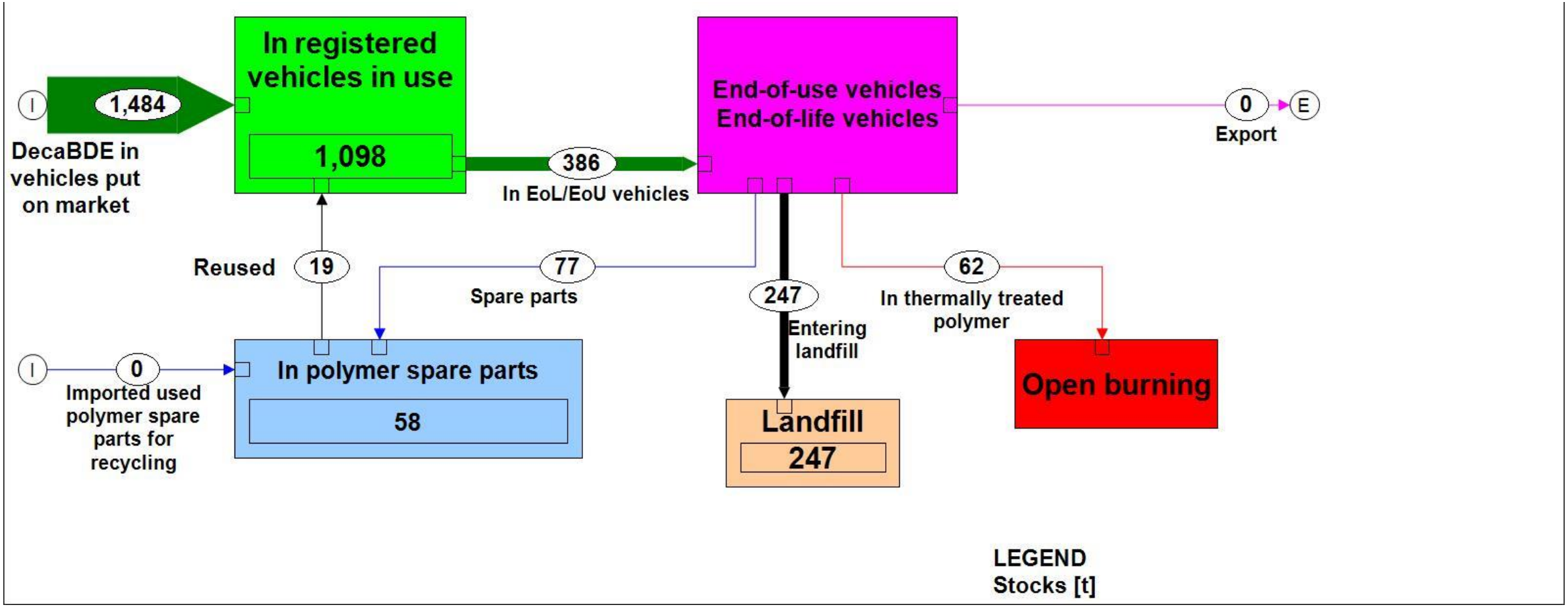
- Largest stock of DecaBDE in transport sector with long service life!
- In **developing countries** the **electronics and vehicles are used longer!**



Abbasi et al., (2015) Environ Sci Technol 49(3), 1521-1528

Materials and substance flow of DecaBDE in vehicle fleet in Nigeria

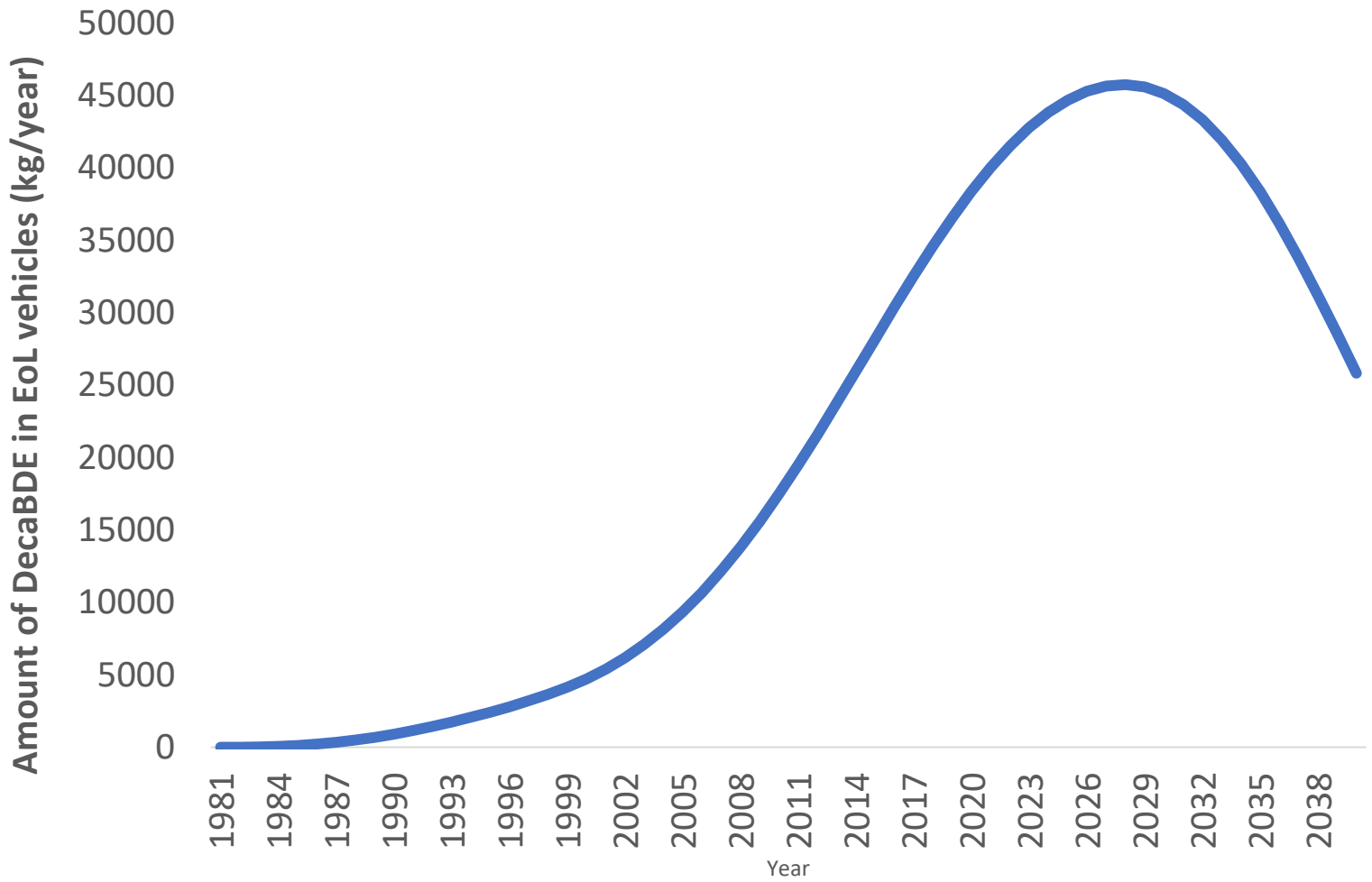
- 1480 t of decaBDE entered Nigeria in vehicles and more than 1000 t are still in vehicles in use
- 380 t of decaBDE in end-of-life vehicles with 250 t disposed to landfills in **800,000 t of plastic**
- 77 t of decaBDE were reused in spare parts from which 58 t are in still in stocks**!**
- 62 t decaBDE contained in were openly burnt together with 200,000 t of plastic from EoL vehicles



UNEP (2023) Sectoral guidance for inventories of POPs and other chemicals of concern in buildings/construction, electrical and electronic equipment, and vehicles. Annex 3: Inventory of POPs in the Transport Sector in NIGERIA.

