



Burning Questions

**ENFIRO 2-day workshop
7-8 November Brussels**

A workshop on alternative flame retardants looking at flammability, applications, toxicity, exposure and life cycle assessment

Programme book



Abbreviations

ABS Acrylonitrile butadiene styrene copolymers
Alpi Aluminum diethylphosphinate (CAS 225789-38-8)
APP Ammonium polyphosphate (CAS 68333-79-9)
ATH Aluminium trihydroxide (CAS 21645-51-2)
ATO Antimonytrioxide (CAS 1309-64-4)
BDP or **BAPP** Bisphenol-A-bis-diphenylphosphate (CAS 5945-33-5, 181028-79-5)
BFR Brominated flame retardant
BPS Brominated polystyrene (CAS 88497-56-7)
Deca-BDE Decabromodiphenyl ether (CAS 1163-19-5)
DOPO Dihydro-oxa-phosphaphenantrene-oxide (CAS 35948-25-5)
EVA Poly-ethyl-co-vinyl acetate
HBDC Hexabromocyclododecane (CAS 25637-99-4)
HFFR Halogen-free flame retardant
HIPS High impact polystyrene
LCA Life cycle assessment
MC Melamine cyanurate (CAS 37640-57-6)
MDH or **MgOH₂** Magnesium hydroxide (CAS 1309-42-8)
MPP Melamine polyphosphate (CAS 218768-84-4)
PA Polyamide
PA6 Polyamide 6
PA6,6 Polyamide 6,6
PBDE Polybrominated diphenyl ethers
PBT Persistent, bioaccumulative, and toxic or (different meaning)
PBT Polybutyleneterephthalate
PC Polycarbonate
PE Polyethylene
PER Pentaerythritol (CAS 115-77-5)
PET Polyethylene therephthalate
PPE Polyphenyl ethers
PWB Printed wiring board (synonymous to printed circuit board)
RDP Resorcinol bis-diphenylphosphate (CAS 57583-54-7, 125997-21-9)
TBBPA Tetrabromobisphenol-A (CAS 79-94-7)
TPP Triphenyl phosphate (CAS 115-86-6)
ZB Zinc borate (CAS 138265-88-0 or 12767-90-7)
ZS Zinc stannate CAS 12036-37-2)
ZHS Zinc hydroxystannate (CAS 12027-96-2)

Scientific program, Wednesday 7th of November

- 8.30 Registration at Silken Berlaymont Hotel, Brussels
- 9.00 Welcome and opening (Pim Leonards)
- 9.15 Keynote
Status and trends of fire safety regulations and standards in the fields building, electrical engineering & electronics as well as transportation (Jürgen Troitzsch, FEPS)
- 10.00 Highlights of the ENFIRO project: assessment of alternatives for specific brominated flame retardants (Pim Leonards, VU University)
- 10.30 Coffee break

Session 1: Prioritization and selection of viable flame retardants

Chair: Pim Leonards

- 11.00 Regulatory challenges for brominated flame retardants (Stefan Posner, Swerea IVF)
- 11.30 Results of US EPA alternatives assessment for decabromodiphenyl ether (Emma Lavoie, EPA)
- 12.00 Using the GreenScreen™ for safer chemicals to identify chemicals of concern and safer alternatives (Lauren Heine, GPA)
- 12.30 Lunch

Session 2: Flammability and product evaluation

Chair: Adrian Beard

- 13.30 Compounding and testing of UL-94 optimised polymer formulations containing brominated versus halogen-free flame retardants (Jeremy Pearce or Paul Cusack, ITRI)
- 14.00 Comparison of the reaction to fire of brominated versus halogen-free flame retardants in polymers (Michael Delichatsios, University of Ulster)
- 14.30 Flame retarded thermoplastics for injection moulding - mechanical properties and processability (Jonas Aspling, Swerea IVF)
- 15.00 Flame Retardants in textile coatings and printed circuit boards - performance and mechanical properties (Jonas Aspling and Per Erik Tegehall, Swerea IVF)
- 15.30 Coffee break

- 16.00 Intumescent coatings for polymers – a novel approach (Claudio Pagella, Iris Vernici Srl)
- 16.30 Recent developments in non-intumescent coatings (Sabyasachi Gaan, EMPA)
- 17.00 New developments in flame retardancy of bio-based polymers and composites (Sophie Duquesne, UMET)

- 17.30 Transfer to BOZAR for evening events:
- 18.00 Reception
- 18.30 ENFIRO film premiere “Burning Questions”
- 19.00-22.00 Dinner

Scientific program, Thursday 8th of November

Session 3: Toxicity and exposure

Chair: Cynthia de Wit

- 9.00 Recent developments in human hazard and risk assessment of brominated and organophosphate flame retardants (Martin van den Berg, Utrecht University)
- 9.30 In vitro neurotoxic hazard characterization of brominated and halogen-free flame retardants (Hester Hendriks, Utrecht University)
- 10.00 Aquatic ecotoxicity and aerobic biodegradation of halogen-free flame retardants (Susanne Waaijers, University of Amsterdam)
- 10.30 Coffee break

- 11.00 Indoor exposure of humans to organophosphate flame retardants (Nele van den Eede, University of Antwerp)
- 11.30 Exposure to new flame retardants from indoor environments - results of air emission experiments and dust sampling (Cynthia de Wit, Stockholm University)
- 12.00 Leaching and exposure of halogen-free compared to brominated flame retardants (Sicco Brandsma, VU University)
- 12.30 Lunch

Session 4: Impact assessment of alternative FRs

Chair: Hildo Krop

- 13.30 Environmental risk minimization method based on lifecycle risk assessment and alternative assessment for persistent organic pollutant, such as HBCD, in products (Shigeki Masunaga, Yokohama National University)
- 14.00 Halogen-free and brominated flame retardants, from mining to recycling: the life cycle assessment approach (Niels Jonkers, IVAM)
- 14.30 Phosphorus flame retardants – State of the art and what's next (Adrian Beard, Clariant)
- 15.00 **Panel discussion:** Challenges and opportunities for alternative flame retardants

- 15.45 **Closing remarks** (Pim Leonards)
- 16.00 **Drinks**

Social events

7 November

18:00 Reception at BOZAR, Paleis voor Schone Kunsten, Rue Ravenstein 23, 1000 City of Brussels, Belgium, room Terarken 2

