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Safe and Sustainable-by-Design Flame Retardants

A case study for electronic components and electric vehicle parts

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Flame Retardants
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SSbD – criteria and procedure have been proposed by EU-JRC


European Commission

JRC TECHNICAL REPORT

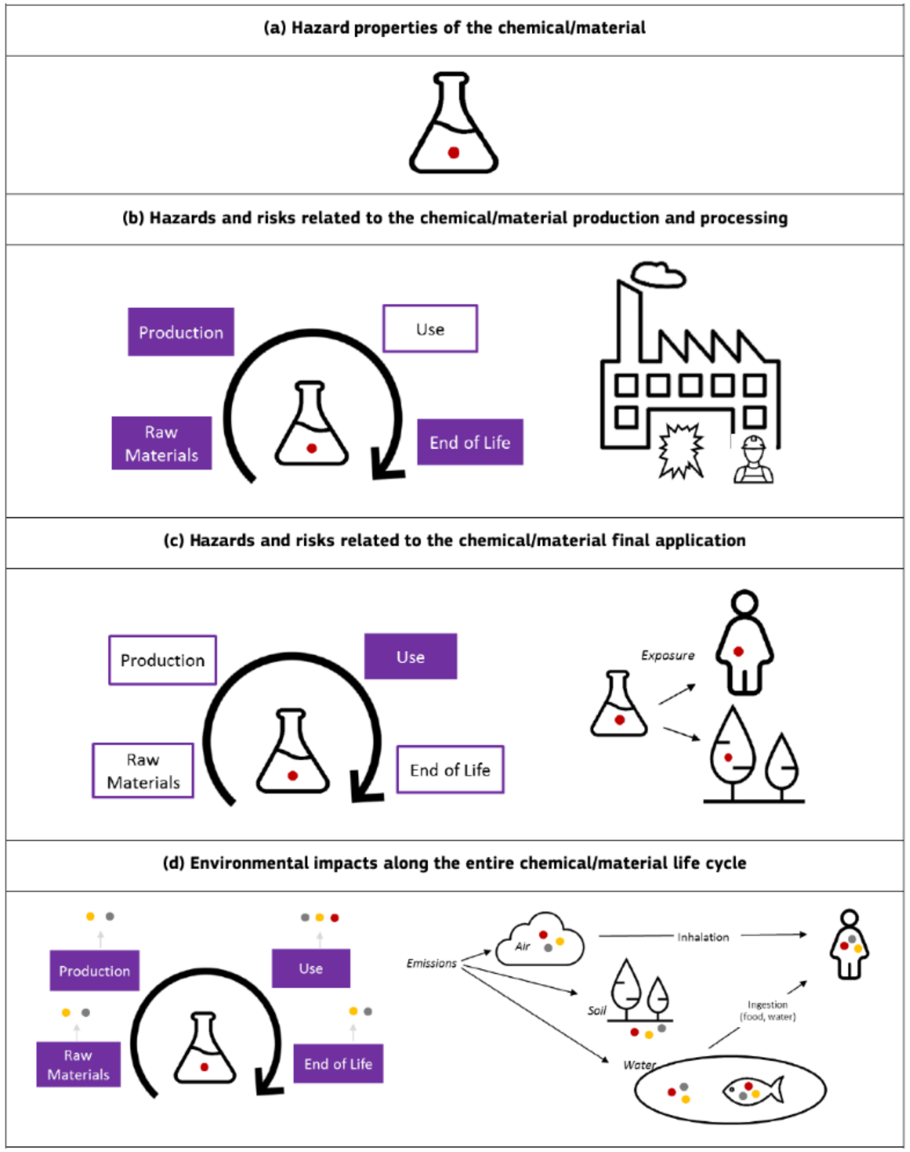
Safe and Sustainable by Design chemicals and materials

Framework for the definition of criteria and evaluation procedure for chemicals and materials

Caldeira, C. Farcal, R., Garmendia Aguirre, I., Mancini, L., Tosches, D., Amelio, A., Rasmussen, K., Rauscher, H., Riego Sintes, J., Sala, S.

2022

Framework to be revised / finalised in 2025



What is a sustainable Flame Retardant?

