LIFE CYCLE AND RISK ASSESSMENT OF ENVIRONMENT-COMPATIBLE FLAME RETARDANTS: ENFIRO, A PROTOTYPICAL CASE STUDY

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Abstract: ENFIRO is a European Commission-funded project which performs a prototypical case study on substitution options for specific brominated flame retardants (BFRs). The project delivers a comprehensive dataset on viability of production and application, environmental safety, and a life cycle assessment of the alternative flame retardants (FRs). Three FR/product combinations (e.g. metal-based FRs, phosphorus-based and nanoclay-based FRs in printed circuit boards, paints and foam) are studied for environmental and toxicological risks, viability of industrial implementation, i.e. production of the FR and final products as well as fire safety requirements. The information is used for a risk assessment of the alternative FRs. The outcome of that assessment together with socio-economic information is used in a life cycle assessment. The project follows a pragmatic approach, avoiding final recommendations on environment-compatible substitution options that would not be viable for implementation by industry. The ENFIRO approach and the results are useful for similar substitution studies, e.g. in REACH.

1. INTRODUCTION

Some brominated flame retardants (BFRs) have unintended negative effects on the environment and human health. Some of them show a strong bioaccumulation in aquatic and terrestrial food chains, some are very persistent, and some show serious toxicological effects such as endocrine disruption. During the last decade an increasing number of reports have presented evidence of these negative effects caused by BFRs. A number of BFRs (polybrominated diphenyl ethers (PBDE's), hexabromocyclododecane (HBCD) and tetrabromobisphenol-A (TBBPA) in particular) can be found in increasing concentrations in the human food chain, human tissues and breast milk [1-4]. 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 a prototypical case study on substitution options for specific BFRs resulting in a comprehensive dataset on viability of production and application, environmental safety, risk assessment, and a life cycle assessment.

2. ENFIRO APPROACH

A practical approach (Fig. 1) is followed, in which the alternative FRs are evaluated regarding their flame retardant properties, their influence on the function of products once incorporated, and their environmental and toxicological properties. This is achieved by performing case studies, which gather a comprehensive set of information on environmental behaviour and toxicological impact, as well as an assessment of the performance of the FR in a specific application. The case studies give recommendations for industrial and governmental stakeholders.

ENFIRO starts with a prioritization and selection phase to select the most promising three FR/product combinations for further detailed studies. The three selected combinations are studied on hazard characterization, exposure and fate, FRs emissions and fire retarding properties (FR capability studies), and the technical suitability of the FRs when used as such or as mixtures in specific applications (PCBs, coatings, etc.). The collected information is analysed in a risk assessment. After collection of socio-economic information on the FR/product combinations together with the risk assessment, the outcome is digested in a

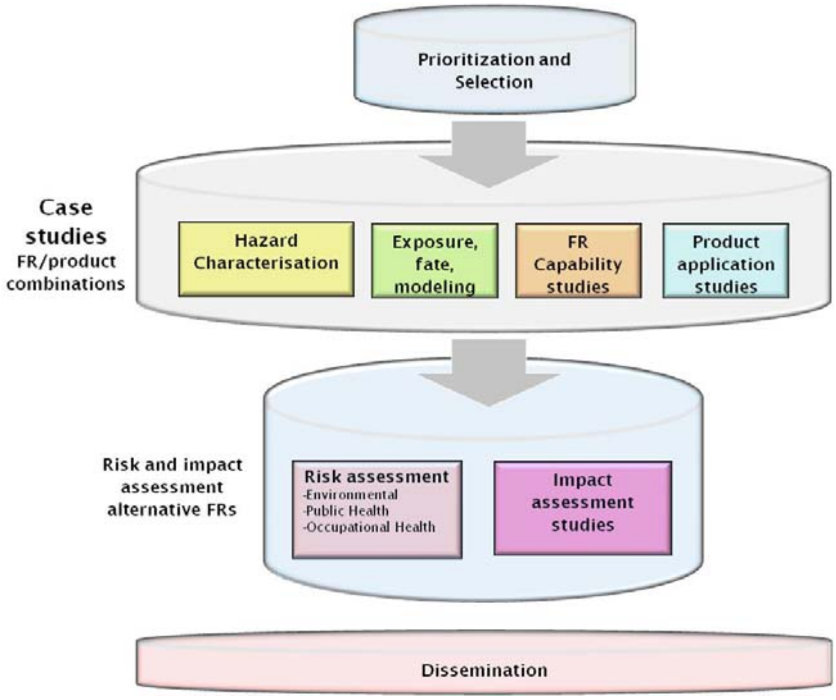

Figure 1: ENFIRO approach to study flame retardant substation options.

