September 22, 2023

Non-confidential comments for Annex XV restriction report: Persistence, ecotoxicity, and emissions of PFAS to the environment

Dear Madam or Sir,

We welcome the opportunity to provide input on the restriction proposal regarding per- and polyfluoroalkyl substances (PFAS). This submission was prepared by Prof. Dr. Martin Scheringer (Masaryk University, Brno, Czech Republic, and ETH Zürich, Zürich, Switzerland) with input of members of the Global PFAS Science Panel (GPSP), in particular Prof. Dr. Ian Cousins (Stockholm University, Stockholm, Sweden) and Prof. Dr. Xenia Trier (University of Copenhagen, Copenhagen, Denmark). The GPSP is a collaborative partnership among academic researchers, regulatory scientists and policy analysts dedicated to enhancing understanding of PFAS and to protecting human and environmental health from potentially adverse effects associated with PFAS through better informed decision-making. The scientific work of the GPSP in the last five years has considerably advanced the understanding of PFAS and the GPSP would like to take the opportunity to also give input to the PFAS restriction proposal.

We see the restriction proposal as a very important initiative and good way forward to counteract the ongoing emissions of PFAS in Europe (and in part even worldwide). Our submissions should therefore be seen as a support of the restriction proposal to make it even stronger and more fully complete. The current submission provides additional information on the persistence and ecotoxicity of PFAS, and on PFAS emissions to the environment.

All references cited below are provided at the end of this document.

1) Additional information regarding Section 1.1.4.2, Persistence, and Annex B.4.1

Most PFAS are characterized by their extremely high persistence in the environment. Here we present arguments, in line with Scheringer (2023), that the extreme persistence of PFAS should be considered a hazardous property in itself, which adds further weight to the concern about the persistence of PFAS. Scheringer (2023) states:

> "Persistence has been seen as a property that merely indicates the presence of a chemical in a given environment. It may seem that persistent chemicals are inert and thus relatively benign. However, they still have many ways to interfere with an organism's physiology and cause adverse effects. Therefore, persistence is a property that makes the toxicity of any chemical much worse because it leads to—as long as uses and corresponding emissions are ongoing—ever increasing concentrations, and toxic effects will manifest at some point. In other words, **persistence acts as a multiplier of toxicity**. This insidious aspect of persistence has been underestimated in chemicals assessment for a long time, and now in the case of PFAS, it has hit home" (Scheringer, 2023; our emphasis in bold).

The reasoning behind this argument is as follows: Exposure to a chemical has two components: (i) use pattern and emission rates, and (ii) persistence as a factor that makes exposure last longer. Use patterns and emission rates are not chemical specific and are a factor that scale with the amount of chemical present (or, rather, the amount of chemical present scales with emissions). Persistence, in contrast, is chemical specific and a property of the chemical (and, of course, does not depend in any way on emissions).

If these two elements are lumped together in what is called "exposure", the chemical-specific aspect is easily overlooked. It is not obvious that, for persistent chemicals, many aspects of exposure are directly linked to persistence as a property of the chemical. Therefore, it is justified to see the component of exposure that is governed by a chemical's persistence not just as an element of exposure, but as a chemical-inherent hazardous property.

This point is even more important because for non-persistent chemicals, exposure actually is more or less completely governed by emissions and emission patterns. This picture obtained from non-persistent chemicals may easily dominate how people see and understand exposure in general. Only if a chemical's persistence is high, it takes over as a dominant factor governing exposure. So, it is a "fallacy of the wrong perception" that exposure is seen as generally governed by emissions, and persistence is just some "additional factor". In conclusion, exposure should be split into the two contributions of emissions and of persistence, and persistence should be added to the hazardous chemical properties.

Finally, it is important to see the truly "insidious" features of persistence that justify calling it a hazard: persistence makes exposure longer and, as long as emissions are ongoing, higher, and it makes it largely irreversible, i.e. exposure does not react quickly to changes in emissions – persistence makes exposure uncontrollable and decouples it from emissions (which are often perceived as the most relevant factor, see above, but here exactly the opposite is true: emissions may have ceased, but exposure continues for long): emission reductions do not lead to lower and shorter exposure – because of the chemical-inherent property of persistence. From, "the dose makes the poison", follows, for chemicals with high

persistence, “persistence makes the poison” because, as stated above, it makes exposure higher and more chronic and decouples it from emissions.