Hazards

- PBT: Persistence, Bioaccumulation, Toxicity
- CMR: Carcinogenicity, Mutagenicity, Reproductive Toxicity
- Endocrine effects, Mobility (new)

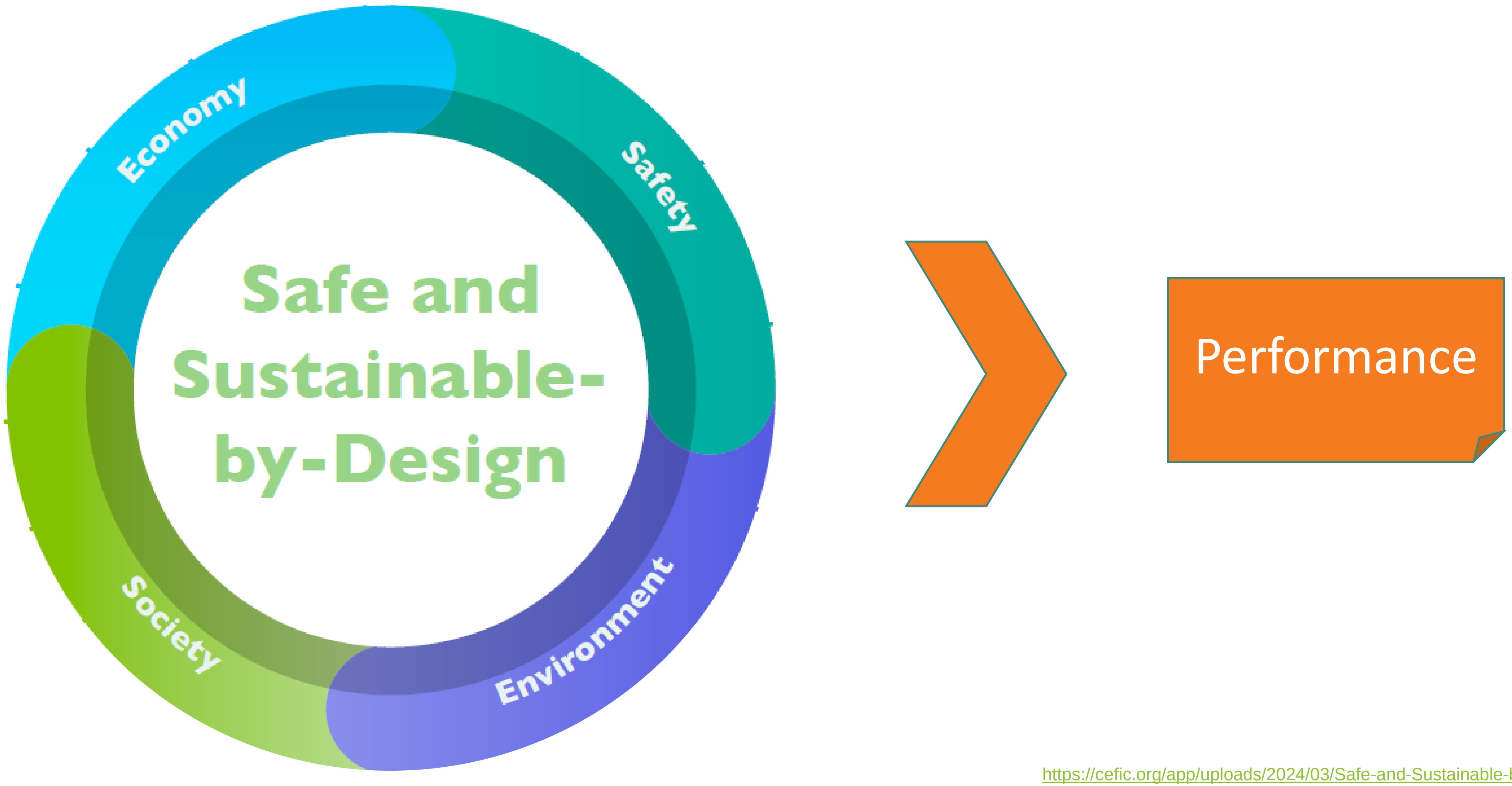
Life Cycle

- Carbon footprint (global warming potential) and other Product Environmental Footprint criteria
- Production (value chain): impact on workers
- Use Phase: impact on consumers
- End-of-life → Recycling properties