life-cycle assessment, including an analysis of costs and socio-economic aspects. This will finally result in a recommendation of certain FR/product combinations.

3. RESULTS AND DISCUSSION

3.1. Prioritization and selection

For the selection and prioritization phase information on a range of non-brominated FRs that are viable alternatives to specific commercial BFRs through literature and other reliable scientific sources based on how they affect the material's characteristics of the polymers is collected. Information on the performance criteria as compatibility behaviour in marketable polymers and the evaluation of fire behaviour are collected, as well as toxicological and ecotoxicological properties of the selected FRs, and the impact on function and reliability of end products, and finally economic aspects are gathered (see Figure 2)..

3.2. Exposure and effect assessment

ENFIRO performs a health hazard characterisation of the selected FRs with the focus on a molecular and cellular level. The emphasis is on human/mammalian geno-, endocrine- and neurotoxicity (sensitive targets for metals, nanoclays, PFRs and BFRs) in vitro studies, including biotransformation, and a limited number of ex vivo validation studies.

The ecotoxicological hazard characterization studies investigate the acute toxicity using water and sediment toxicity tests (Daphnia, Chironomus riparius, algae PAM), and the chronic toxicity with the Daphnia and Lumbriculus variegates tests. Bioavailability is taken into account, and structure-activity relationships for toxicity are derived.

3.3. ENFIRO Stakeholder Forum (ESF)

An ENFIRO Stakeholder Forum with members representing FR users (large industries) was invited to guide this project. The ESF functions as a reference group for the identification, elaboration and evaluation of the drivers and barriers connected to the flame retardant substitution project. The ESF consists of representatives that exchange valuable input with the project objectives. They are requested to give feedback to the different options and questions that are raised during the analysis of the environmental, economic and social impacts of the alternative flame retardants. The ESF consists of a balance of relevant stakeholder (groups) not only from the value chain like producers of alternative of flame retardants,

