Supporting information (SI)

Safe and sustainable by design: Case study of a magnetic torus microreactor and bionanocompounds for wastewater treatment

*Olga P. Fuentes [a], Amaimen Guillén-Pacheco [b,c], Johann F. Osma [d, e], Guido Sonnemann [a]**

[a] Univ. Bordeaux, CNRS, Bordeaux INP, ISM, UMR 5255, F-33400, Talence, France.

[b] Davinci - School of Basic Sciences, Technology, and Engineering (ECBIT), Electronic, Telecommunication, and Network Training Chain (ETR), Universidad Nacional Abierta y a Distancia (UNAD), Calle 14 Sur No. 14–23, 111711, Bogotá, DC, Colombia.

[c] Laboratory of Neuroscience and Circadian Rhythms. School of Medicine, Universidad de Los Andes, Cra. 1E No. 19a-40, 111711, Bogotá, DC, Colombia.

[d] Department of Electrical and Electronic Engineering, Universidad de Los Andes, Cra. 1E No. 19a-40, 111711, Bogotá, DC, Colombia.

[e] Department of Biomedical Engineering, Universidad de Los Andes, Cra. 1E No. 19a-40, 111711, Bogotá, DC, Colombia.

***Corresponding author**

Guido Sonnemann; E-mail: guido.sonnemann@u-bordeaux.fr

Number of pages: 30

Number of tables: 27

Number of figures: 4

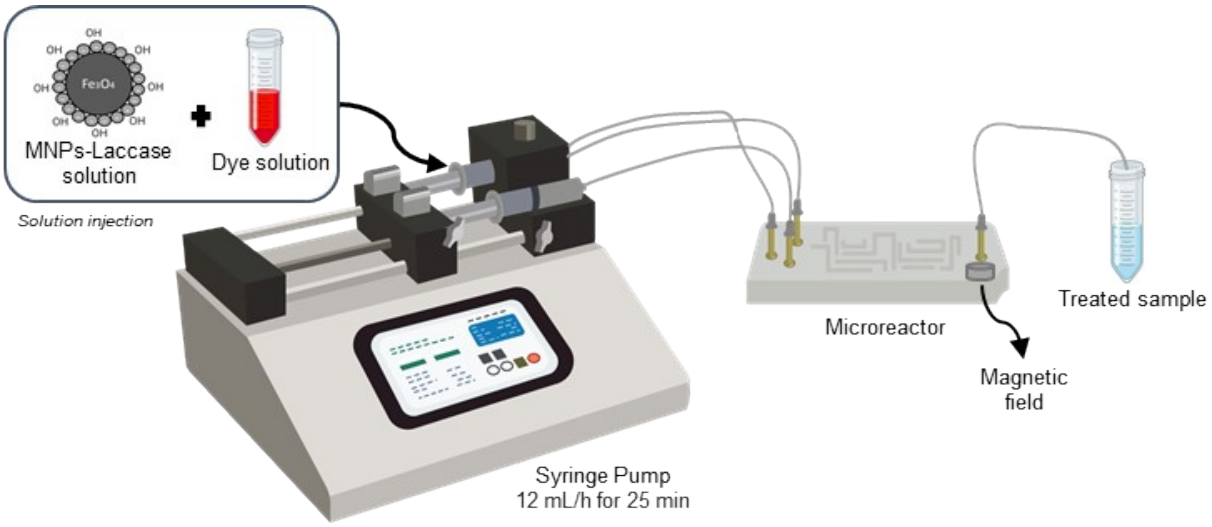

Figure S-1. Schematic representation of the wastewater treatment process**.** The magnetic torus microreactor has a continuous operation, allowing a steady flow of wastewater through the inlet, along the microchannels, and toward the outlet. As the wastewater (dye solution) moves through the microchannels, it encounters the MNPs@laccase solution, which is held in place by the magnetic field of a permanent magnet. During this interaction, the wastewater is treated by the immobilized MNPs@laccase. While the treated wastewater continues its flow toward the outlet, the MNPs@laccase remains retained within the microreactor. Adapted from Peñaranda et al. study.[1]

Table S-1. Measured water quality parameters of the real wastewater used in this study. Adapted from Peñaranda et al. study.[1]

Wastewater Compound	Value	Units
Phenols	19.60	mg Phenol/l
Biochemical oxygen demand (BOD)	385.00	mg O2/l
NH3 nitrogen	0.60	mg N/l
Kjeldahl nitrogen	12.40	mg N/l

Table S-2. Raw material information from ECHA database (Step 1).