Other

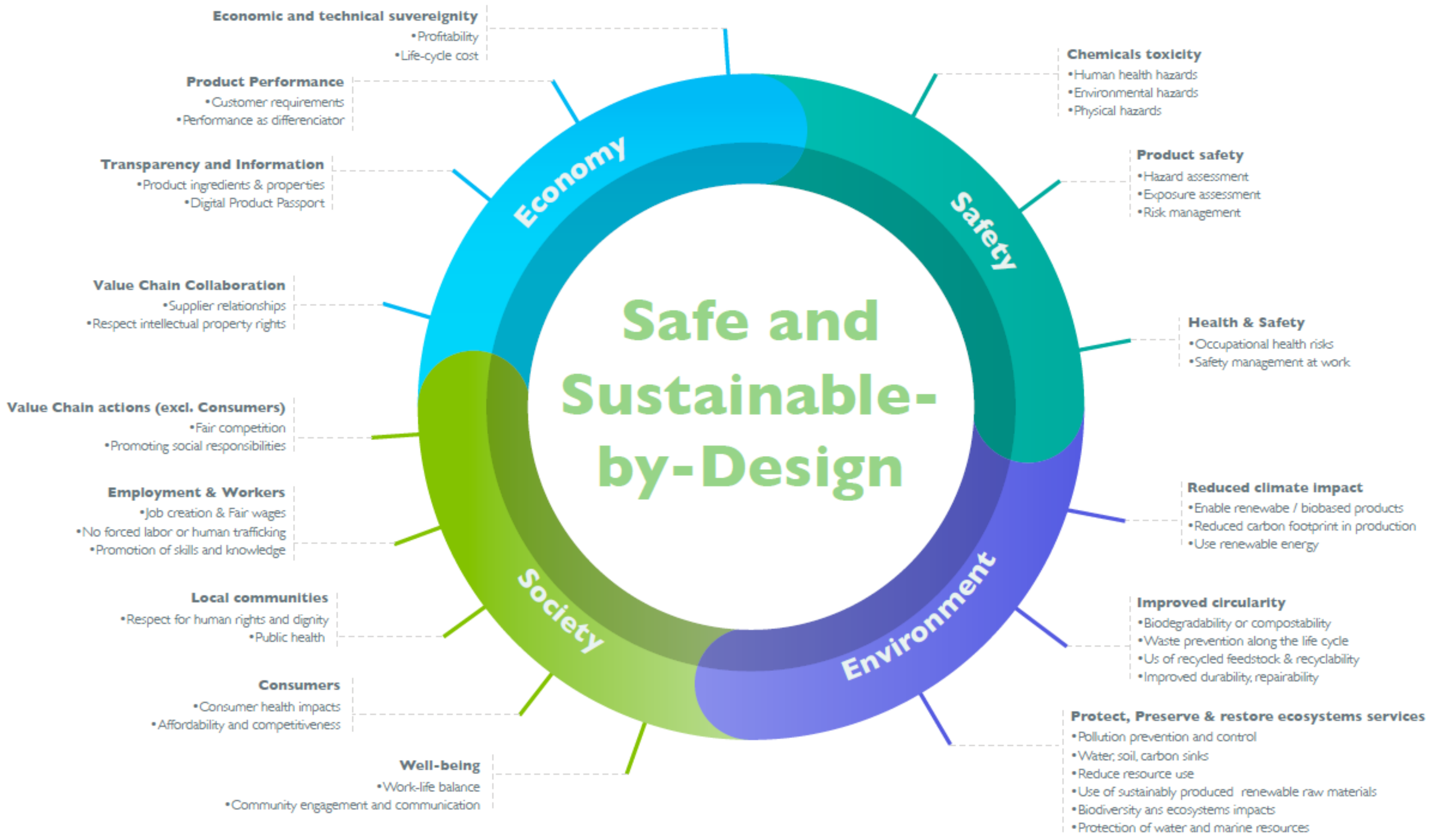
- Critical raw materials
- Fires: Smoke formation / toxicity
- Social impact

Cefic SSbD Guidance



https://cefic.org/app/uploads/2024/03/Safe-and-Sustainable-by-Design-a-guidance-to-unleash-the-transformative-power-of-innovation.pdf

Safety and sustainability dimensions to assess for innovation

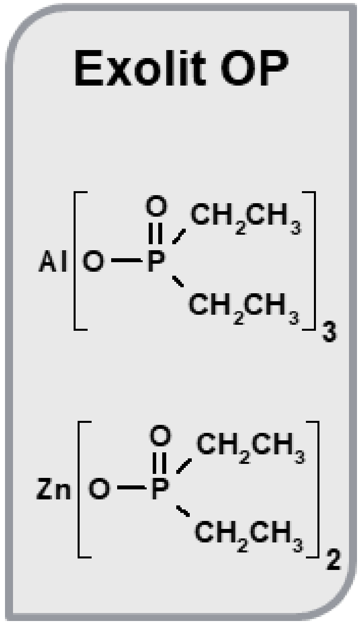


Considerations to be included in the industrial innovation process stem from **4 main dimensions**:

- **Safety**
- **Environmental sustainability**
- **Societal sustainability**
- **Economic sustainability**

Exolit® OP phosphinate based flame retardants for engineering plastics

Non-melting filler like flame retardants,
available as single substance or
in the combination with synergists,
typical dosage 20%