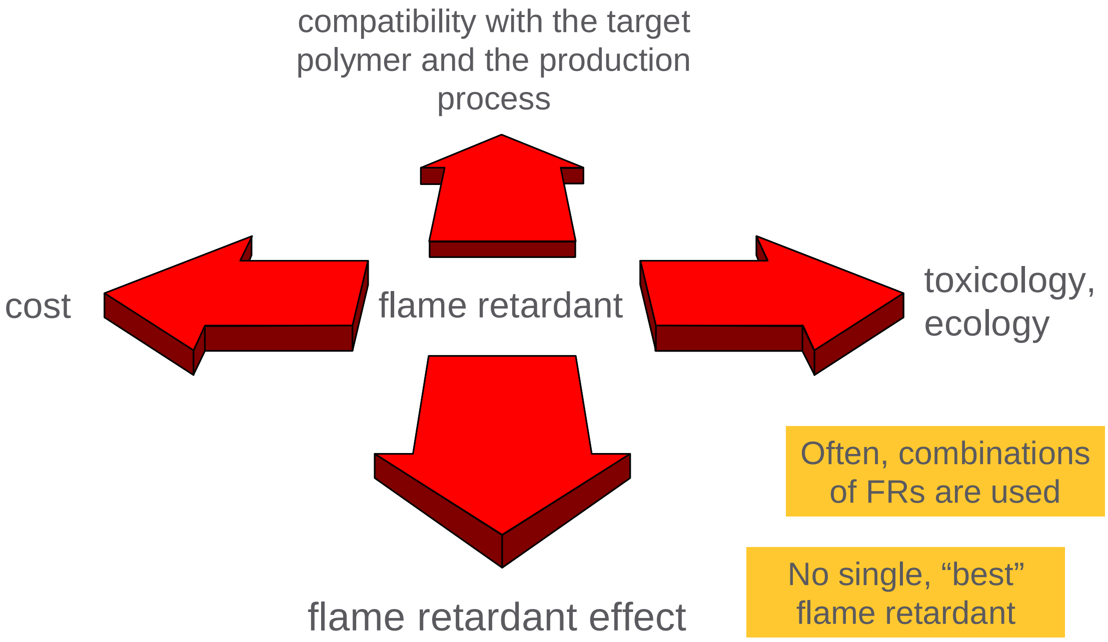

Figure 2: The generic factors influencing the choice of a suitable flame retardant. The technical requirements on flame retardants are manifold and depend on the application and target polymer (or other material like textiles, wood). For example, if the flame retardant is mixed into the molten polymer as is commonly done with thermoplastics, it must chemically "survive" the compounding temperature and form a homogeneous phase with the polymer. Otherwise "blooming" occurs, when the flame accumulates on the surface.

formulators and users of these substances, and waste (processing) plants but also from other institutes like NGOs and policy-related ones.

4. PRACTICAL APPLICATIONS OF THE ENFIRO APPROACH FOR REACH

The approach and the results of ENFIRO will be useful for similar substitution studies, e.g. under the REACH regulation in Europe (Registration, Evaluation and Authorization of Chemicals, EC 1907/2006). Under REACH, problematic substances can be restricted or banned, such as those with carcinogenic, mutagenic or repro-toxic properties (CMR) or those which are persistent, bioaccumulative and toxic (PBT). Such critical chemicals can only receive an "authorization" for certain uses, if it is shown that the socio-economic benefits outweigh the risk to human health or the environment arising from the use of the substance and if there are no suitable alternative substances and technologies. ENFIRO addresses the latter by evaluating the overall environmental and health performance of alternatives.

One current example is hexabromocyclododecane (HBCD) which is mainly used for foamed polystyrene. This brominated flame retardant is classified as a PBT substance and is on the candidate list of "substances of very high concern" (SVHC) for authorization. If HBCD becomes subject to authorization, its prolonged use will only be granted, if no suitable alternatives exist or if the desired of function (e.g. fire safe insulation materials for buildings) cannot be achieved with other materials or technologies. ENFIRO develops a methodology to assess potential alternatives in a comprehensive way, including environmental and toxicological properties as well as technical feasibility and fire performance.

Similar studies have not taken into account the full scope of an assessment including the life cycle of flame retarded products. The US Environmental Protection Agency (US-EPA) is currently running a project to assess alternatives to tetrabomo bisphenol-A (TBBPA) in printed circuit boards [6]. The electronics industry formed this partnership with the US-EPA in 2006 to develop information that will improve their understanding of the environmental and human health impacts of new and current materials that can be used to meet the fire safety requirements for printed circuit boards. This information will be presented to allow industry to consider these impacts along with cost and performance of circuit boards as they review alternative materials and technologies. However, this project focuses on an evaluation of the inherent hazards of the flame retardants, with only limited scope for life cycle aspects. The end of life scenario of controlled and uncontrolled burning such as in crude recycling operations will also be investigated. In 2010, alternative flame retardant materials were used in about 10 % of the current FR-4 boards, and their market share is growing steadily. Additional alternative flame retardant materials are also under development. Little information exists concerning the potential environmental and human health impacts of the materials which are being developed as alternatives to those used today that are based on brominated epoxy resins.

A full lifecycle study is a challenging task, as there are many stages and actors in a product chain of e.g. flame retardants used in electronics: material suppliers, printed wire board production and printed circuit board assembly, final product assembly, retailers, private users, dismantlers, re-manufacturers, incineration, landfills, and others. Collaboration between FR manufacturers, users, and scientists is needed to produce such a comprehensive dataset.

5. CONCLUSIONS

The approach and the results of ENFIRO will be useful for similar substitution studies, e.g. in REACH. The first phase, prioritisation and selection of the alternative FR/product combinations using a viabilty scheme is finished. The exposure and effect studies are ongoing.

6. REFERENCES

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