Time trend of DecaBDE in end-of-life vehicle in Nigeria (1980 to 2040)

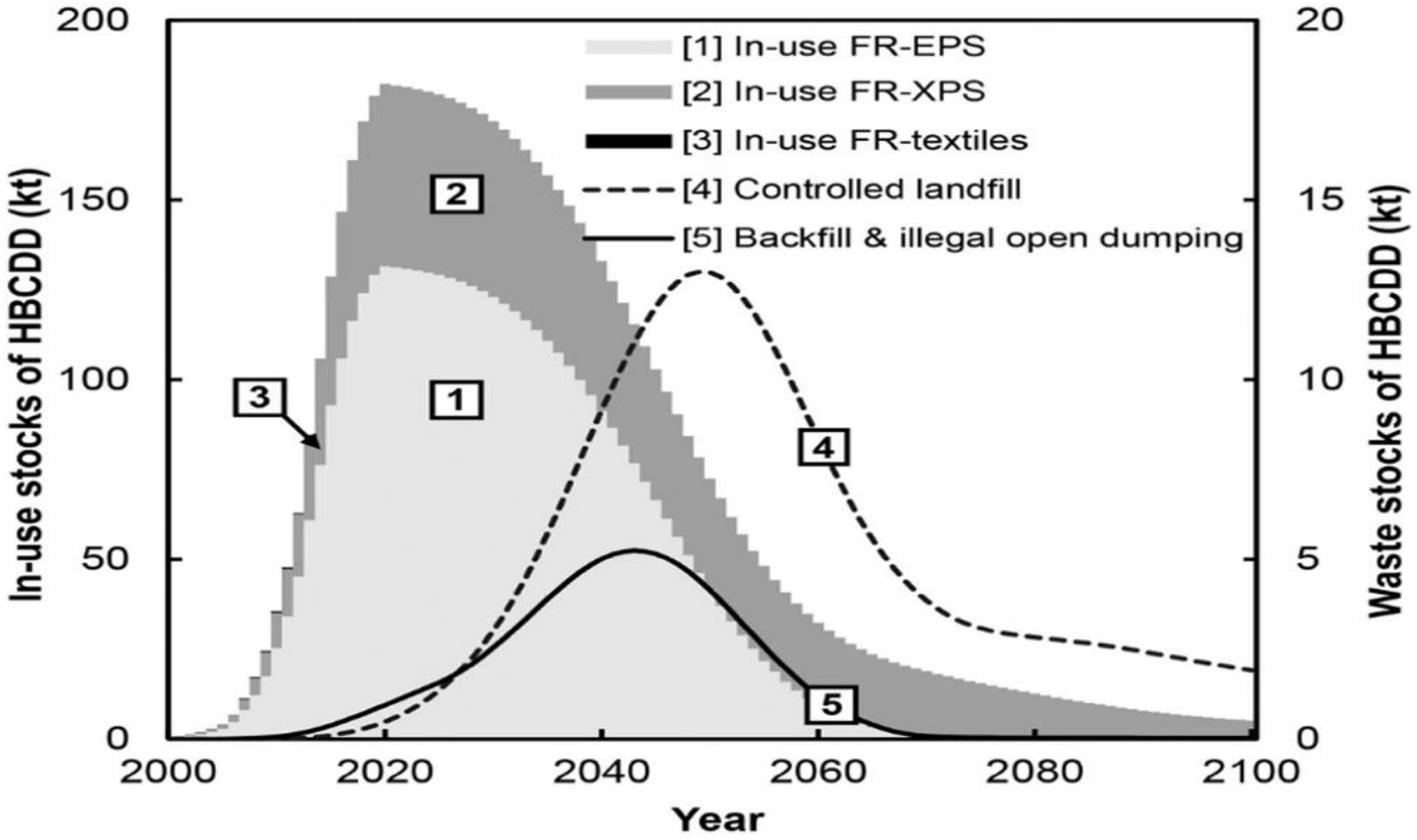
- Relevant stock of DecaBDE in transport sector with long service life in **developing countries** !
- The amount of DecaBDE in vehicles is still increasing in Nigeria (and other developing countries) due to the import of used cars produced in the last 20 years.



UNEP (2023) Sectoral guidance for inventories of POPs and other chemicals of concern in buildings/construction, electrical and electronic equipment, and vehicles. Annex 3: Inventory of POPs in the Transport Sector in NIGERIA.

Dynamic material and substance flow analysis of HBCD in construction sector and wastes

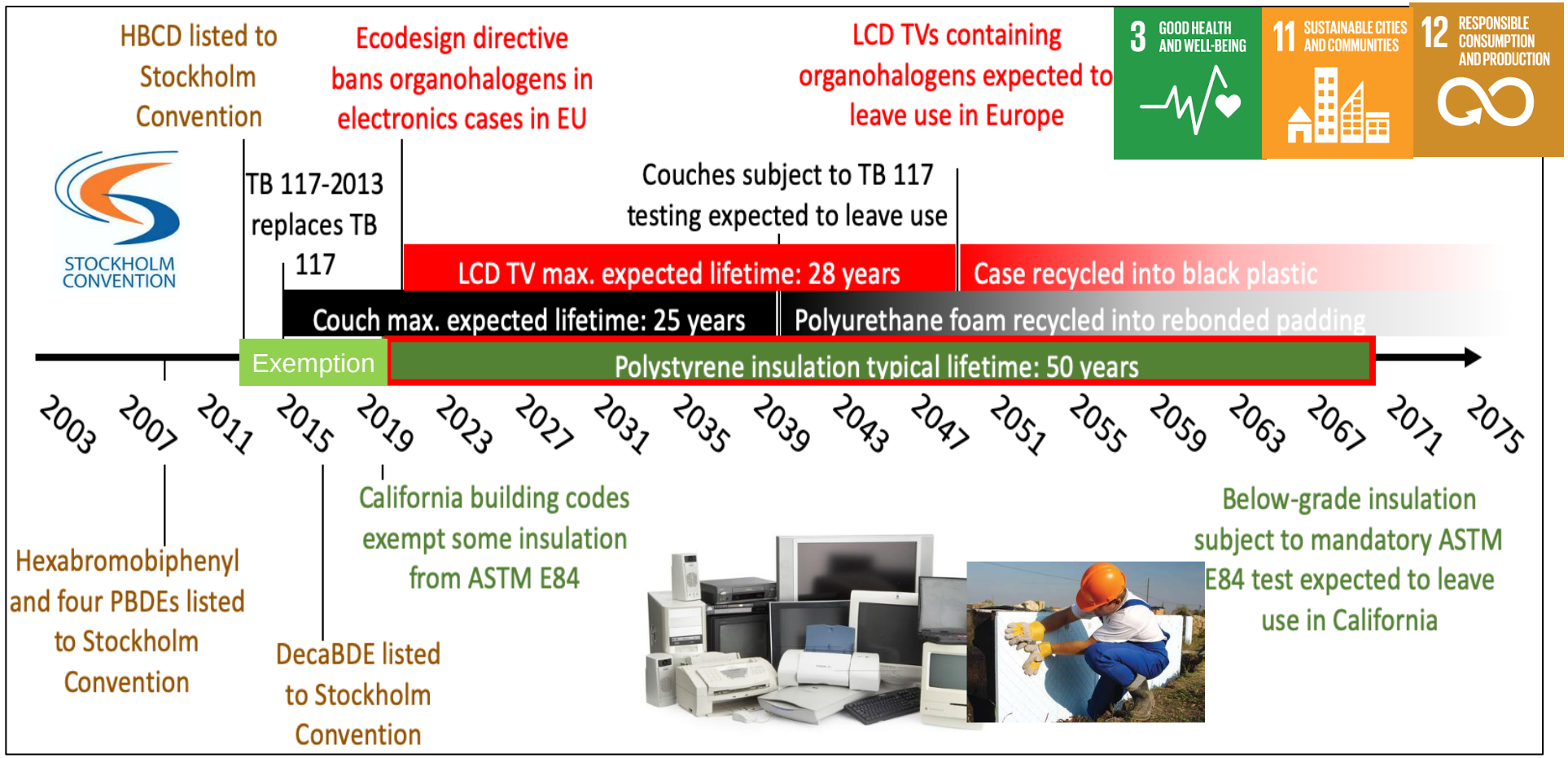
Dynamic MFA/SFA of HBCD containing EPS/XPS for China indicate that maximum HBCD-EPS/XPS waste will be generated around 2050 but that also 2100 and longer HBCD-EPS/XPS waste will be generated!