2) Additional information regarding Section 1.1.4.7, Ecotoxicity, and Annex B.7.1.3

Delor et al. (2013) have investigated the adverse impacts of PFAS on earthworms. Their summarize their findings as follows:

> “Soil contamination by PFAS is a major environmental concern, and there is a lack of knowledge on both their ecotoxicological mechanisms and the concentrations that induce adverse effects especially to non-target organisms, particularly in the case of PFAS mixtures. This study contributes to filling these gaps by assessing and modelling the effects of PFAS (in single and in mixtures for PFOS and PFOA at different environmental doses) on juvenile endogeic earthworms of a common species in European soils (Aporrectodea caliginosa) at different levels of biological organization (sub-individual and individual). **The results showed for the first time combined strong ecotoxicological effects of PFAS on earthworm survival, integumental integrity, growth, sexual maturity and on genomic stability notably with the induction of DNA breaks associated with no abnormal oxidative DNA-lesion levels.** Our results demonstrated significant effects at 0.3 mg kg^{-1} and additive effects in case of mixtures” (Delor et al., 2023, abstract, our emphasis in bold).

This new information should be added to the restriction proposal and be considered by RAC and SEAC.

3) Additional information regarding Section 1.1.5.1, Emissions to the environment, and Annex B.9.13.2, Annex B.9.18.2.3–7

In Annex B, section B.9.13.2, the life-cycle stage of disposal is missing and needs to be added. Emissions of PFAS from lithium ion batteries at the end of their use phase have been reported (Guelfo et al. 2023) and need to be included in the proposal.

> “Emerging LiB technologies have incorporated a novel class of per- and polyfluoroalkyl substances (PFAS, i.e., "forever chemicals") known as bis-perfluoroalkyl sulfonimides (bis-FASIs)3–8. PFAS are recognized internationally as recalcitrant, mobile, and toxic environmental contaminants[9]. Despite this, virtually nothing is known about environmental impacts of bis-FASIs released during LiB manufacture, use, and disposal. **Here we demonstrate that occurrence, ecotoxicity, and treatability of this novel class of PFAS are comparable to PFAS that are now prohibited and highly regulated worldwide[10–15] and confirm the clean energy sector as an unrecognized and growing source of global PFAS release.** U.S. and European surface water, soil, and sediment measurements confirmed bis-FASI release internationally at concentrations as high as 2,437 parts per trillion (ppt). Toxicity data demonstrated effects on swimming behavior in Daphnia magna at bis-FASI exposures of 10 ppt and swimming behavior and metabolic process changes in Danio rerio resulting from exposures of 25 ppt. **Occurrence of up to 881 ppt of bis-FASIs in landfill leachates highlights current impacts of LiB**

disposal. Although fully recalcitrant to advanced oxidation processes, select bis-FASIs were removed from water during adsorptive treatment with similar or better efficiency as more hydrophobic PFAS such as perfluorooctane sulfonate (PFOS). L**iB use is anticipated to increase globally over the next decade, and 8 million tons of LiB waste are projected by 2040 as a result of low recycling rates[16]. This suggests that environmental exposure to this novel, unregulated class of PFAS will increase with time and will be relevant to the majority of the world's population.** Results underscore that environmental impacts of clean energy infrastructure merit scrutiny to ensure that reduced CO2 emissions are not achieved at the expense of increasing global releases of persistent organic pollutants" (Guelfo et al. 2023, abstract; our emphasis in bold).

In Annex B, section B.9.18.2.3, additional information on PFAS contained in landfill leachate should be added, as detailed by Liu et al. (2022):