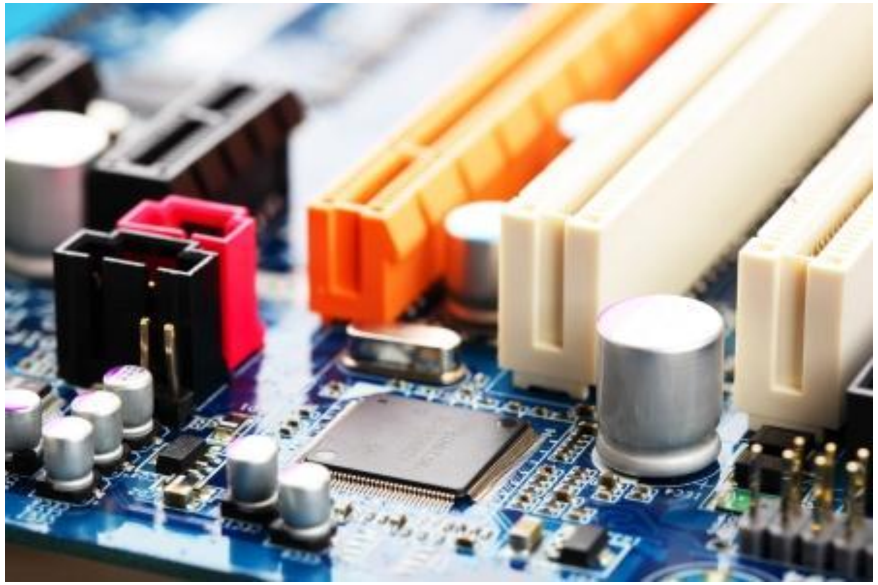


Polyamides

Polyesters

Thermoplastic Elastomers

Epoxies, Adhesives,
Textile Coating . . .



Hazard Profile – only persistence is flagged

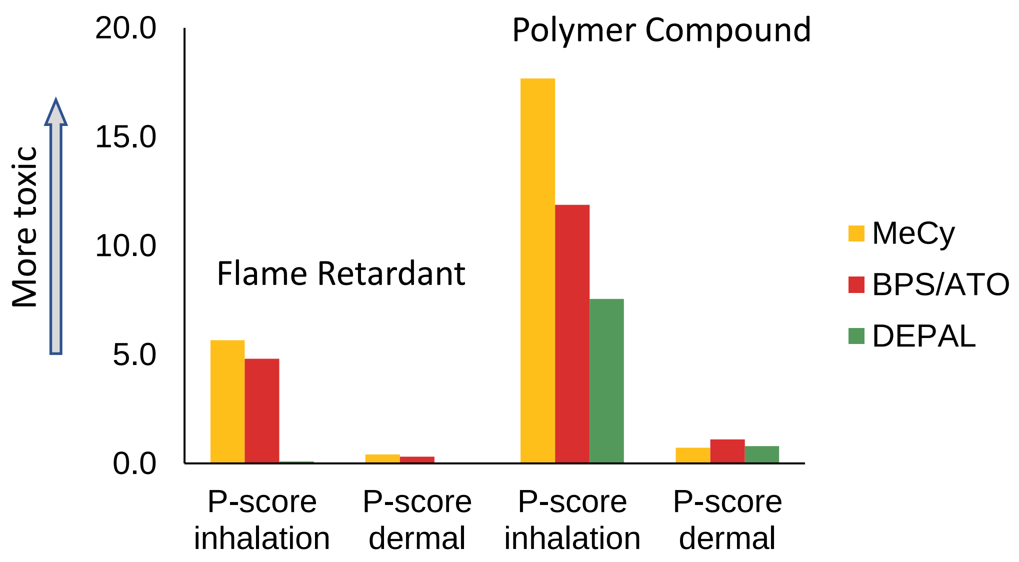
EU ENFIRO Project

GreenScreen® Hazard Summary Table for Aluminum Diethylphosphinate

Group I Human					Group II and II* Human									Ecotox		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS	SnR	IrS	IrE	AA	CA	P	B	Rx	F
						s	r*	s	r*	*	*								
L	**L**	**L**	*L*	DG	**L**	**L**	**L**	*L*	**L**	**L**	*L*	**L**	**L**	**L**	**L**	**vH**	**vL**	**L**	**L**

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect lower confidence in the hazard classification while hazard levels in **BOLD** font reflect higher confidence in the hazard classification. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M, and L) instead of three (i.e., H, M, and L), and are based on single exposures instead of repeated exposures. Group II* Human Health endpoints are indicated by an * after the name of the hazard endpoint or after "repeat" for repeated exposure sub-endpoints. Please see Appendix A for a glossary of hazard acronyms.

ProScale shows low toxicity potential for Workers



Scores for the Flame Retardant share of the compound recipe: MeCy and BPS/ATO have high scores, driven hydrocarbon production and intermediates. DEPAL has low scores in comparison.

Scores for the full polymer compound: MeCy has the highest score, but this also linked to the high contribution of the polymer and the low MeCy dosage. Again, DEPAL compound has lowest scores overall.