Li, Weber et al. (2016) Long term emission HBCD in China, Environ Int. 91, 291-300.

Brominated Flame Retardants (BFRs; HFRs) in Products and related Waste & Recycling

- Several products containing legacy POP-BFRs have long service life.
- Therefore they can reach recycling cycles for decades or even longer.
- If these POPs in polymers are recycled then they will impact longer.

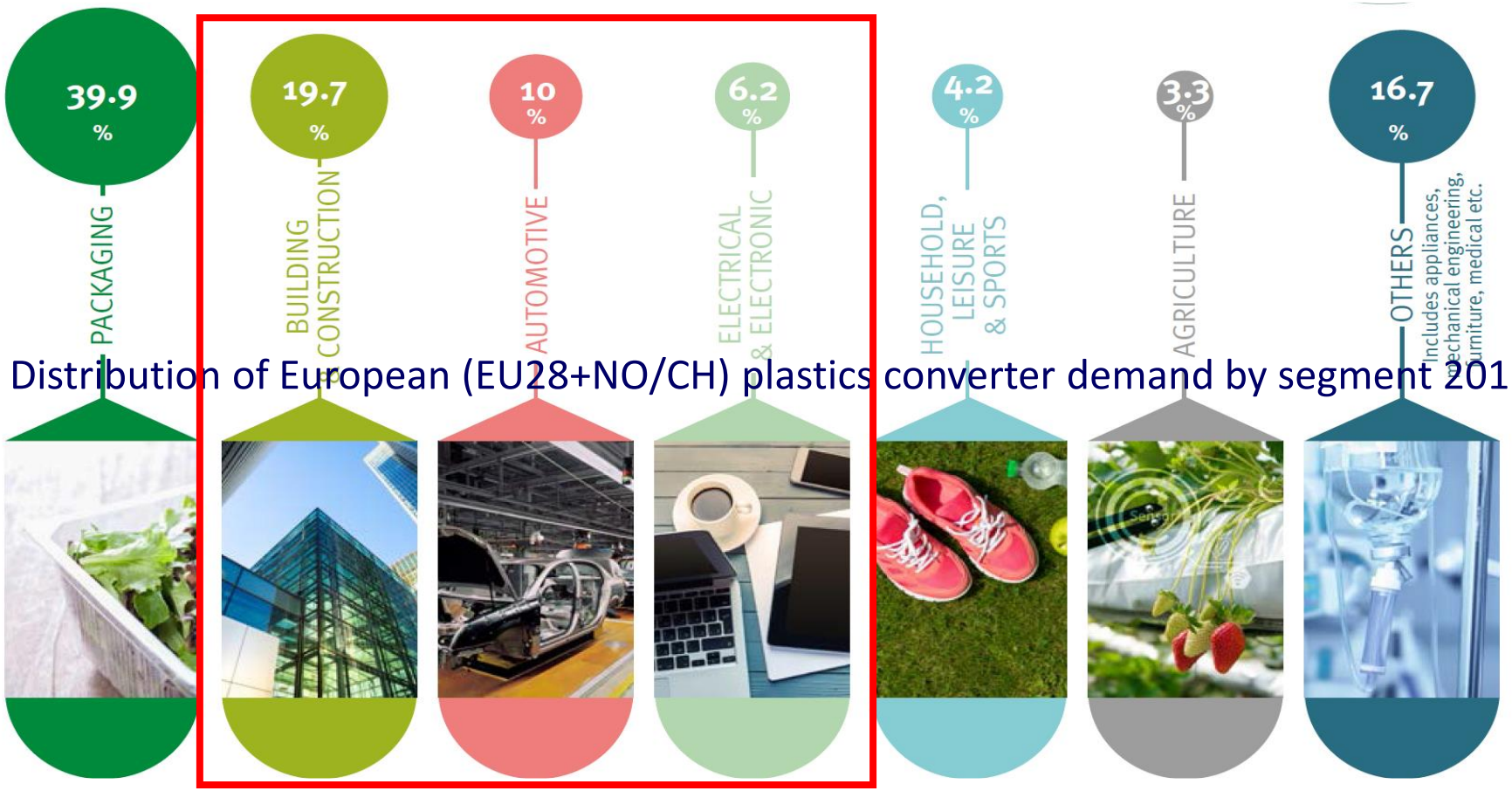


Charbonnet, Weber, Blum (2020) Emerg. Contam. https://www.sciencedirect.com/science/article/pii/S2405665020300160

The major plastic uses containing PBDE/HBCD affect large sectors

These plastic use categories contain hazardous additives which are difficult to recycle or cannot be recycled:

- POP-BFRs affect plastics in vehicles, electronics and buildings (and additional textiles)
- Chlorinated paraffins (SCCPs listed as POP; MCCP proposed as POP) and heavy metals (e.g. in PVC)
- Certain UV stabilizer, phthalates, bisphenols and other endocrine disrupting chemicals



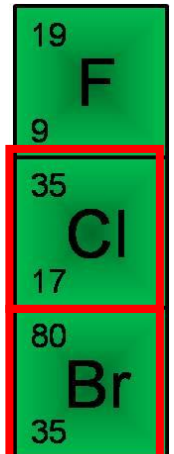
- Distribution of European (EU28+NO/CH) plastics converter demand by segment 2016

Source: PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH

POP-BFRs are contained in large waste flows – plastic in vehicles

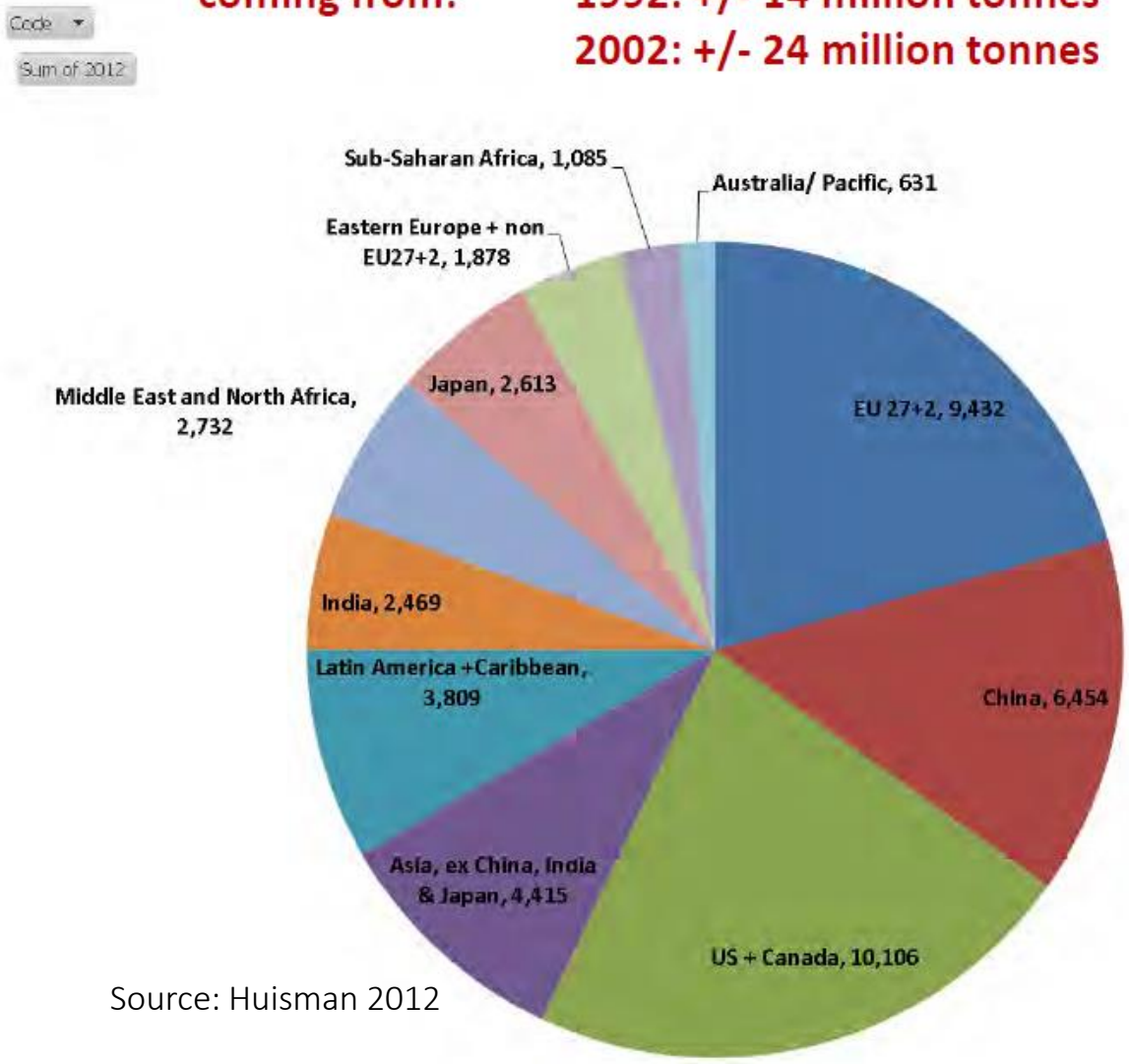
End-of Life Vehicle and related BFR containing plastic/polymer waste