"Municipal solid waste incineration (MSWI) ash is often managed through co-disposal with unburned wastes in landfills, a practice previously reported to result in enhanced leaching of pollutants (e.g., heavy metals) in landfill leachate. The objective of this study was to evaluate the effect of co-disposed unburned wastes on per- and polyfluoroalkyl substances (PFAS) in MSWI ash landfill leachate. The objective of this study was to evaluate the effect of co-disposed unburned wastes on per- and polyfluoroalkyl substances (PFAS) in MSWI ash landfill leachate. Leachate was collected from four landfills containing MSWI ash, either as a sole waste stream or co-disposed of with sewage sludge and MSW screenings. Samples of ash and unburned materials were collected and assessed separately for leachable PFAS in the laboratory. All samples were analyzed for 26 PFAS. Results showed that greater ash content was associated with lower leachate PFAS concentrations. **The pure ash monofill exhibited the lowest PFAS in landfill leachate (290 ng L^{-1}) while the landfill contained a large amount of unburned waste had the highest PFAS (11,000 ng L^{-1}).** For laboratory leaching tests, average $\sum_{26}$PFAS concentration in lab ash leachate (310 ng L^{-1}) was 10 and 24 times lower than observed in lab sewage sludge leachate (3,200 ng L^{-1}) and lab MSW screenings leachate (7,500 ng L_{-1}), respectively. Leachate from the ash-only landfill had $\sum_{26}$PFAS concentration similar to what was measured in the ash itself. **On the contrary, $\sum_{26}$PFAS concentration in co-disposal landfill leachates were similar to those in PFAS-rich unburned waste itself, regardless of the percentages of landfilled unburned wastes.** We hypothesize that leachate generated in co-disposal scenarios preferentially flows through PFAS-rich unburned materials and that biotransformation of precursors enhanced by unburned waste degradation further contributes to higher concentrations of terminal PFAS in ash co-disposal sites. **Landfill operators should expect PFAS in leachates to be higher when PFAS-rich unburned wastes are disposed of alongside MSWI ash, even if the unburned fraction is small**" (Liu et al. 2022, abstract; our emphasis in bold).

In Annex B, section B.9.18.2.4, additional information on PFAS, in particular perfluorinated carboxylic acids, emitted from waste incineration plants should be added, as detailed by Björklund et al. (2023):

> "Per- and polyfluoroalkyl substances (PFASs) are a large group of compounds commonly used as industrial chemicals and constituents of consumer products, e.g., as surfactants and surface protectors. When products containing PFASs reach their end of life, some end up in waste streams sent to waste-to-energy (WtE) plants. However, the fate of PFASs in WtE processes is largely unknown, as is their potential to enter the environment via ash, gypsum, treated process water, and flue gas. This study forms part of a comprehensive investigation of the occurrence and distribution of PFASs in WtE residues. Sampling was performed during incineration of two different waste mixes: normal municipal solid waste incineration (MSWI) and incineration of a waste mix with 5–8 wt % sewage sludge added to the MSWI (referred to as Sludge:MSWI). **PFASs were identified in all examined residues, with short-chain (C4–C7) perfluorocarboxylic acids being the most abundant.** Total levels of extractable PFASs were higher during Sludge:MSWI than during MSWI, with the total annual release estimated to be 47 and 13 g, respectively. Furthermore, **PFASs were detected in flue gas for the first time (4.0–5.6 ng m–3). Our results demonstrate that some PFASs are not fully degraded by the high temperatures during WtE conversion and can be emitted from the plant via ash, gypsum, treated process water, and flue gas**" (Björklund et al. 2023, abstract; our emphasis in bold).

In Annex B, sections B.9.18.2.5 to B.9.18.2.7, additional information on PFAS, in particular PFAS formed from PFAA precursors, contained in biosolids should be added, as detailed by Thompson et al. (2023):

> "Wastewater treatment plants generate a solid waste known as biosolids. The most common management option for biosolids is to beneficially reuse them as an agricultural amendment, but because of the risk of pathogen exposure, many regulatory bodies require pathogen reduction before biosolids reuse. Per- and polyfluoroalkyl substances (PFAS) are well documented in biosolids, but limited information is available on how biosolids treatment processes impact PFAS. Furthermore, quantification of PFAS has focused on perfluoroalkyl acids (PFAAs) which are a small fraction of thousands of PFAS known to exist. The objective of this study was to quantify 92 PFAS in biosolids collected from eight biosolids treatment facilities before and after four pathogen treatment applications: composting, heat treatment, lime treatment, and anaerobic digestion. **Overall, total PFAS concentrations before and after treatment were dominated by PFAA precursor species, in particular, diPAPs which accounted for a majority of the mass of the Σ92PFAS.** This differs from historic data that found PFAAs, primarily PFOS, to dominate total PFAS concentrations. Treatment options such as heat treatment and composting changed the ratio of PFAA precursors to PFAAs indicating a transformation of PFAS during treatment. **This study finds that PFAA precursors are likely underrepresented by other studies and make up a larger percentage of the total PFAS concentration in biosolids than previously estimated**" (Thompson et al. 2023, abstract; our emphasis in bold).

4) References

Björklund, S., Weidemann, E., Jansson, S. (2023) Emission of Per- and Polyfluoroalkyl Substances from a Waste-to-Energy Plant–Occurrence in Ashes, Treated Process Water, and First Observation in Flue Gas, *Environmental Science & Technology* **57**, 10089–10095. https://doi.org/10.1021/acs.est.2c08960.

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