The values shown are ProScale scores normalized to 1 kg of polymer compound. Inhalation scores are an order of magnitude higher than dermal scores. Oral scores are negligible and therefore not shown.

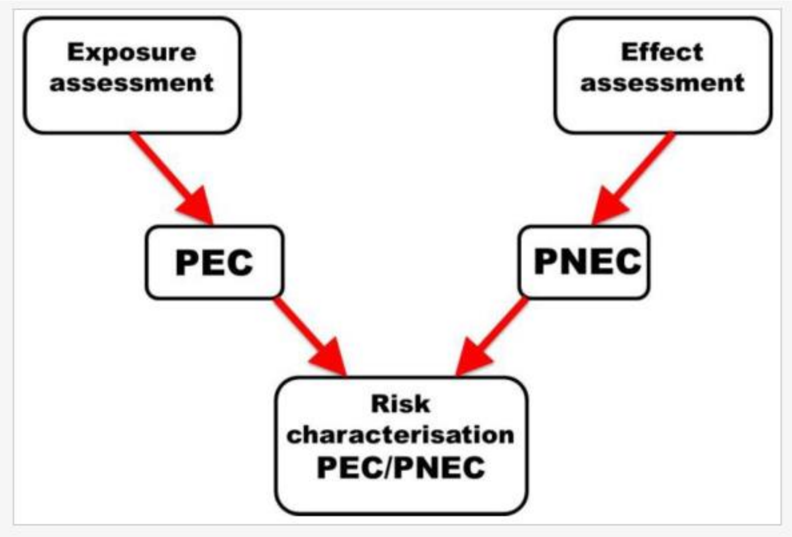
Comments:

- MeCy: high scores caused by natural gas from a steam cracker (>80%), production process
- BPS / ATO: main contribution from naphtha and ethylene
- DEPAL: main contribution from P4 and related intermediates

Points for further research:

- Are differences significant?
- Can reference points be provided?
- Sensitivity analysis

Consumer Exposure: no unacceptable risks identified in Chemical Safety Report



Environmental compartment	PEC consumer use	PEC service life	PNEC	RCR
Fresh water	0.45	0.57	1000	< 0.001
Marine water	0.04	0.05	100	< 0.001
Sewage treatement	0.14	1.37	48300	< 0.001
Sediment			no exposure expected	
Soil			no exposure expected	
Air			no hazard identified	

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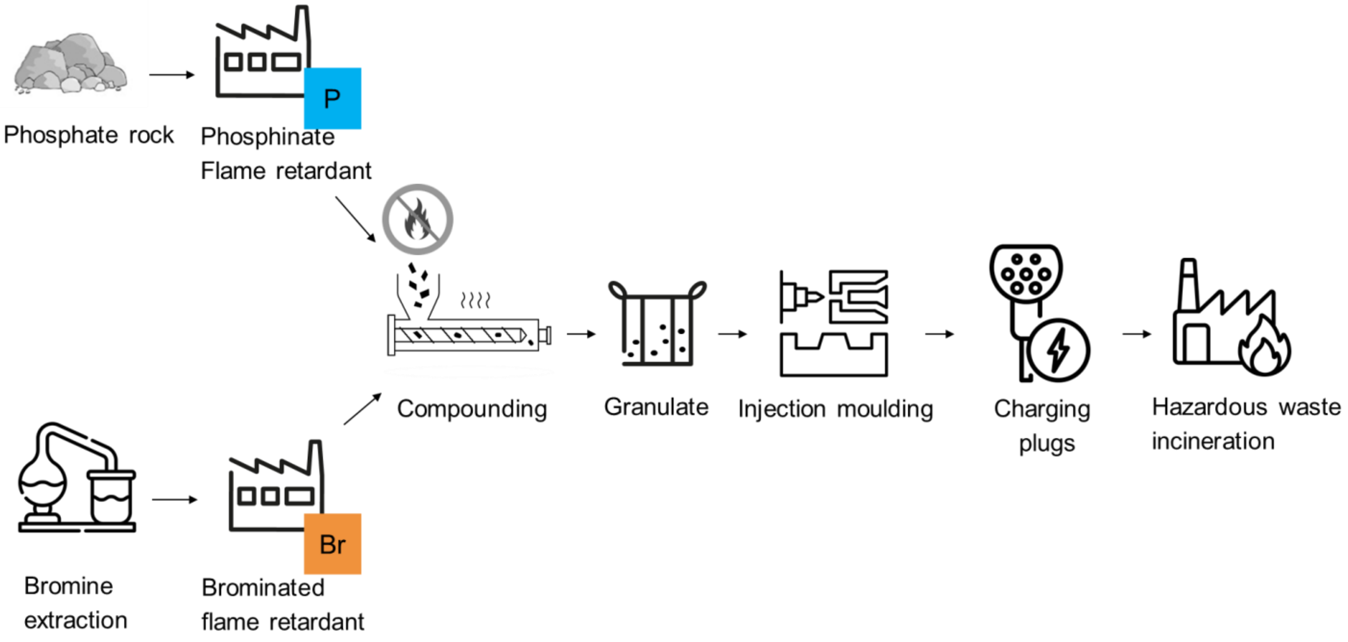
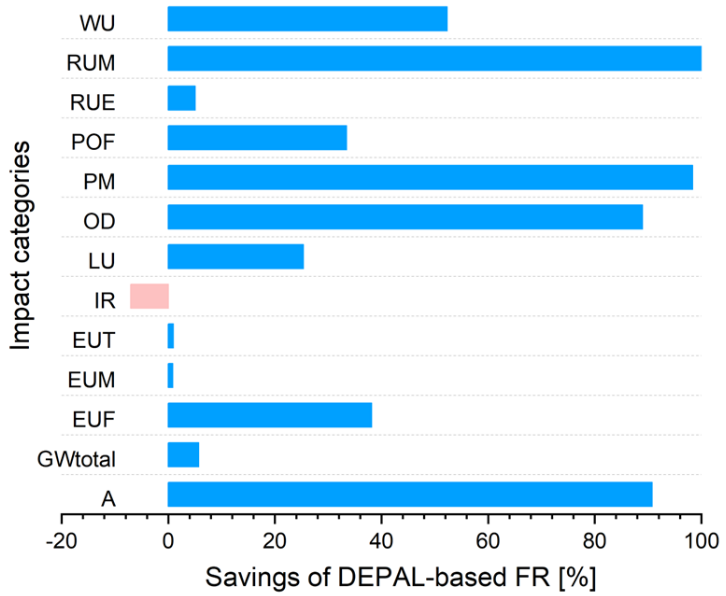
- PEC = predicted environmental concentration
- PNEC = predicted no effect concentration
- RCR = risk characterisation ratio