- The global light-duty vehicle fleet is **1.31 billion vehicles** (2020) expected @2.2 billion by 2050.
- With a service live of approx. 20 years approx. ~65 million ELVs/year. Considering that an average vehicle contain approx. 200 kg of plastic/polymers, every year ~13 million tonnes of plastic and other polymer **waste partly containing BFR** (& CPs, PFOS/PFOA, PFRs).
- After shredding, plastic/foam/rubber/glass fraction with challenges to recycle. **Pre-separation?**
- High halogen (chlorine, bromine, lower fluorine) content with challenges of thermal treatment.
- In Europe ELV directive vehicle require recycling rate (85%) and recovery rate (95%) which require that some of the plastic fraction is recycled.



E-waste fastest growing waste stream – POP plastic fraction

coming from: 1992: +/- 14 million tonnes
2002: +/- 24 million tonnes



Source: Huisman 2012

2019 total: ~53.6 million tonnes

2030 estimate: ~74 million tonnes

Average plastic in EEE: ca. 20%. Therefore now 10 million t WEEE plastic/year.

WEEE categories and related plastic share

The average share of plastic in EEE/WEEE is ~20%. Therefore the 53.6 million tonnes of **WEEE contain ~10.7 million tonne WEEE plastic/year increasing.**

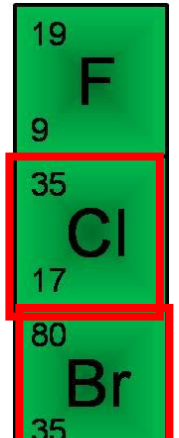
WEEE Category/Product Category		Plastic share [in % by weight]	Annual plastic flow in the EU [in t/year]
1	Large household appliances w/o cooling appliances	19%	**500'500**
1	**Cooling and freezing appliances**	28%	**473'100**
2	**Small household appliances**	37%	**369'400**
3	**ICT equipment w/o screens**	42%	**317'600**
3	**Computer screens (CRT and flat)**	20%	**156'100**
4	**Consumer equipment w/o screens**	24%	**180'900**
4	**TV screens (CRT and flat)**	20%	**200'100**
5	Lighting equipment – Lamps	3%	**7'300**
6	Electrical and electronic tools	11%	**37'800**
7	Toys, leisure and sports equipment	73%	**7'600**
8	Medical devices	3%	**400**
9	Monitoring and control instruments	60%	**11'900**
10	Automatic dispensers	20%	**3'500**
	Total amount	**Average of ca. 20%**	**2'266'100**

Estimation of the total plastic quantities in European WEEE for the year 2008. Printed wiring boards and cables are not included.
(Source: Wäger et al. 2010)

POP-BFRs are contained in large waste flows – Chance for environmental sound waste management

E-waste/WEEE plastic (EU WEEE directive)

- Only a fraction of the WEEE plastic contain PBDEs.
- Heterogeneous plastic fraction with challenges to recycle (downcycle).
- High halogen content with associated challenges in thermal treatment The bromine content of WEEE plastic shredder fractions were 1.7 - 5.2% and the chlorine content 0.1 to 4.4% (Schlummer et al. 2007).
- EU WEEE directive require separation of WEEE plastic BFR fraction.
- Then appropriate treatment needed.



Brominated Flame Retardants (BFRs; HFRs) in Products and related Waste & Recycling

- Electrical device plastic (computer, TV, cables, etc.) ending up in E-waste,

  Recycling/treatment of WEEE plastic

- Transport sector (plastic, textile and upholstery in cars, trains, air plane)

  Recycling/treatment of polymers/SR

- Textiles, curtains, carpets, mattresses. US: Baby/kids sleep wear.

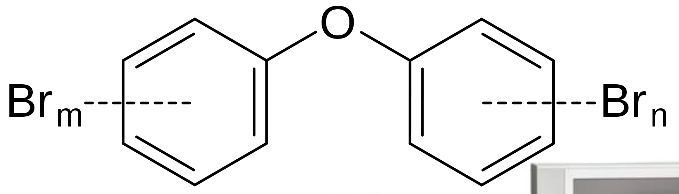
  Recycling/treatment of PUR; textiles

- Insulation in construction materials (increasing with increasing GHG incentives for insulation of houses)

  Recycling/treatment of insulation

PBDEs in the Stockholm Convention (SC) and recycling

- TetraBDE, pentaBDE, hexaBDE & heptaBDE (homologues to restrict c-PentaBDE & c-OctaBDE) were listed in the **Stockholm Convention 2009 in** Annex A.
- Some **PBDE containing materials** (e.g. **WEEE plastic**) **are recycled to some extent** and a **restriction of recycling of PBDE** containing materials **might have resulted in the stop of these polymer recycling activities globally**.
- **Therefore for the PBDE listed** in **2009** (tetra- to heptaBDE) **the Stockholm Convention included an exemption for recycling of tetra- to heptaBDE containing polymers**.
- **But when DecaBDE was listed in the SC 2017**, **no exemption for recycling** has been requested. Therefore decaBDE containing plastic cannot be recycled & need a phase out.

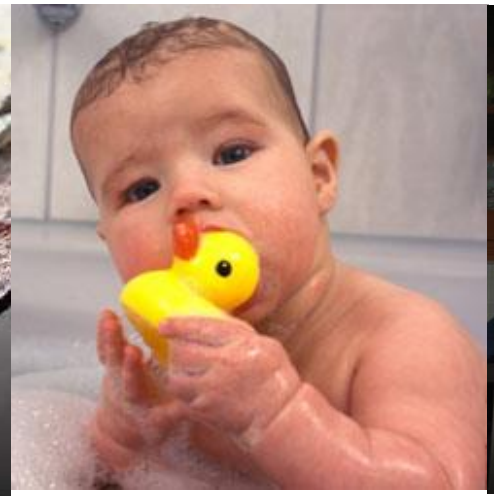


STOCKHOLM CONVENTION

PBDE/BFR Contamination of Recycled Plastic

- What is the flow of PBDE/BFR in recycled materials? What articles are contaminated? What are risks to human and the environment?