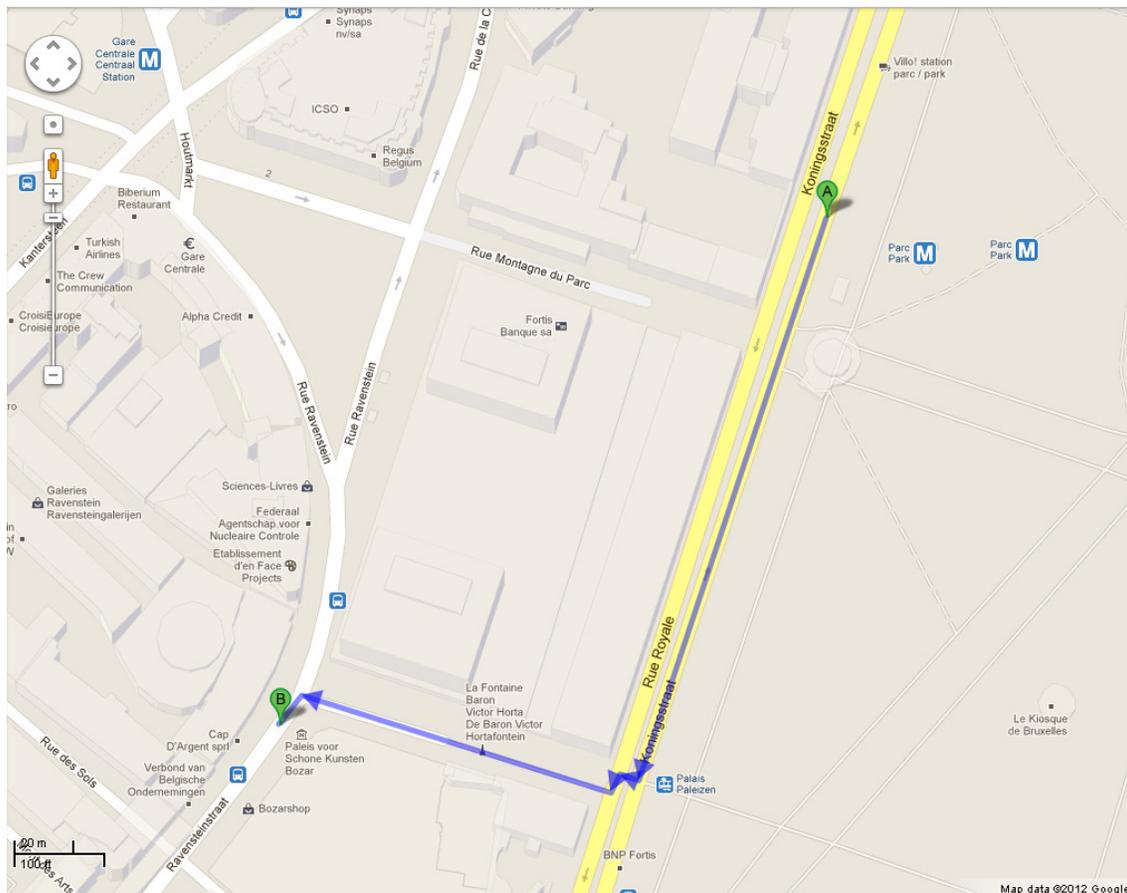
18:30 ENFIRO film premiere “Burning Questions”, BOZAR room Terarken 1

19:00 Dinner at BOZAR, room Terarken 2



From Silken hotel to BOZAR

Metro station Schuman to Metro station Parc (3 stops): Metro 1A or 1B at Schuman direction Erasme or Koning Boudewijn, alight at Parc stop. Take entrance Rue Royale and follow the Rue Royale and take the stairs downward to the Rue Ravenstein 23 (walk about 4 minutes).



Abstracts

Fire safety regulations and standards in building, electrical engineering & electronics and transportation - Status and trends

Jürgen Troitzsch, FEPS

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Fire safety regulations aim at protecting lives, property, and the environment. Fire safety requirements are mainly applied in building construction, transportation (road and rail vehicles, ships, airplanes), electrical engineering and electronics (E&E) as well as for furniture in public and private buildings.

An overview on the current status and trends in fire safety regulations and tests in the fields building, E&E and transportation is given. In Europe, no major changes for fire safety in building construction take place. However, national health and environmental regulations of Member States on indoor emissions may impact on free trade in the EU. In transportation, the harmonized and stringent EN 45455-2 requirements will lead to higher fire safety levels in railways. The same applies to ships with the revised and more stringent IMO FTP-Code. Fire safety in road vehicles and particularly in buses is more and more perceived as being too low. In E&E, there are basically no major new developments in fire safety regulations and tests. Campaigns against flame retardants may dramatically reduce the fire safety levels of consumer and IT equipment in the future and may lead to more fire deaths.

Highlights of the ENFIRO project: assessment of alternatives for specific brominated flame retardants

Pim Leonards

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Some brominated flame retardants (BFRs) have unintended negative effects on the environment and human health. Less toxic alternatives appear to be available already but comprehensive information on their possible toxicological effects are lacking. The European Commission-funded project ENFIRO investigates the substitution options for some BFRs and compares the hazard, exposure, fire performance, application, and performs a risk assessment and impact assessment studies. ENFIRO follows a practical approach in which halogen-free flame retardants (HFFRs) are evaluated and compared to BFRs regarding their flame retardant properties, their influence on the function of products once incorporated, and their environmental and toxicological properties. This is achieved using a tiered approach. In the first phase, a prioritization and selection of the most viable flame retardant/product combinations was conducted. In total 14 HFFRs as alternatives for decaBDE, TBBP-A, and brominated polystyrenes were selected. These flame retardants were studied in five applications - printed circuit boards (PCBs), electronic components, injection moulded products, textile coatings and intumescent paint. In the second phase, screening and case studies of the selected HFFRs were carried out to gather a comprehensive set of information.

ENFIRO showed that all of the selected alternative flame retardants do fulfil the regulatory fire test. An important finding was that halogen free systems have clear benefits as demonstrated, e.g. less visible smoke, in some cases lower PHRR with halogen free products, and less toxic components in smoke. Both polymers with brominated and non brominated FR showed similar loss in mechanical properties compared to the polymer alone. All formulations (both HFFR and BFR) showed equal or better performance regarding processability for injection moulding. An important part of the project was the input received from the Stakeholder forum on formulations. For all polymer systems investigated a HFFR option was found. The results for the PCBs with the HFFRs were as good as or better compared to the reference PCBs produced using BFRs.

From the initial selection of 14 alternative flame retardants seven were found to be less toxic and also accumulated less in the food chain than the BFRs. Environmental fate models predicted that the organic HFFRs would be found primarily in soils, sediments and dust and to a lesser extent in water and air. Controlled air emission experiments showed that all organic HFFRs emitted from polymers at elevated temperature but not at lower temperatures. Leaching experiments showed that HFFRs and BFRs can leach to water, but in general no differences in leaching between BFRs and HFFRs for each polymer type were found, except for the polymeric based FRs. The type of polymer is the main parameter determining the leaching properties.