Life Cycle Assessment of Exolit OP 1400, published:

Phosphorus-based flame retardants for electrical parts have life cycle benefits vs. bromine-based flame retardants





Challenges:
process / substance info from suppliers, confidentiality, €€€

ACS Sustainable Chemistry & Engineering
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pubs.acs.org/journal/ascecg
Research Article

Toward Sustainable Fire Safety: Life Cycle Assessment of Phosphinate-Based and Brominated Flame Retardants in E-Mobility and Electronic Devices

Daniel Maga,* Venkat Aryan, and Adrian Beard

Cite This: https://doi.org/10.1021/acssuschemeng.3c07096

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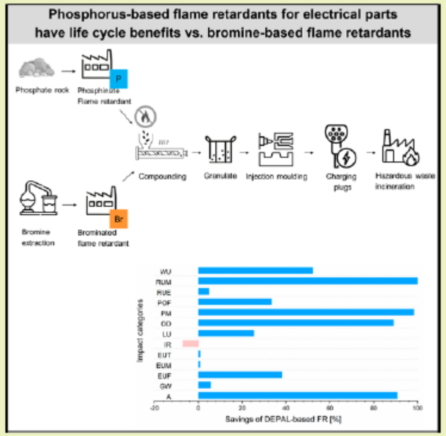
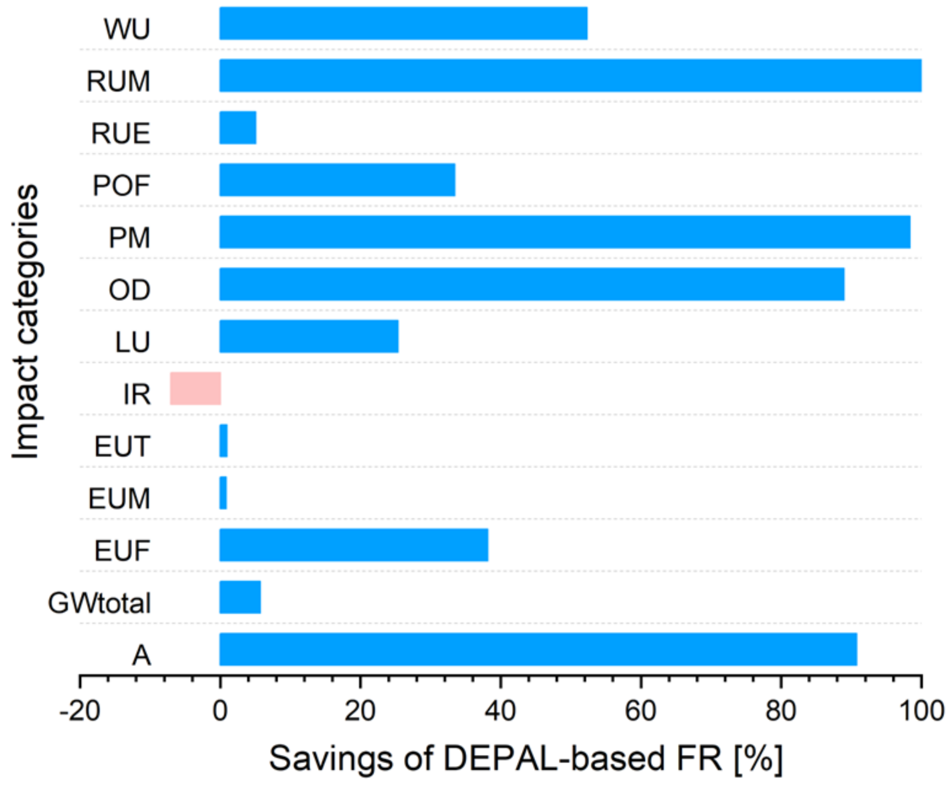