PBDE in carpet padding
(DiGangi et al, OHC , 2011)



PBDE in children toys China
(Chen et al, ES&T 43, 4200, 2009)

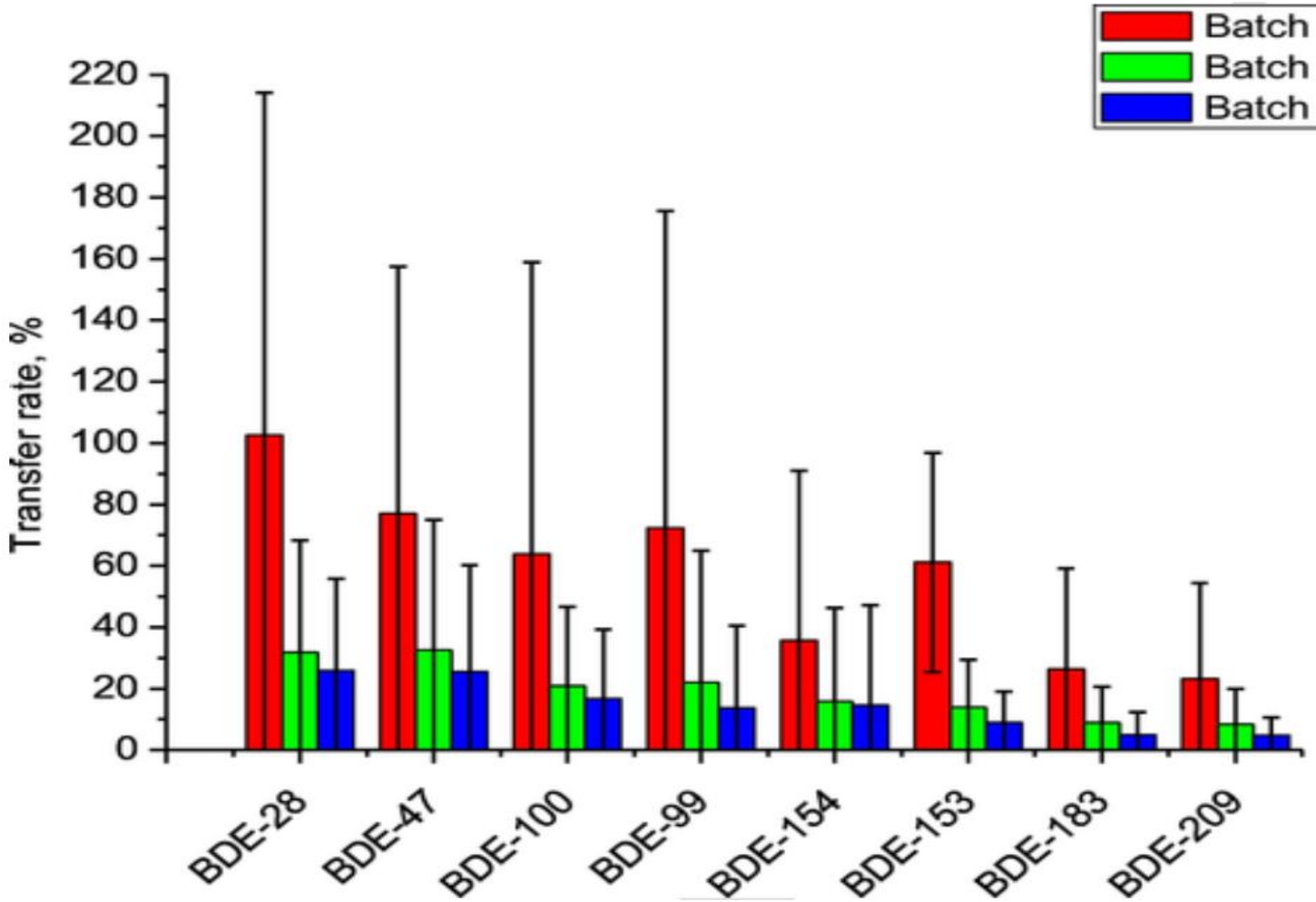
PBDE in thermo-cup (Samsonek & Puype Food Add. & Contam. 2013)

⇒ The recycling flow of PBDE/BFR containing plastic seems largely uncontrolled. Need a better life cycle management & control!

⇒ Recycling sector needs considerable improvement and BAT/BEP for separation of problematic materials. Not into sensitive uses! Global SC approach came to the right time.

BFR exposure from recycling – kitchen tools

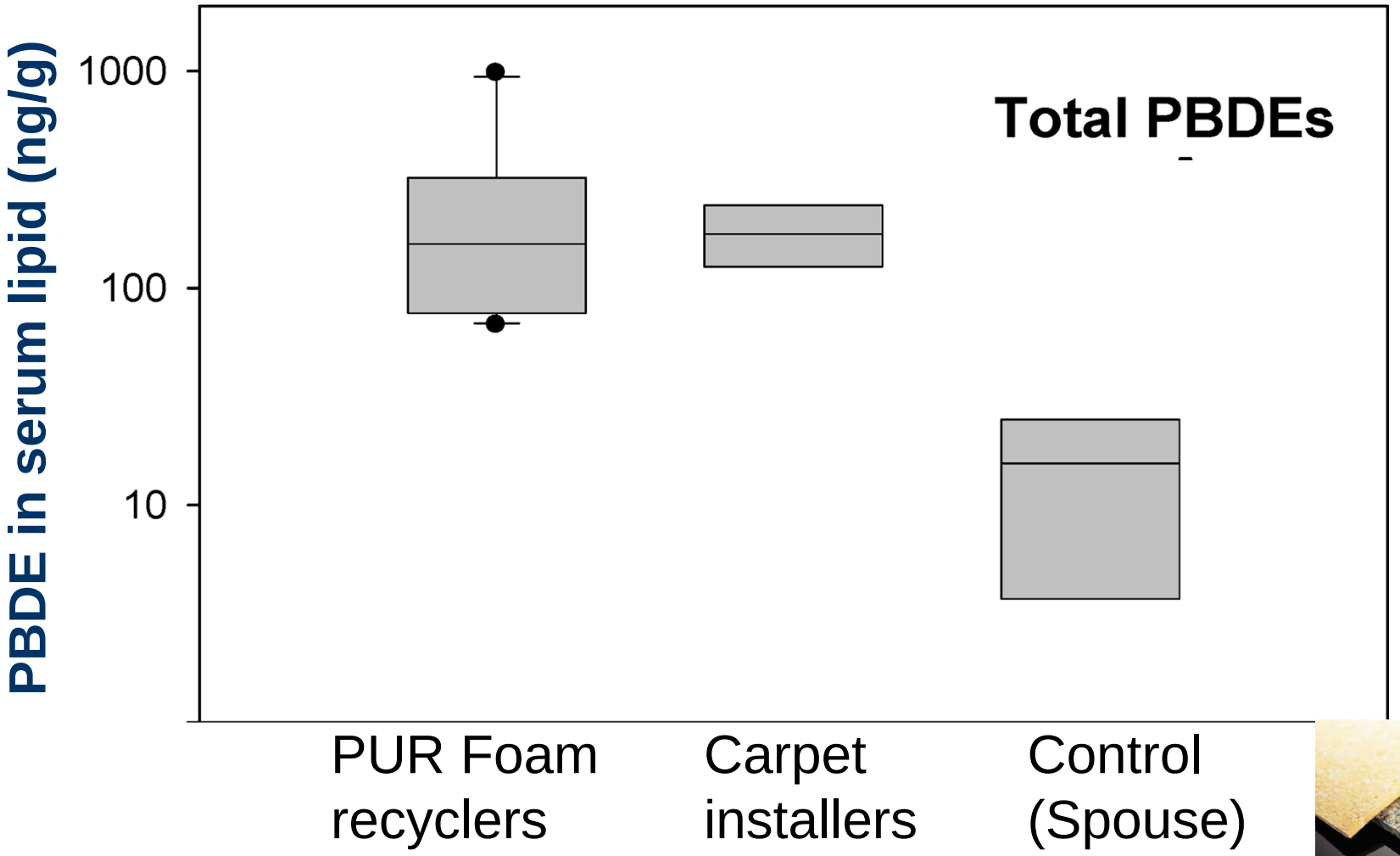
- Brominated PBDEs in kitchen tools are “extracted” in hot cooking oil within 15 minutes.
- Low brominated PBDEs are extracted with high efficiency already within 3 cookings. The higher brominated PBDEs are slower extracted and partly debrominated to lower PBDEs.