ENFIRO showed that viable alternative flame retardants are available. Some HFFRs show less risk for the environment and human health, and show similar fire performance and technical application capabilities as BFRs. The lower risk is mainly due to the lower hazards of the HFFRs, and probably not due to a lower exposure.

Regulatory challenges for brominated flame retardants

Stefan Posner

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With the increasing use of thermoplastics and thermo sets on a large scale for applications in buildings, transportation, electrical engineering and electronics, a variety of flame-retardant systems have been developed over the past 40 years to match tightened legislation and a variety of fire requirements that are the major forces that have driven forward development towards functionally better and more effective flame retardants.

Among all these various flame retardant systems, there is a wide range of brominated flame retardants (BFR) other than the most common described PBDEs, HBCDD and TBBPA and its derivatives. BFRs are still relatively popular because they considered to hardly impairing the plastic characteristics, being effective in relatively low amounts compared to other FRs, and considered as relatively cheap.

During the last decade scientists have in an increasing number of reports presented evidence that some BFRs show a strong bioaccumulation in aquatic and terrestrial food chains, some are very persistent, and some show serious toxicological effects such as endocrine disruption.

ENFIRO has demonstrated that for all studied applications, BFRs can be replaced with non-halogenated flame retardants (HFFRs) that well match the feasibility criteria of BFRs.

Conclusively with our increasing knowledge of flame retardants and increasingly successful substitution to less harmful flame retardant systems, than legal restrictions against a wider range of harmful BFRs should expected in the near future.

Results of US EPA alternatives assessment for decabromodiphenyl ether

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The US EPA Design for Environment (DfE) Program undertook a chemical alternatives assessment for decabromodiphenyl ether (decaBDE) as part of the Action Plan for PBDEs published in December 2009. The alternatives assessment was done via a multi-stakeholder partnership that identified functional alternatives to decaBDE for a variety of polymers and applications. The hazard assessment for decaBDE and the alternatives used the DfE hazard evaluation criteria to assign hazard designations for human health toxicity, ecological toxicity and environmental fate endpoints. The alternatives included a range of flame retardant chemistries including halogenated and non-halogenated organic substances, inorganic substances, and polymers. Some alternatives were well characterized for all endpoints. Other alternatives were poorly characterized, wherein analog data or EPA expertise for predictive models and structural alerts were used to make hazard designations for data gaps. Trends in the hazard profiles were observed for some flame retardant classes due to particular molecular size ranges and/or molecular structures. Persistence is not a distinguishing characteristic for flame retardants. For discrete substances there are trade-offs between human toxicity, aquatic toxicity and bioaccumulation potential. For polymers, high molecular weight products had generally preferable profiles when low molecular weight components are absent. The stakeholder partnership provided valuable opportunity for expressing diverse views and technical expertise on flame retardant chemistry and policy issues. The partnership also encouraged sharing of data to improve hazard profiles. Effective hazard assessment approaches, coupled with decision-making protocols that are practical tools for businesses to use in materials selections, can lead to more sustainable product development when human health or ecological toxicity concerns exist. The resulting hazard profiles should be of value to manufacturers making substitution decisions in preparation for the upcoming decaBDE phase out.

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (**VL, L, M, H, and VH**) were assigned based on empirical data. Endpoints in black italics (*VL, L, M, H, and VH*) were assigned using values from predictive models and/or professional judgment.

[§] Based on analogy to experimental data for a structurally similar compound.

^d This hazard designation is driven by potential for lung overloading as a result of dust forming operations.

◆ Different formulations of the commercial product are available. One of these many formulations has an average MW of ~1,600 and contains significant amounts of lower MW components. These lower MW components are primarily unchanged starting materials that have hazard potentials different than the polymeric flame retardant, as follows: VERY HIGH- Estimated potential for bioaccumulation; HIGH-Experimental concern for acute aquatic toxicity; HIGH- Estimated potential for chronic aquatic toxicity; MODERATE-Experimental concern for developmental; and MODERATE-Estimated potential for carcinogenicity, genotoxicity, repeated dose, reproductive, and skin and respiratory sensitization toxicity

⊠ This alternative may contain impurities. These impurities have hazard designations that differ from the flame retardant alternative, Confidential Brominated Polymer, as follows, based on experimental data: HIGH for human health, HIGH for aquatic toxicity, VERY HIGH for bioaccumulation, and VERY HIGH for persistence

^T This chemical is subject to testing in an EPA consent order.

Chemical	CASRN	Human Health Effects											Aquatic Toxicity		Environmental Fate		
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation	
DecaBDE and Brominated Flame Retardant Alternatives (BFRs)																	
DecaBDE and Discrete BFR Alternatives																	
Bis(hexachlorocyclopentadieno) Cyclooctane	13560-89-9	L	M [§]	M [§]	VL	VL	L	M	L			VL	L	L	L	VH	H
Decabromodiphenyl Ethane	84852-53-9	L	M [§]	L	L	VL	H [§]	L	L			VL	VL	L	L	VH	H
Decabromodiphenyl Ether	1163-19-5	L	M	L	L	H	H	M	L			L	L	L	L	VH	H
Ethylene Bis-tetrabromophthalimide	32588-76-4	L	M [§]	L	L	L	M [§]	L	L			VL	VL	L	L	VH	H
Tetrabromobisphenol A Bis (2,3-dibromopropyl) Ether	21850-44-2	L	M	M	M	M	L	M	M			L	L	L	L	VH	H
Tris(tribromoneopentyl) Phosphate	19186-97-1	L	M	M	L	H	H	M	H			L	L	L	L	H	M
Tris(tribromophenoxy) Triazine	25713-60-4	L	L	L	L	L	L	L	L			L	VL	L	L	VH	H
Polymeric BFRs																	
Brominated Epoxy Resin End-Capped with Tribromophenol	135229-48-0	L	L	L	L	L	L	M ^d	L			L	VL	L	L	VH	L
Brominated Polyacrylate	59447-57-3	L	L	L	L	L	L	M ^d	L			L	L	L	L	VH	L
Brominated Polystyrene	88497-56-7	L	L	L	L	L	L	M ^d	L			L	L	L	L	VH	L
Confidential Brominated Epoxy Polymer #1	Confidential	L	L	L	L	L	L	M ^d	L			L	L	L	L	VH	L
Confidential Brominated Epoxy Polymer #2	Confidential	L	L◆	L◆	L◆	L◆	L	M◆ ^d	L◆	◆		L	L	L◆	L◆	VH	L◆
Confidential Brominated Epoxy Polymer Mixture #1	Confidential	L	L◆	L◆	L◆	L◆	L	M◆ ^d	L◆	◆		L	L	L◆	L◆	VH	L◆
Confidential Brominated Epoxy Polymer Mixture #2	Confidential	L	L◆	L◆	L◆	L◆	L	M◆ ^d	L◆	◆		L	L	L◆	L◆	VH	L◆
Brominated poly(phenylether)	Confidential	L	L⊠	L	L⊠	L⊠	L⊠	L⊠	L			L	VL	L	M ^{T⊠}	VH ^T	M ^{T⊠}
TBBPA Glycidyl Ether, TBBPA Polymer	68928-70-1	L	L◆	L◆	L◆	L◆	L	M◆ ^d	L◆	◆		L	L	L◆	L◆	VH	L◆