Name	Acronym	CAS number	Source
Methyl methacrylate*	PMMA	80-62-6	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/15528
Bis(4-fluorophenyl) ketone**	PEEK	345-92-6	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/5154
Copper***	Rivets	7440-50-8	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/15562
Ethanol	-	64-17-5	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/16105
Iron dichloride****	Iron (II)	7758-94-3	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/15494

Iron trichloride*****	Iron (III)	7705-08-0	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/16109
Sodium hydroxide	NaOH	1310-73-2	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/15566
Tetramethylammonium hydroxide	TMAH	75-59-2	https://echa.europa.eu/es/registration-dossier/-/registered-dossier/14295

* Chemical substance assumed for polymethyl methacrylate (PMMA) production.
** Chemical substance assumed for PEEK fittings production as thermoplastics.
*** Chemical substance assumed for rivets fittings production.
**** Chemical substance assumed for Iron (II) chloride tetrahydrate.
***** Chemical substance assumed for Iron (III) chloride hexahydrate.

Table S-3. Classification of the raw materials used in the wastewater treatment based on the ECHA database information – Human Health (HH) hazards (Step 1).

Human health hazards	Raw materials							
	Manufacturing stage				Operation stage			
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Acute toxicity - oral	NC	NC	NC	4	NC	4	4	2
Acute toxicity - dermal	NC	NC	NC	NC	NC	NC	NC	1
Acute toxicity - inhalation	NC	NC	NC	DL	NC	NC	NC	DL
Skin corrosion/irritation	2	NC	NC	NC	1A	NC	2	1B
Serious eye damage/eye irritation	NC	NC	2	NC	1	1	1	1
Respiratory sensitisation	NC	NC	NC	DL	NC	NC	NC	DL
Skin sensitisation	1	NC	NC	NC	NC	NC	NC	NC
Aspiration hazard	NC	NC	NC	DL	NC	NC	NC	DL
Reproductive toxicity	NC	NC	NC	DL	NC	NC	NC	NC
Effects on or via lactation	NC	NC	NC	DL	NC	NC	NC	DL
Germ cell mutagenicity	NC	NC	NC	NC	NC	NC	NC	NC
Carcinogenicity	NC	NC	NC	DL	NC	NC	NC	DL
Specific target organ toxicity - single (STOT-SE)	3	NC	NC	DL	NC	NC	NC	1
Specific target organ toxicity - repeated (STOT-RE)	NC	NC	NC	DL	NC	NC	NC	1

NC	Not classified according to CLP criteria
Cat.	Classified according to CLP criteria - Hazard category
DL	Data lacking

Table S-4. Classification of the raw materials used in the wastewater treatment based on the ECHA database information – Environmental hazard (Step 1).

Environmental hazard	Raw materials							
	Manufacturing stage				Operation stage			
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
PBT/vPvB	No PBT	N/A	No PBT	No PBT	N/A	N/A	N/A	No PBT
PMT/vPvM	DL	DL	DL	DL	DL	DL	DL	DL
Aquatic toxicity (acute)	NC	NC	NC	DL	NC	NC	NC	NC
Aquatic toxicity (long-term)	NC	NC	NC	2	NC	NC	NC	2
Ozone layer	NC	NC	NC	DL	NC	NC	NC	DL

NC	Not classified according to CLP criteria
Cat.	Classified according to CLP criteria - Hazard category
DL	Data lacking
No PBT	The substance is not PBT/vPvB
N/A	PBT assessment does not apply

Table S-5. Classification of the raw materials used in the wastewater treatment based on the ECHA database information – Physical hazard (Step 1).

Physical hazards	Raw materials							
	Manufacturing stage				Operation stage			
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Explosives	NC	NC	NC	NC	NC	NC	NC	NC
Flammable gases and chemically unstable gases	NC	NC	NC	DL	NC	NC	NC	NC
Aerosols	NC	NC	NC	DL	NC	NC	NC	NC
Oxidising gases	NC	NC	NC	DL	NC	NC	NC	NC
Gases under pressure	NC	NC	NC	DL	NC	NC	NC	NC
Flammable liquids	2	NC	2	DL	NC	NC	NC	NC
Flammable solids	NC	NC	NC	NC	NC	NC	NC	NC
Self-reactive substances	NC	NC	NC	DL	NC	NC	NC	NC
Pyrophoric solids	NC	NC	NC	DL	NC	NC	NC	NC
Self-heating substances	NC	NC	NC	DL	NC	NC	NC	NC
Emits flammable gases	NC	NC	NC	DL	NC	NC	NC	NC
Oxidising liquids	NC	NC	NC	DL	NC	NC	NC	NC
Oxidising solids	NC	NC	NC	NC	NC	NC	NC	NC
Organic peroxides	NC	NC	NC	DL	NC	NC	NC	NC
Corrosive to metals	NC	NC	DL	DL	1	1	1	DL
Desensitized explosives	NC	NC	DL	DL	DL	DL	DL	NC