Kuang et al. (2017) Science Total Env, 610-611:1138-1146.

Assessment of Possible Health and Environmental Impact: Recycling of Polyurethane Foam & Human Exposure (US)

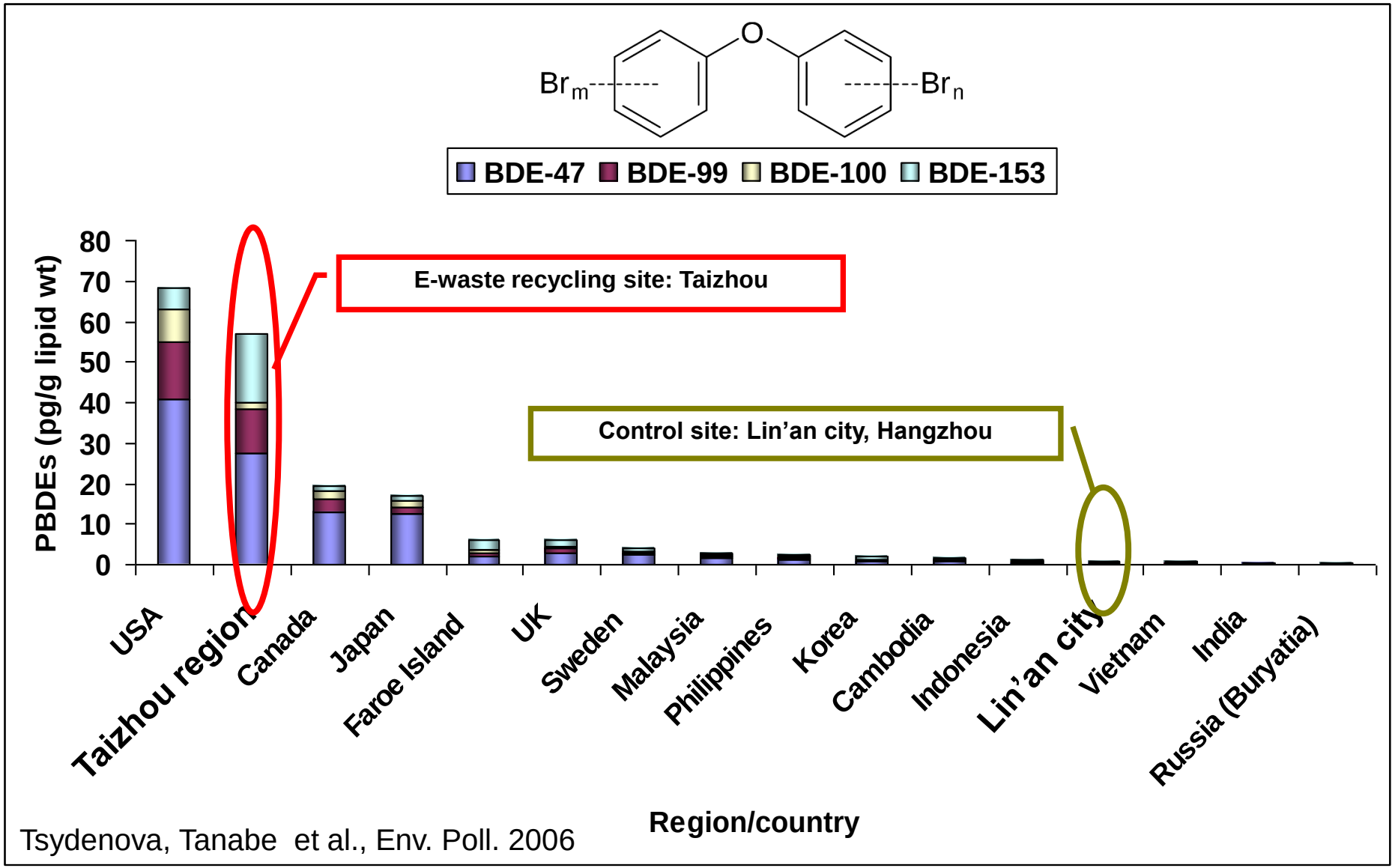
PBDE levels in workers recycling Polyurethane Foam (US)



Source: Stapleton et al. ES&T 42, 3453 (2008)

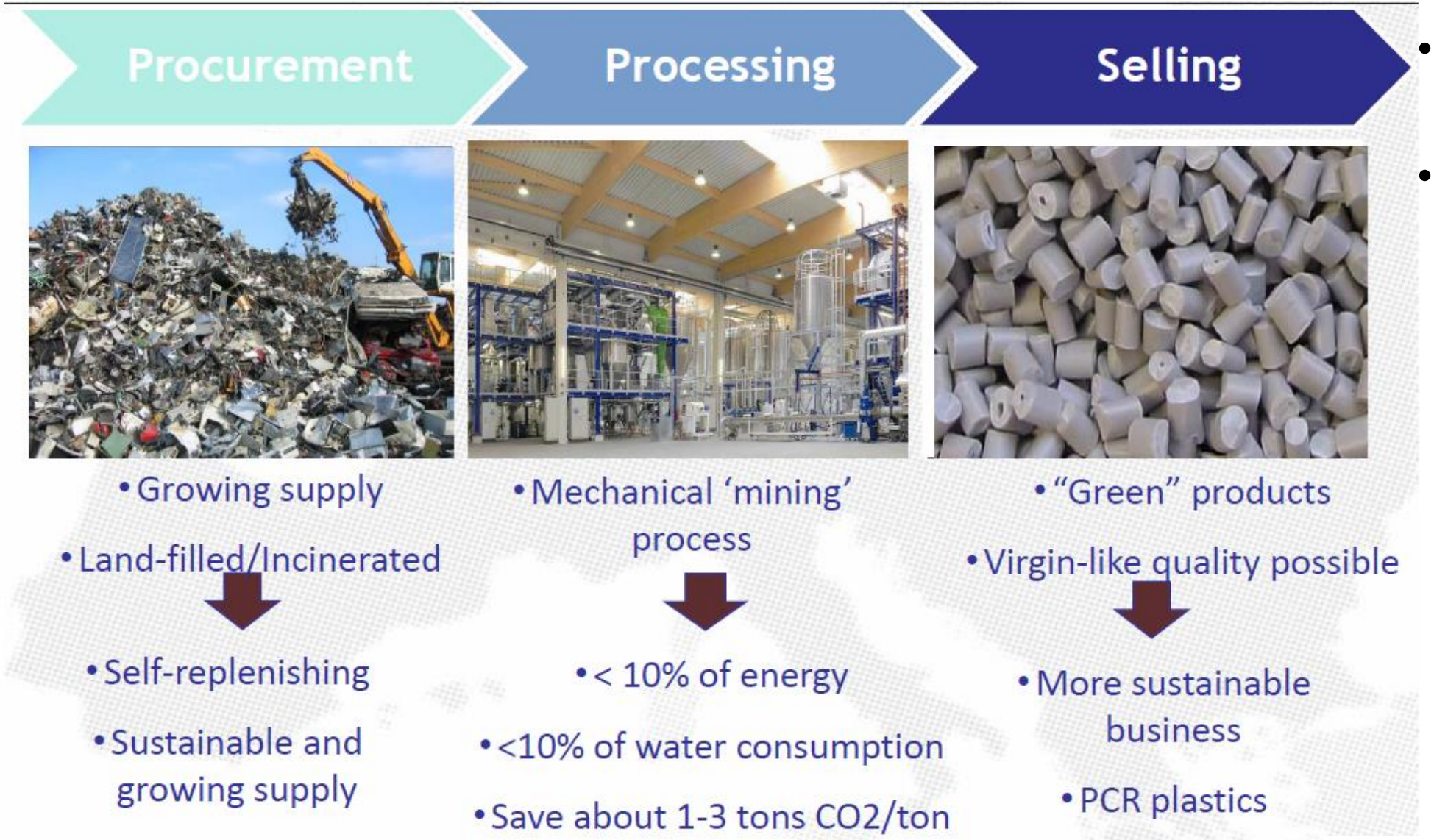
Global Comparison of PBDEs in Human Milk

Large scale recycling of e-waste resulted in pollution (PBDEs, PCBs, lead, other heavy metals) in Chinese recycling cities (such recycling have largely stopped in China but continues elsewhere).