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (**VL, L, M, H, and VH**) were assigned based on empirical data. Endpoints in black italics (*VL, L, M, H, and VH*) were assigned using values from predictive models and/or professional judgment.

^d This hazard designation is driven by potential for lung overloading as a result of dust forming operations.

[§] Based on analogy to experimental data for a structurally similar compound.

[‡] The highest hazard designation of any of the oligomers with MW <1,000.

[◊] The highest hazard designation of a representative component of the oligomeric mixture with MWs <1,000.

[‡] Phosphonate Oligomer, with a MW range of 1,000 to 5,000, may contain significant amounts of an impurity, depending on the final product preparation. This impurity has hazard designations that differ from the polymeric flame retardant, as follows: MODERATE-Experimental concern for repeated dose, skin sensitization and eye irritation; and HIGH-Experimental concern for reproductive, developmental, and acute aquatic toxicity.

^R Recalcitrant: Substance is comprised of metallic species that will not degrade, but may change oxidation state or undergo complexation processes under environmental conditions.

* Ongoing studies may result in a change in this endpoint

Chemical	CASRN	Human Health Effects											Aquatic Toxicity		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Organic Phosphorus or Nitrogen Flame Retardants (PFRs or NFRs) Alternatives																
Discrete PFR, NFR and P/NFR Alternatives																
Substituted Amine Phosphate Mixture ¹	Confidential	<i>H</i>	<i>M</i>	<i>M</i>	<i>M</i>	<i>M</i>	<i>L</i>	<i>M</i>	<i>M</i> <i>L</i>	<i>M</i> [§]	<i>M</i> [§] <i>M</i>	<i>VH</i> <i>VL</i>	<i>M</i>	<i>L</i>	<i>H</i>	<i>L</i>
Triphenyl Phosphate	115-86-6	<i>L</i>	<i>M</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i>	<i>L</i>		<i>L</i>	<i>VL</i>	<i>VH</i>	<i>VH</i>	<i>L</i>	<i>M</i>
Polymeric PFR and NFR Alternatives																
Bisphenol A bis-(diphenyl phosphate), BAPP	181028-79-5	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i> [§]	<i>L</i>	<i>L</i>	<i>L</i>		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>H</i>	<i>H</i> [◊]
Melamine Cyanurate ¹	37640-57-6	<i>L</i>	<i>M</i>	<i>M</i>	<i>M</i> [§]	<i>M</i> [§]	<i>L</i>	<i>H</i>	<i>L</i>		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>VH</i>	<i>L</i>
Melamine Polyphosphate ¹	15541-60-3	<i>L</i>	<i>M</i>	<i>M</i>	<i>L</i> [§]	<i>L</i>	<i>L</i> [§]	<i>M</i>	<i>L</i>		<i>L</i>	<i>VL</i>	<i>L</i>	<i>L</i>	<i>H</i>	<i>L</i>
N-alkoxy Hindered Amine Reaction Products	191680-81-6	<i>L</i>	<i>M</i>	<i>L</i>	<i>H</i>	<i>H</i>	<i>L</i>	<i>H</i>	<i>L</i>		<i>L</i>	<i>VL</i>	<i>H</i>	<i>H</i>	<i>H</i>	<i>H</i> [‡]
Phosphonate Oligomer	68664-06-2	<i>L</i>	<i>M</i>	<i>L</i> [§]	<i>L</i> [‡]	<i>L</i> [‡]	<i>M</i> [‡]	<i>L</i> ^{§‡}	<i>L</i> ^{§‡}		<i>M</i> ^{‡‡}	<i>M</i> [‡]	<i>L</i> [‡]	<i>H</i> [‡]	<i>VH</i>	<i>H</i> [‡]
Polyphosphonate	68664-06-2	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i> ^d	<i>L</i>		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>VH</i>	<i>L</i>
Poly[phosphonate-co-carbonate]	77226-90-5	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i> ^d	<i>L</i>		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>VH</i>	<i>L</i>
Resorcinol bis-diphenylphosphate	125997-21-9	<i>L</i>	<i>M</i> [§]	<i>L</i>	<i>L</i>	<i>VL</i>	<i>M</i> [§]	<i>M</i>	<i>L</i>		<i>L</i>	<i>VL</i>	<i>VH</i>	<i>H</i> [‡]	<i>M</i>	<i>H</i> [‡]
Inorganic Flame Retardant Alternatives																
Aluminum Diethylphosphinate	225789-38-8	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i>	<i>M</i>	<i>L</i>	<i>L</i>		<i>L</i>	<i>VL</i>	<i>M</i>	<i>M</i>	<i>H</i> ^R	<i>L</i>
Aluminum Hydroxide	21645-51-2	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i>	<i>L</i>	<i>L</i>		<i>VL</i>	<i>VL</i>	<i>M</i>	<i>M</i>	<i>H</i> ^R	<i>L</i>
Ammonium Polyphosphate	68333-79-9	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i> ^d	<i>L</i>		<i>VL</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>VH</i>	<i>L</i>
Antimony Trioxide ¹	1309-64-4	<i>L</i>	<i>L</i> [*]	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i> [*]	<i>L</i>		<i>L</i>	<i>M</i>	<i>M</i>	<i>M</i>	<i>H</i> ^R	<i>L</i>
Magnesium Hydroxide	1309-42-8	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>		<i>M</i>	<i>M</i>	<i>L</i>	<i>L</i>	<i>H</i> ^R	<i>L</i>
Red Phosphorus	7723-14-0	<i>VH</i>	<i>L</i>	<i>M</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>		<i>M</i>	<i>H</i>	<i>L</i>	<i>L</i>	<i>H</i>	<i>L</i>
Zinc Borate	1332-07-6	<i>L</i>	<i>L</i>	<i>H</i>	<i>M</i>	<i>M</i>	<i>H</i>	<i>L</i>	<i>L</i>		<i>L</i>	<i>L</i>	<i>H</i>	<i>H</i>	<i>H</i> ^R	<i>L</i>