ABSTRACT: The increasing market demand for electronic devices has raised concerns regarding the environmental impact of the flame retardants used in their production. Traditionally, brominated flame retardants have been used for their effectiveness despite their detrimental effects on the environment and hindrance to the principles of a circular economy. Evidently, harmful flame retardants should be replaced with less harmful ones. Hence, the exploration of alternatives, such as organophosphorus flame retardants like aluminum diethyl phosphinate (DEPAL), presents a promising avenue. Therefore, the goal of this study is to investigate the environmental impacts of DEPAL-based flame retardants in polyamides for use in connectors, plugs, and USB-C ports and to compare their impacts with those of their brominated flame-retardant counterparts. The life cycle impact results show that the flame-retardant polyamides using DEPAL have lower environmental impacts than the ones using halogenated flame retardants. Nonetheless, it is important to note that the production of phosphorus still requires large amounts of energy. Hence, switching to renewable energy can significantly lower the footprint of DEPAL. Furthermore, it offers an eco-friendly alternative to traditional flame retardants.

KEYWORDS: *LCA, flame retardants, bromine, phosphorus, exolit, electronics, electric vehicles, SSbD (safe and sustainable-by-design)*

– Link to full text

LCA: Savings of Exolit-based Polyamide across Impact Categories



For calculating the environmental impacts, the life cycle impact assessment (LCIA) methods selected by the Product Environmental Footprint (PEF, or more generally EF) 3.0 will be used (see table below).

Impact category	Unit	LCIA Method
Acidification	Mole of H+ eq.	Accumulated Exceedance model [Seppälä et al. 2006; Posch et al. 2008]
Climate Change	kg CO_2 eq.	Bern model – Global Warming Potentials (GWP) over 100-year time horizon [IPCC 2013]
Eutrophication freshwater	kg P eq.	EUTREND model [Struijs et al. 2009] as implemented in ReCiPe
Eutrophication marine	kg N eq.	EUTREND model [Struijs et al. 2009] as implemented in ReCiPe
Eutrophication terrestrial	Mole of N eq.	Accumulated Exceedance model [Seppälä et al. 2006; Posch et al. 2008]
Ionizing radiation - human health	kBq U^{235} eq.	Human Health effect model [M. Dreicer et al. 1995]
Land Use	Dimensionless (aggregated index)	Soil quality index based on LANCA [Bos et al. 2016]
Ozone depletion	kg CFC-11 eq.	Steady-state ODPs [WMO 1999]
Particulate matter	Disease incidences	PM model recommended by UNEP [UNEP 2016]
Photochemical ozone formation - human health	kg NMVOC eq.	LOTOS-EUROS model [van Zelm et al. 2008] as applied in ReCiPe 2008
Resource use, fossils	MJ	CML 2002 model [Guinée 2002; L. van Oers et al. 2002]
Resource use, mineral and metals	kg Sb eq.	CML 2002 model [Guinée 2002; L. van Oers et al. 2002]
Water use	kg world eq. deprived	Available WAter REmaining (AWARE) as recommended by UNEP [UNEP 2016]

These LCIA methods are recommended by the European Commission and the Joint Research Centre in order to measure the environmental performance of a product throughout its life cycle. The EF 3.0 consists of multiple impact categories as shown the prior table.