Tsydenova, Tanabe et al., Env. Poll. 2006

Moving towards more circular WEEE plastic management with separation



- Ca. 60% of plastic is recycled. Best go back to production of EEE.
- Ca. 40% of plastic cannot be recycled (PBDEs/BFR; plastic mixture) and are thermally destroyed/ recovered.

Stockholm Convention PBDE BAT/BEP guidance including separation techniques

Chris Slijkhuis (2018) MBA Polymers THE PLASTICS RECYCLING PROFESSIONALS **Now Müller-Guttenbrunn**

Plastic & POP-PBDE content in EEE/WEEE plastic

Total polymer fractions and c-octaBDE (hexaBDE/heptaBDE) and decaBDE concentrations in relevant EEE categories (data from Europe; Waeger et al., 2010; Hennebert & Filella 2018)

Relevant EEE	Total polymer fraction (mean)	Hexa/heptaBDE content (mean) in plastics	DecaBDE content (mean) in plastics
	$f_{Polymer}$ [in % by weight]	$C_{\sum hexa/heptaBDE;Polymer}$ in [mg/kg]*]	$C_{decaBDE;Polymer}$ in [mg/kg]*]
Cooling/freezing appliances; washing machines	25%	**<50**	**<50**
Heating appliances	30%	<50	**800**
Small household appliances	37%	<50	170
ICT equipment. w/o monitors	42%	120	**800**
CRT comp. monitor casings	30%	**1370**	**3200**
Consumer equipment w/o monitors (1 composite sample)	24%	80	**800**
TV CRT monitor casings	30%	**470**	**4400**
Flat screens TVs (LCD)	37%	9	**2750**

*RoHS limit for c-octaBDE or decaBDE is 1000 mg/kg or 0.1 wt %.

Proposed low POP content is **1000 mg/kg or 500 mg/kg or 50 mg/kg**

UNEP (2019) Stockholm Convention PBDE inventory guidance. UNEP/POPS/COP.9/INF/18

Separation and upgrading steps in the recycling of (WEEE) plastic: Combination of technologies

A range of full scale plants to separate PBDE/bromine-containing WEEE polymers operate (list from SC guidance).

WEEE input	Separation techniques	Polymers Separated	Quality of separated polymers	PBDE/bromine Elimination (RoHS compliant products)	Development Stage*	Reference
Mixed polymer from WEEE (Austria, China)	Not disclosed	A) Low-bromine types of ABS, HIPS and PP	A) Good (Customer specify)	Yes bromine rich fraction incinerated	Industrial scale	MBA Polymer Patent
Small electronic equipment, White good (Switzerland)	Includes XRT	bromine and PVC free polymers	Good	Yes	Industrial scale	(Gerig 2010)
WEEE polymers (UK)	Undisclosed	Low-bromine types of ABS and HIPS	Good	Yes	Industrial scale	(Morton 2007)
WEEE polymers (Germany)	Undisclosed (incl. S/F and Electrostatic)	Low-bromine types of PP, ABS and HIPS	Good	Yes	Industrial scale	(wersag 2011)
TV and computer casings (Sweden)	Manual, not disclosed	Low-bromine types of ABS and HIPS	Good	Yes	Industrial scale	(Retegan 2010)
Mixed polymer from WEEE (Germany)	Successive Grinding and XRT	bromine and PVC free polymers	Not approved yet	Yes	Industrial scale	(Adamec 2010)

UNEP (2021) PBDE BAT/BEP guidance Stockholm Convention

PBDEs in WEEE plastic after separation – high Br-fraction

High PBDE contents in different WEEE plastic fractions (EU) are detected in the brominated plastic fraction from CRTs, small household appliances and flat screen LCDs after separation (Hennebert & Filella 2018; SC PBDE inventory guidance 2021). PBDE levels are above Basel Convention low POPs content (1000 mg/kg or 50 mg/kg) or the German POP regulation defining levels for hazardous waste (2500 mg/kg).

Bromine-containing WEEE plastic fraction after separation*	**DecaBDE (mg/kg)**	**∑hexa/heptaBDE (mg/kg)**	**Bromine (mg/kg)**
CRTs	**8100**	**1900**	36100
Small household appliances	**2800**	672	20300
Flat screens (LCD)	**4600**	45	45900

*After separation, the bromine-containing plastic waste fraction accounts for 20 to 40% of the original plastic volume.

Provisional **Basel low-POP-content** **1000 mg PBDE/kg** (1kg/t) and **50 mg/kg**

EU-POP Regulation Limit for PBDE 1000 mg/kg (1 kg/t).

German regulation 1000≤X≤2500 mg PBDE/kg waste is not categorized as hazardous but need to be supervised & managed in ESM (POP-Abfall-ÜberwV).

German LAGA (2019) limit value for hazardous waste 2500 mg PBDE/kg.

Limit value decides on the recyclability

PBDE in plastic is a challenge for recycling. Technologies for separation of PBDE containing plastic have been developed and can separate **WEEE plastics today to below ca. 150 mg/kg PBDE**.

WEEE/ASR plastic for recycling after separation of the bromine-rich fraction	Average* PBDE-209 content (mg/kg)	Average* ΣPOP-PBDE (2009)** content (mg/kg)	Average* bromine content (mg/kg)	Percentage of samples above 250 mg Br/kg
ABS	**77**	6	696	63 % (5/8)
PS	**81**	< 5	695	56 % (5/9)
PS / ABS	**119**	< 5	916	80 % (4/5)
PP / PE	**76**	< 5	795	50 % (1/2)
PP	**130**	<5	685	– (1/1)

*As only 65% of the samples (n'=17 of n=26) were analysed for PBDEs exceeding 250 mg/kg bromine (Swerea 2018), the average total content of PBDEs and bromine in the total samples analysed is lower (on average perhaps 70%) than those listed.
** PBDEs listed 2009 in Annex A of the Convention (tetra-, penta-, hexa- and hepta-PBDEs)
Swerea (2018) Decabromodiphenyl ether and other flame retardants in plastic waste destined for recycling. Swerea IVF Project Report M-973|2018.

- **If a 50 mg/kg PBDE Basel Convention low POP content would be adopted** then **recycling** of **e-waste plastic would not be feasible even for industrial countries**.
- Recycler are lobbying for 1000 mg/kg; EU and Switzerland support 500 mg/kg.

POPs regulatory limits – recycling challenge

- Currently 2 provisional Basel Convention low POPs limits pending for decisions (**50 ppm** and **1000 ppm**). If **50 ppm** would be selected then WEEE plastic recycling would have a considerable challenge.
- More limits likely to come for other POPs and other hazardous chemicals (e.g. Cd, DEHP). Challenge & cost of monitoring pollutants in recycling!
- Presence and formation of PBDD/Fs in these recycling flows: The approx. 1,500,000 t PBDEs might have resulted in 1000 t of PBDD/F in treated polymers. Control? Limits??
  (Sindiku et al. Environ Sci Pollut Res 22, 14462)
- ⇒ **Need to phase out & substitute hazardous additives in plastic to facilitate circular.**

Fantke, Weber, Scheringer (2015) From incremental to fundamental substitution. Sustain. Chem. Pharm, 1, 1-8. https://www.sciencedirect.com/science/article/abs/pii/S2352554115300024

Decrease in PBDE levels in WEEE over time

Due to the stop of use of c-OctaBDE in 2004 and reduction in 1990s, the level of c-OctaBDE decreased in Europe. Also decrease of decaBDE in WEEE plastic is observed for Europe.