Using the GreenScreen™ for safer chemicals to identify chemicals of concern and safer alternatives

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The GreenScreen™ for Safer Chemicals (GreenScreen) is a method for comparative chemical hazard assessment that is currently used by a growing number of large manufacturers of products ranging from chemicals to electronics, apparel and footwear. The method is based on national (US) and international precedents including USEPA Design for the Environment (DfE) Alternatives Assessment (AA) Criteria for Hazard Evaluation, OECD harmonized test methods, the Globally Harmonized System for Classification and Labeling and EU REACH regulatory guidance. The method involves first assessing and classifying hazards for a chemical for 18 different hazard endpoints ranging from human health (e.g., carcinogenicity, reproductive and developmental toxicity) to environmental toxicity and fate (e.g., aquatic toxicity, persistence and bioaccumulation potential) to physical properties (e.g. flammability and reactivity). This first step is very similar to the DfE AA approach. The next step is to apply a set of Benchmarks that rank each chemical based on its hazard classifications by considering individual hazards and their simultaneous occurrence. The value system behind the Benchmarking system is aligned with that used to define a Substance of Very High Concern under REACH and also in alignment with US and Canadian guidance for chemicals of concern. A Benchmark 1 chemical is considered a substance of very high concern. A Benchmark 4 chemical has low hazard for all hazard endpoints. Benchmarks 2 and 3 reflect increasing levels of low hazard for all endpoints using the same decision logic. The last step in a full GreenScreen assessment is to use the hazard information and the resulting Benchmark score to make informed decisions. The GreenScreen is being used for materials procurement, for product development, in corporate chemicals management policies, as the basis for NGO initiatives, as a reference in ecolabels and standards and as a reference in US State regulations focused on safer consumer products, particularly children's products. Hewlett Packard (HP) has been a global leader in using comparative chemical hazard assessment, specifically the GreenScreen, to identify safer alternatives to chemicals of concern in their global material supply chain.

Compounding and testing of UL-94 optimised polymer formulations containing brominated versus halogen-free flame retardants

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ITRI has over 30 years background experience in the fields of polymer compounding and fire testing. During this time, research at ITRI has led to the development of novel inorganic flame retardants, several of which have been subsequently commercialised by industrial partners in the UK and elsewhere. ITRI's primary tasks within the ENFIRO project have focused on compounding and moulding of polymeric materials, containing brominated or halogen-free flame retardants, and evaluation of the resulting formulations in standard laboratory-scale fire tests.

Four specific thermoplastics (PC/ABS, PPE/HIPS, glass fibre-reinforced PA66 and glass fibre-reinforced PBT), one thermosetting resin (epoxy) and one elastomer (EVA) were selected, these materials all finding use in electrical and electronic applications, where brominated flame retardants, usually in conjunction with antimony trioxide as synergist, currently prevail. In each case, the selected flame retardant additives were incorporated by appropriate blending methods and the compounded materials subsequently moulded into test pieces for testing.

Formulations were tested and optimised using the Underwriters Laboratory UL-94 vertical flame test, which classifies materials according to a ranking system with V0 representing the best performance, followed by V1, then V2, and finally non-classifiable for those specimens that fail the test. Since brominated FR systems have been designed to pass this test with V0 rating for most polymeric materials, a key objective of ENFIRO was to demonstrate that similar V0 ratings are achievable using halogen-free FRs. Since UL-94 classification is the global benchmark for flammability in the electronics industry, it is critical that the new FRs can meet this criterion.

Having achieved UL-94 V0 ratings, optimised brominated and halogen-free FR containing formulations were then subjected to more comprehensive fire testing procedures, these designed to assess fire safety of materials in terms of ignitability, heat release and generation of smoke and toxic gases. Since it is widely accepted that the vast majority of fire deaths are caused by smoke inhalation, a comparison of the performance of polymers that have been flame-retarded with the new halogen-free FRs against those containing the conventional brominated FRs is critical.

In this connection, one of the major drawbacks of brominated FRs is their tendency to markedly increase the amounts of smoke and toxic gases evolved during combustion. Tests carried out within the ENFIRO project have confirmed the UL-94 V0 performance of the optimised halogen-free formulations for each of the polymer types and Cone Calorimeter tests (undertaken in accordance with the International Standard ISO 5660-1) have demonstrated the expected superiority of the new materials in terms of reduced levels of smoke and toxic gases.

Comparison of the reaction to fire of brominated versus halogen-free flame retardants in polymers

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We have developed both a detailed numerical method using intrinsic flammability properties as well as a simple method for characterizing the fire performance and fire toxicity of polymers using three parameters based on measurements in the cone calorimeter at four different heat fluxes supported by thermal and gas analysis in FTIR from TGA and Tube Furnace. One parameter is related to fire spread and growth (simulating UL-94 and the FIGRA of SBI) , the second parameter is the smoke and Carbon Monoxide yield (simulating the SMOGRA of SBI) and the third parameter is the inefficiency of combustion (related to unburned hydrocarbon compounds and possibly, their toxicity). We note that even though the parameters are extracted for over - ventilated conditions , they are expected to have the same relative significance for under -ventilated conditions based on under ventilated experiments in the controlled atmosphere flammability apparatus , the Tube Furnace and in corridors. The developed methodology and proposed parameters are applicable for charring, non charring and intumescent materials and has been applied to all the fire retarded polymers used in the ENFIRO program. Another possibly important parameter is how much of the initial material is left behind as residue. This is not significant for fire spread and fire growth but it can provide the amount of total fuel load in a fully developed fire, not relevant for the present applications.

Flame retarded thermoplastics for injection moulding - mechanical properties and processability

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The basic requirements for an injection moulded part are that the thermoplastic material must be processable and have enough mechanical properties. By processable meaning having low enough melt viscosity to be able to fill the mould during injection moulding. Incorporating different additives and/or fillers can affect this property. If the viscosity should increase drastically, it would result in an unfilled tool and thereby no plastic part can be produced, without compensating with increased wall thickness, larger gates and runners for example. All these are not preferred as they lead to heavier parts, increased production time etc, in other words increased costs. Additives and/or fillers also affect the mechanical properties of the material and thereby the properties of the injection moulded part. Should they drastically lower the mechanical properties, this would typically result in a very brittle unusable plastic part.