Fires: Smoke Toxicity
is in the same range as neat polymer, lower than for brominated FRs

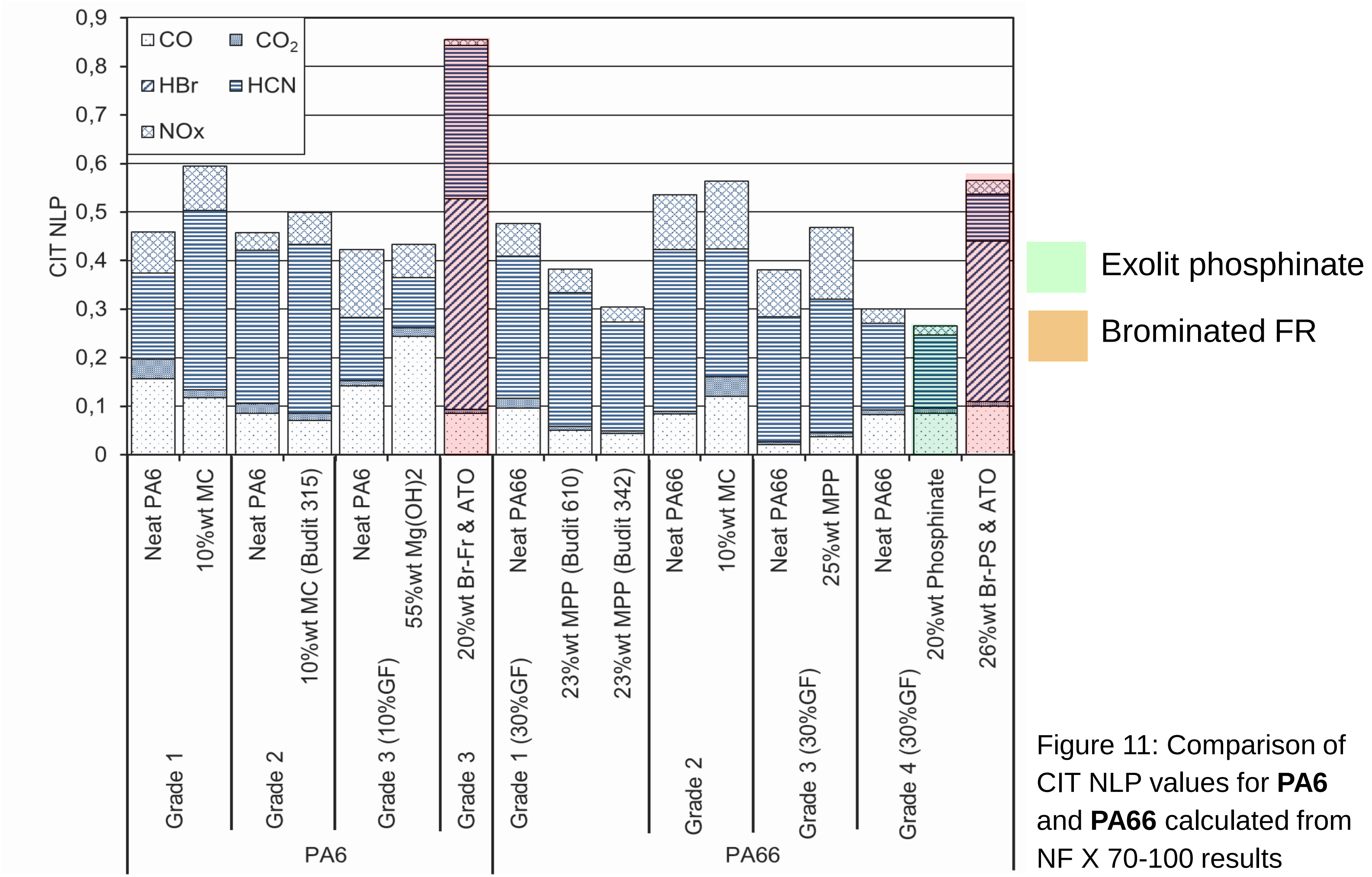


Figure 11: Comparison of CIT NLP values for **PA6** and **PA66** calculated from NF X 70-100 results

The smoke toxicity for Exolit samples is in the same range as the non-flame retarded polymers

- CIT NLP = conventional index of toxicity for non-listed products
- NF X 70-100 = French standard using a tube furnace
- AlPi = Aluminium Phosphinate = DEPAL = Exolit OP 1230
- Br-PS = brominated polystyrene

“The impact of halogen free phosphorus, inorganic and nitrogen flame retardants on the toxicity and density of smoke from 10 common polymers”, H. Feuchter, F. Poutch, A. Beard, Fire and Materials. 2023;1–21, https://doi.org/10.1002/fam.3145

Conclusion – Flame Retardants can be Sustainable

- The phosphinate-based FR showed a better environmental performance vs. the brominated FR / ATO.
- SSbD concept is good → needs workable approach along innovation process
- Toolboxes and databases
  → e.g. life cycle properties
- Need to align with Portfolio Sustainability Assessments (PSA)
- Detailed review of existing products
  → hotspots, improvement potential
- Trade-offs cannot be avoided

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Thank you for your attention!

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20.06.2024

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References and Further Reading

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