This might be different if a developing country starts today WEEE plastic management

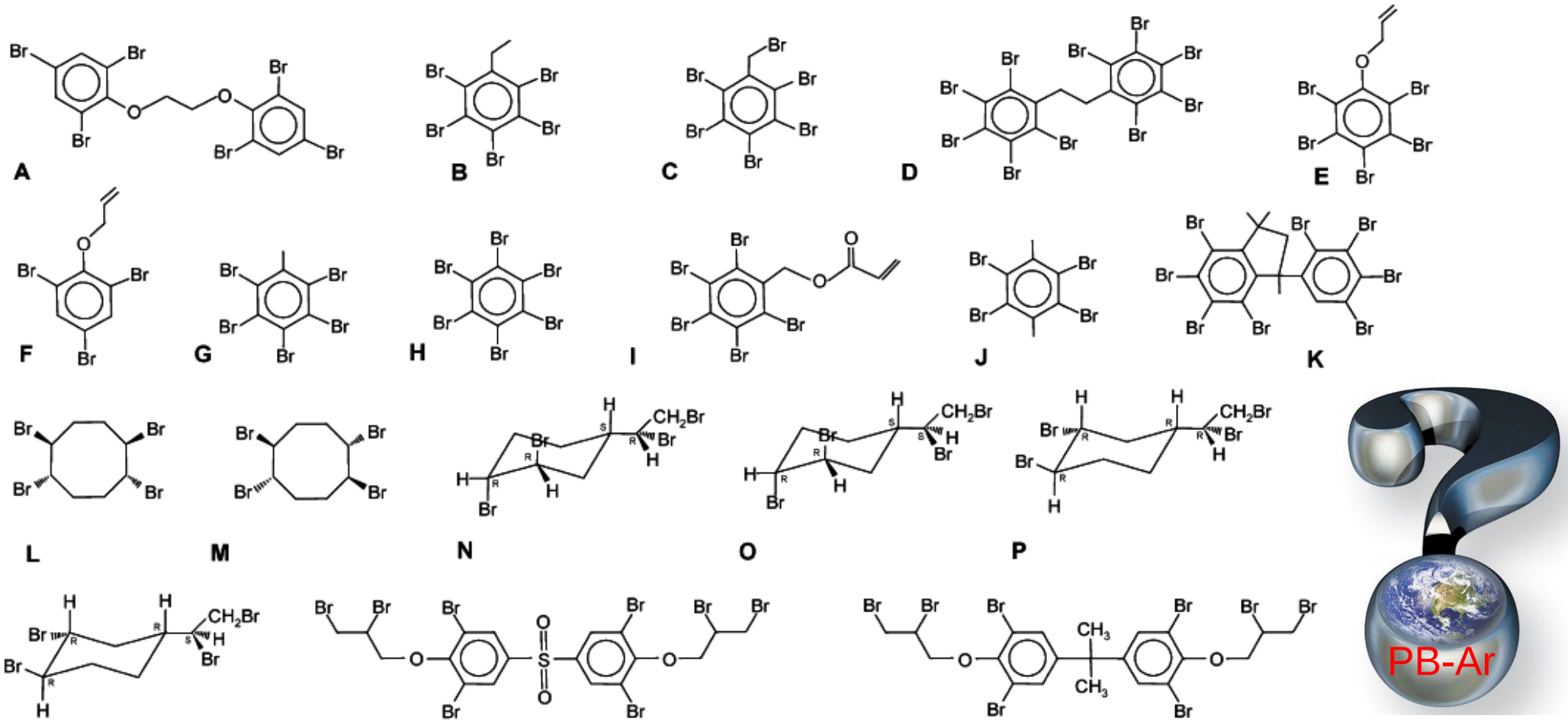
POP-PBDE 2009 (hexa-/heptaBDE and c-OctaBDE)* content in WEEE shredder fractions from CRTs, ICT and mixed WEEE from Europe (2003 to 2009).

WEEE shredder fractions	Conc. PBDE2009 (c-OctaBDE) (mg/kg)*	Sampling time (Location) (Reference)	Comments
TV/computer CRT casings	**4050** (7,500 ± 600)	Sampled 2003 (Switzerland) (in Bipro 2011)	mean concentrations in typical Ewaste fraction
TV CRT casings	**4160** (7,700 ± 3600)	Sampled 2003 (Switzerland) (Bipro 2011)	mean concentrations in typical Ewaste fraction
CRT casings	**3024** (5600; Range n.d. - 14000)	Schlummer et al (2007) Sampled 2006 (Germany)	Well defined sampling with small particle size in different shredder plants
Computer CRT casings	**1372** (2540; range 140-10600)	Sampled 2009 (Europe) (Waeger et al. 2010)	Different shredder plants in Europe; well-developed sampling protocol
TV CRT casings	**470** (870; range 50-3540)	Sampled 2009 (Europe) (Waeger et al. 2010)	Different shredder plants in Europe; well-developed sampling protocol

*The POP-PBDE content in c-OctaBDE (heptaBDE + hexaBDE) is approximately 54%

Other Brominated Flame Retardants (BFRs)

- Approx. 75 BFR on the market as alternatives (Fisk et al 2003). Assessment for EU (Detritus 16, 16-25).
- Many of them are persistent polybrominated aromatic chemicals
- European Chemical Agency: “Regulatory Strategy for Flame Retardants” https://echa.europa.eu/de/-/echa-identifies-certain-brominated-flame-retardants-as-candidates-for-restriction



Structures of BFRs addressed by Gauthier (Gauthier, Potter *et al.* ES&T 2009)

European Chemical Agency: Regulatory strategy for flame retardants

- ECHA has assessed the regulatory needs for halogenated and organophosphorus flame retardants (approximately 70% of the market for organic flame retardants).
- The **regulatory strategy (03/2023) has a particular focus on brominated flame retardants and their prioritization for restriction**, as indicated in the Restrictions Roadmap.
- For **the aromatic brominated flame retardants, a general concern has been identified due to their known or potential PBT/vPvB properties. Therefore, the release of these kind of flame retardants should be minimised. Viewing the challenges to control release of individual substances and the general availability of alternatives, a wide & generic restriction seems to be the most appropriate regulatory approach**.

- For the aliphatic brominated and the organophosphorus flame retardants, the human and environmental health hazards seem more diverse compared to the aromatic brominated flame retardants.

ECHA (03/2023) https://echa.europa.eu/de/-/echa-identifies-certain-brominated-flame-retardants-as-candidates-for-restriction

Thank you for your attention !

More Information

UNEP Chemical in Plastics: www.unep.org/resources/report/chemicals-plastics-technical-report

UNEP Plastics Treaty: https://www.unep.org/about-un-environment/inc-plastic-pollution

Basel Convention: www.basel.int

Stockholm Convention: http://chm.pops.int/

Rotterdam Convention: www.pic.int

SAICM: http://www.saicm.org/

IOMC/OECD: https://iomctoolbox.org/; http://www.oecd.org/chemicalsafety/

Science: www.ipcp.ch; www.foodpackagingforum.org/; www.isde.org/; https://ikhapp.org/scientistscoalition/

Industry: https://endplasticwaste.org/; https://plasticseurope.org/; http://www.suschem.org/

NGO: www.ipen.org; www.ciel.org/; www.ban.org; www.chemsec.org; www.wecf.org; https://chemtrust.org/

Better-world-links: http://www.betterworldlinks.org/; https://www.plasticstreaty.org/scientists-declaration/

IPCP International Panel on Chemical Pollution

UN environment programme

gef