The formulations within the ENFIRO-project, which were optimised for fire performance according to UL-94, have been evaluated regarding their processability and mechanical properties. The processability has been tested using capillary rheometer and the more production like method, spiral flow. For mechanical properties, standard tensile and impact tests were used.

Flame Retardants in textile coatings and printed circuit boards - performance and mechanical properties

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Textile coating is used in numerous applications in products used for personal or industrial use. Some of these applications require flame retardant properties. Industry, military equipment and rescue personal garments have such requirements. In coated textiles it is beneficial and common to use standard grade yarn and then add the fire proofing agents in the coating instead of adding flame retardants to both fibre polymer and coating. That means that the coating has to flame proof both the textile and the coating. In this study we have used the same area weight of coating as the area weight of textile which is a common case in real life.

The efficiency of flame retardants is dependent on polymer systems. Therefore two different fibre types were investigated with two different coating polymers frequently used on the market. Polyamide (PA) weave and polyether terephthalate (PET) weave (also referred to as polyester) are used as filament plain weaves. The coating polymers were water based emulsion systems without crosslinkers. The polymers in the two emulsions are acrylic respectively polyurethane. A reference was also made for comparing the studied systems with best practise. This best practise was composed with DECA/Antimony trioxide.

The measure of the study is expressed as minimum amount of flame retardant added to the solid coating polymer. This is expressed in weight-% and a lower value means that we have more efficient flame retardant for the system. Less amount of flame retardant is normally favourable for improved mechanical properties so the measure is well adapted to requirements.

Due to the strong pressure to use more environmentally friendly materials in many commercial electronic products, laminates with halogen-free flame retardants (HFFRs) for production of PCBs have been commercially available since mid nineties. Today, most laminate produces offer halogen-free laminates, although the market share is still quite small for these laminates. One reason for this is the uncertainty how the long-term reliability is affected for high-reliability applications used in harsh environments.

Major failure mechanisms that may be affected by the flame retardant used include:

- Cracking of metal platings in through holes and internal interconnect failures
- Fracturing of the resin and adhesion failure between the resin and copper foils or glass fibres
- Current leakage due to formation of conductive anodic filament (CAF)
- Current leakage due to decreased surface insulation resistance and electrochemical migration

In the ENFIRO project, the impact of HFFRs on the listed failure mechanisms has been evaluated. For the evaluations, PCBs were produced using four commercially available laminates with HFFRs and a laminate with brominated flame retardant as reference. The reliability tests indicated that the PCBs produced using HFFRs were as reliable as or better than the PCBs produced using brominated flame retardant.

Intumescent coatings for polymers – a novel approach

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The regulatory pressure to phase out halogenated compounds is a powerful driver for the search of new flame retardants, which in the case of polymers are generally supposed to be added into the mass. However most of the novel FRs being discovered are not working according to the same principle as halogenated FRs (in the gas phase via quenching of the flame propagation radical chain reaction) but rather in the solid phase via physical actions (building a barrier to heat and oxygen transfer, generating inert gases through the mass or providing strong endothermal effects). The generation of intumescent char is proving to be one of the most effective techniques. On the other hand, the principle of intumescence has been used since the 60s to formulate intumescent coatings that have later been widely used, e.g. for fire protection of steel structures. Intumescent coatings already exist in waterborne, very low VOC and halogen-free formulations.

In ENFIRO, intumescent coatings have been used for the flame retardancy of HIPS (High Impact PolyStyrene) which has proved a difficult substrate to protect with other non-halogen techniques and is a commonly used polymer in the electric and electronic industry.

HIPS is a thermoplastic polymer and for this reason the key factor when designing an intumescent heat transfer barrier proved to be the prevention of melting that can occur long before thermal decomposition begins. This means the need of special intumescent formulations activating fast at low temperatures.

After a screening based on ISO 11925-2 small flame tests, the best coatings has been extensively studied on HIPS substrates at the cone calorimeter, further optimizing the formulation. Having achieved very good results in terms of expansion ratio, HRR, smoke emission and even stickability (in the vertical configuration of the cone), the system was then assessed following industry standards relevant to the electronics industry such as UL or IEC. Excellent results were obtained at UL 94 (V0) and the IEC Glow wire test.

Recent Developments in Non-Intumescent Flame Retardant Coatings

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In this presentation we will review the recent developments (last decade) in the halogen free retardant polymeric coating. Advancements in the method of application such plasma, sol gel method, layer by layer application and UV curable coatings on various substrates will be briefly discussed. This presentation will highlight some of the most important approach in development of flame retardant coatings *i.e.* incorporation of reactive and non-reactive inorganic and organic compounds and polymers based on metals, Si, P, N and halogens in suitable polymeric coatings and evaluation of its flame retardant characteristics using various analytical techniques. Furthermore we will also present our recent work on development of new phosphorus nitrogen based additives for flame retardant coatings on textiles.

New developments in flame retardancy of bio-based polymers and composites

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In recent decades, the development of environmentally friendly materials has led to a particular interest of the scientific community for the bio-based polymers and composites. Among the different polymeric matrix, polylactic acid, polyamide such as for example Rilsan from Arkema or starch based materials such as for example Galaiene from Roquette appears as a good candidates for the substitution of oil-based materials in several domains such as packaging, transportation or electrical and electronic equipment. For some of those applications, a high level of flame retardant properties is required. The objective of this paper is to present and to discuss, using different examples from works carried out in the laboratory, different approaches for flame retarding bio-based thermoplastic materials. Moreover, the flame retardant behaviour of bio-based composites will also be discussed.

In vitro neurotoxic hazard characterization of brominated and halogen-free flame retardants

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Brominated flame retardants (BFRs) are abundant persistent organic pollutants with well-studied toxicity. The toxicological and ecological concern associated with BFRs argues for replacement by safer alternatives. Previous research identified the nervous system as a sensitive target organ for BFRs. However, the (neuro)toxic potential of alternative halogen-free flame retardants (HFFRs) is largely unknown.

Since it is essential to assess the (neuro)toxic potential of HFFRs before large scale use, we investigated the direct cytotoxic effects of three BFRs and 13 HFFRs on neuronal cell lines using a combined Alamar Blue and Neutral Red test. Most HFFRs did not induce overt cytotoxicity, though ZHS and ZS evoked moderate cytotoxicity at low concentrations comparable to the TBBPA-induced cytotoxicity. Next, the effects of the selected compounds on the production of reactive oxygen species (ROS) was determined. Oxidative stress occurs when ROS levels in the cell dramatically increase, potentially resulting in significant damage to cell structures. In line with the observed cytotoxic effects, TBBPA and ZS showed a significant increase in ROS production. Subsequently, the underlying mechanisms were studied by investigating changes in the intracellular calcium concentration ($[Ca^{2+}]_i$) using single cell fluorescent microscopy as a prolonged increase in $[Ca^{2+}]_i$ is an important trigger for apoptosis. TBBPA, ATH, MMT, ZHS and ZS were able to disturb basal Ca^{2+} homeostasis. Changes in $[Ca^{2+}]_i$ also play an essential role in intra- and intercellular signaling pathways, including neurotransmission. Therefore, we also determined effects of BFRs and HFFRs on depolarization-evoked increases in $[Ca^{2+}]_i$ in PC12 cells. This proved to be a sensitive endpoint since 10 of 16 tested compounds were able to inhibit depolarization-evoked calcium influx. We also measured the effects of the selected compounds on the function of human $\alpha_4\beta_2$ nACh receptors, expressed in *Xenopus* oocytes, using the two-electrode voltage-clamp technique since previous studies identified postsynaptic excitatory $\alpha_4\beta_2$ nicotinic acetylcholine (nACh) receptors as a sensitive target for persistent organic pollutants. The results demonstrate that TBBPA, TPP, ATH and MMT act as nACh receptor antagonists.

As a final step in the health hazard characterization, *ex vivo* validation experiments were performed with TBBPA, Alpi and ZS. Long-term potentiation (LTP), which requires proper function of both pre- and postsynaptic mechanisms, was measured using extracellular field recordings in hippocampal slices from neonatally exposed mice. Though this study is still ongoing, the preliminary results don't show clear adverse effects on LTP.

The current data on neurotoxic effects of HFFRs in comparison with BFRs is a prerequisite for performing a complete (toxic) risk assessment and to prioritize viable HFFRs for substitution of BFRs.

Aquatic ecotoxicity and aerobic biodegradation of halogen-free flame retardants

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Several halogenated flame retardants have been banned due to their persistence, bioaccumulation potential and toxicity (PBT) and probable environmental risk. Hence, alternative flame retardants are required and a range of new flame retardants have been proposed. The PBT properties of most alternative flame retardants, however, have not been tested. Therefore, an inventory of the available data on persistence, bioaccumulation and toxicity of a selection of halogen free flame retardants (HFFRs) that are already commercially available was made. Despite the current REACH regulations, large data gaps were identified in the PBT properties of the reviewed HFFRs. This is one of the reasons that the European Commission has funded a research project on HFFRs called ENFIRO. ENFIRO aims to fill a large part of the existing data gaps. Several aspects are studied, including the environmental and toxicological risks.

To obtain insight in these aspects, ecotoxicological tests are done on *Daphnia magna* and *Lumbriculus variegatus*. *Daphnia magna*, a pelagic filter feeder, is a commonly used test organism in aquatic ecotoxicology because of its important link in the food chain. *Lumbriculus variegatus*, a endobenthic oligochaete, is also a widely used test organism, mostly in bioaccumulation experiments. And in general for testing the effects of hydrophobic compounds, since for these chemicals the relevant route of exposure in aquatic ecosystems is through sediments.

Furthermore, the fate of the HFFR was studied by means of biodegradability testing in diluted waste water treatment sludge. Primary biodegradation was examined in such systems studying the transformation of organic flame retardants and the potential formation of break-down products.

The alternative flame retardants studied were: 6 organic phosphates (Aluminium Diethyl Phosphinate (ALPI), Bisphenol A bis(diphenyl phosphate) (BDP), Dihydro Oxa Phosphaphenanthrene (DOPO), Melamine Polyphosphate (MPP), Resorcinol bis(diphenyl phosphate) (RDP), Triphenyl Phosphate (TPP) and 6 inorganic compounds (Aluminium Trihydroxide (ATH), Ammonium Polyphosphate (APP), Antimony Trioxide (ATO), Magnesium Hydroxide (Mg(OH)₂), Zinc Hydroxy Stannate (ZHS) and Zinc Stannate (ZS)).

Indoor exposure of humans to organophosphate flame retardants

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Phosphorous-based flame retardants (PFRs) represent 24% of the market share in flame retardants. PFRs are used in polymers, such as cellulose esters, polyvinyl chloride, etc. from which they are released in their environment by abrasion, volatilization and leaching. As people spend in average 90% of their time in the indoor environment, including at home, at work, and during transportation, the monitoring of PFR concentrations in indoor matrices (e.g. air and settled dust) is a valuable tool to evaluate the daily exposure to these contaminants. Recent measurements of PFRs in dust show that PFRs are much more abundant than brominated FRs, with concentrations varying from several $\mu\text{g/g}$ in Western European countries to a few mg/g in Japan or only a few ng/g in developing countries such as Pakistan. Not only do the concentrations differ among countries, but also the profiles of PFRs vary. For example, TDCPP is much more abundant in USA dust compared to European or Asian dust. Another phenomenon is the different patterns observed between microenvironments such as work, transport and home. The estimates of daily dust intake are still being discussed, but generally it is assumed that adults ingest a daily amount of 10 to 50 mg dust/day, while toddlers may ingest up to 200 mg/day . For PFRs, this means that intakes may range from less than 1 ng/kg bodyweight to up to 50 and 300 ng/kg bodyweight per day for adults and toddlers, respectively. For the purpose of human biomonitoring, other sources need to be investigated as well, e.g. indoor air, dermal contact, and diet. Recent publications showed that PFRs reach concentrations of several ng/m^3 in indoor air, and consequently inhalation of suspended particles could have an equal contribution to daily exposure as dust ingestion for adults.

Exposure to new flame retardants from indoor environments - results of air emission experiments and dust sampling

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Previous studies have shown that several brominated flame retardants (BFRs) emit from polymers in products to indoor environments. For several BFRs, the high concentrations in found indoor air and dust are now considered to be important exposure pathways for humans. Little is known about new flame retardants such as halogen-free flame retardants (HFFRs) that are replacing the BFRs. Environmental fate models were used together with physical-chemical properties of several organic HFFRs (DOPO, RDP, BDP) to predict environmental distribution. The models predicted they would be found primarily in soils, sediments and dust and to a lesser extent in water and air. Controlled air emission experiments were carried out and showed that all three HFFRs emitted from polymers at 80°C. However, when tested over a period of 60 days at 40°C, no emissions of the three HFFRs from polymers to air were found. Analysis of dust samples from microenvironments where these HFFRs might be used showed highest concentrations of BDP on and around electronic equipment, such as flat-screen television sets. Lower, but measurable concentrations of RDP and BDP were also found around other electronics, furniture, car seats and in apartments. DOPO was found around electronics in one microenvironment. Based on these results, it is clear that human exposure to HFFRs may occur via dust ingestion.

Leaching and exposure of halogen-free compared to brominated flame retardants

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Information about the production, distribution and consumption of flame retardants in electric and electronic (E&E) equipment (plastics) is well described. However, there is a knowledge gap in the amount of flame retardants leaching from plastics of electric and electronic (E&E) equipment to the environment. In the EU funded project ENFIRO, halogen free flame retardants (HFFR) are studied that are viable alternatives to specific commercial brominated flame retardants (BFR). Leaching studies of BFRs from different types of plastics have been described in literature; however, limited information on leaching of HFFRs is available. ENFIRO studied 15 HFFRs of which 6 are metal-based. Metal-based flame retardants are stable in plastic (polymer) products, but can leach, dissociate and enter the environment. Monitoring of the fate of metal-based HFFRs in the environment is difficult as metals can have various sources of emission. Leaching tests of HFFRs from plastics is an alternative method that may contribute to the exposure and risks assessment and understanding of the fate of HFFRs in the environment. The current study shows leaching properties of different HFFRs from polymers in comparison with BFRs. Thereby, the influences of pellets vs. moulded plates and pH on the leaching properties were studied. Two types of leaching protocols were tested. The TCLP protocol, from the US EPA, use worse-case leaching conditions (low pH) to simulate a municipal waste landfill, and studied if waste has toxic characteristics and is hazardous. The second protocol (DIN 38414-S4) determines leaching by water (neutral pH), and has been widely used for regulatory purposes in Europe. In general, higher leaching rate coefficients of HFFRs are found from pellets than from moulded plates, which is probably a result of the differences in surface:volume ratio and the porosity of the materials. Also the influences of nanoclay on the leaching behaviour of the HFFRs have been studied. In general, no differences in leaching between BFRs and HFFRs for each polymer type were found, except for the polymeric based FRs. The type of polymer is the main parameter determining leaching properties.

Environmental risk minimization method based on lifecycle risk assessment and alternative assessment for persistent organic pollutant, such as HBCD, in products

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In order to minimize environmental risk and to select better a chemical among alternatives, grasping various risks all through the life stage is very important. In this research project, we are developing a material flow based comparative assessment method by studying on a brominated flame retardant, hexabromocyclododecane (HBCD) as a case.

First, we constructed a material flow of HBCD in Japan through its life cycle. By adopting emission factors, environmental emissions of HBCD were estimated for every life stage. Then five potential alternative flame retardants (FRs) were identified for the major HBCD use categories, namely expanded polystyrene (EPS), extruded polystyrene (XPS), curtain and car fabric. Environmental emissions and exposure were estimated for those alternatives and compared with those of HBCD. The results showed that considerable amount of HBCD will be stocked as consumer products (26,000 ton in 2020) due to their long life time, in spite of the introduction of alternatives and indicated that products containing HBCD would be a potential emission source for a long time. The results also indicated that replacement of HBCD would reduce FR emission from polystyrene foam, while it would slightly increase FR emission from curtains.

As a next step, we compared products with HBCD with other products that have similar functions without use of HBCD. Products selected were glass wool and urethane foam as thermal insulating material and flame retardant yarn as a material of textile. Comparison in flame retardant emission, CO₂ emission, landfill space demand for disposal, and price indicated some alternative products have good prospect of reducing environmental impact.

This study showed life-cycle assessment of both risk and other environmental impacts, although it has large uncertainties, would provide useful information for selecting a better option among possible alternatives.

Halogen-free and brominated flame retardants, from mining to recycling: the life cycle assessment approach

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Brominated flame retardants (BFRs) are used in a wide range of commercial products, but unfortunately sometimes have negative effects in the environment. Therefore, they need to be substituted by less harmful substances. Several halogen-free flame retardants (HFFRs) already exist on the market. However, the available information about their environmental and toxicological impact is limited. In the EU-project ENFIRO, the substitution options for BFRs are evaluated from both a technical, environmental and social perspective. One of the tools used for this evaluation was Life Cycle Assessment.

As a case study, the use of FRs in a laptop was chosen. The whole life cycle of the FRs was covered: from mining of raw materials and production of FRs via the use phase (with possible volatilization of FRs from electronics) to the different possible waste scenarios.

For some polymer-FR combinations, in the production phase the HFFR version had a better environmental performance than the BFR version, while for others the BFR version performed better (mainly caused by different energy consumption).

Much more relevant however was the waste phase: especially the formation of brominated dioxins out of BFRs during improper electronics waste treatment had a strong negative impact on the LCA-scores. Overall the life cycle environmental performance of the HFFR scenario was better than for the BFR scenario.

The same life cycles were also evaluated on social criteria. This new method is called Social Life Cycle Assessment. In this more qualitative method, the 'social hotspots' along the life cycle are identified. Several hotspots are found in the raw material mining phase.

Phosphorus flame retardants – State of the art and what's next

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Phosphorus is a very versatile element for creating flame retardants – it can be used in the form of elemental phosphorus as red phosphorus or depending on the number of carbon-phosphorus bonds as phosphates, phosphonates and phosphinates. Whereas halogens like chlorine and bromine are always attached to the perimeter of molecules, due to its three or five bonds, phosphorus acts as a central atom around which a molecule is built. Phosphorus flame retardants mainly function by forming a char layer on the surface of a material, but species reacting in the gas phase of the flame zone are also known. As examples of more recent developments phosphinates for application in engineering thermoplastics will be presented which have become the established solutions for halogen free materials (Exolit® OP). New reactive type flame retardants for epoxy resins for printed circuit boards are also being introduced into the market. The combination with suitable co-flame retardants (synergists) is key in achieving necessary performance levels for different target polymers, not only for flammability but also in terms of mechanical and electrical properties. Among new technical challenges are the continuing miniaturisation towards thinner parts, processing at high speed and temperatures as well as use in hot and humid climates. On the environmental side, flame retardants are under intensified scrutiny to prove a good environmental and health profile. A number of phosphorus flame retardants like the afore mentioned phosphinates have been positively evaluated by third parties and are suitable for ecolabelled products. In addition, efforts have started to recycle not only polymers with phosphorus flame retardants, but also phosphorus itself from e.g. sewage sludge. The next elements in the “toolbox” could be oligomeric or polymeric phosphorus flame retardants which suggest improved processing and environmental/toxicity properties. Overall, phosphorus flame retardants can combine demanding material, application and environmental requirements with high levels of fire safety and therefore, are here to stay.

Participant list ENFIRO workshop Burning Questions

7-8 November 2012, Brussels

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