NC	Not classified according to CLP criteria
Cat.	Classified according to CLP criteria - Hazard category
DL	Data lacking

Table S-6. Data lacking justification: For some materials, the hazard profile could not be fully calculated due to missing information in certain hazard categories. The justifications provided address these data gaps, enabling the completion of the hazard profiles for use in the SSbD evaluation process.

		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Human health hazards	Acute toxicity - inhalation	-	-	-	Its high molecular weight and solid form limit the likelihood of inhalable exposure under normal use, and testing is rarely conducted	-	-	-	Inhalation studies are scarce, with most toxicological data focusing on dermal and oral exposure routes due to its typical liquid handling
	Respiratory sensitisation	-	-	-	No experimental or epidemiological data available	-	-	-	No experimental or epidemiological data available
	Aspiration hazard	-	-	-	Hazard class not applicable since it is a solid polymer	-	-	-	Hazard class not applicable testing is not typically performed
	Reproductive toxicity	-	-	-	No conclusive studies	-	-	-	-
	Effects on or via lactation	-	-	-	This category requires evidence of substance transfer into breast milk and subsequent toxicity to infants. No such studies are available for this material	-	-	-	No available studies
	Carcinogenicity	-	-	-	No long-term carcinogenicity studies were found	-	-	-	This substance lacks chronic exposure datasets, likely due to handling controls in industrial settings
	Specific target organ toxicity - single (STOT-SE)	-	-	-	No data are available. No acute organ effects are expected from brief exposure	-	-	-	-
	Specific target organ toxicity - repeated (STOT-RE)	-	-	-	No data are available	-	-	-	-
Environmental hazard	PMT/vPvM	These endpoints are relatively new under chemical regulations, and testing is not yet widespread							
	Aquatic toxicity (acute)	-	-	-	No acute aquatic toxicity data found	-	-	-	-
	Ozone layer	-	-	-	No data available. Testing is generally focused on halogenated compounds with ozone-depleting potential. PEEK doesn't exhibit such structural features	-	-	-	There is no known environmental pathway by which TMAH could impact the stratospheric ozone layer
Physical hazards	Flammable gases and chemically unstable gases	-	-	-	PEEK is generally regarded as thermally stable and chemically inert, so these tests are not commonly performed outside of specific regulatory framework	-	-	-	-
	Aerosols	-	-	-		-	-	-	-
	Oxidising gases	-	-	-		-	-	-	-
	Gases under pressure	-	-	-		-	-	-	-
	Flammable liquids	-	-	-		-	-	-	-

	Self-reactive substances	-	-	-		-	-	-	-
	Pyrophoric solids	-	-	-		-	-	-	-
	Self-heating substances	-	-	-		-	-	-	-
	Emits flammable gases	-	-	-		-	-	-	-
	Oxidising liquids	-	-	-		-	-	-	-
	Organic peroxides	-	-	-		-	-	-	-
	Corrosive to metals	-	-	No data are available		-	-	-	No data are available
	Desensitized explosives	-	-	These substances are not explosives in their pure form, and thus classification is not relevant					-

Table S-7. Final classification of Human Health (HH) hazards (Step 1).

Human health hazards	Raw materials							
	Manufacturing stage				Operation stage			
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Acute toxicity - oral	NC	NC	NC	4	NC	4	4	2
Acute toxicity - dermal	NC	NC	NC	NC	NC	NC	NC	1
Acute toxicity - inhalation	NC	NC	NC	NC	NC	NC	NC	NC
Skin corrosion/irritation	2	NC	NC	NC	1A	NC	2	1B
Serious eye damage/eye irritation	NC	NC	2	NC	1	1	1	1
Respiratory sensitisation	NC	NC	NC	NC	NC	NC	NC	NC
Skin sensitisation	1	NC	NC	NC	NC	NC	NC	NC
Aspiration hazard	NC	NC	NC	NC	NC	NC	NC	NC
Reproductive toxicity	NC	NC	NC	NC	NC	NC	NC	NC
Effects on or via lactation	NC	NC	NC	NC	NC	NC	NC	NC
Germ cell mutagenicity	NC	NC	NC	NC	NC	NC	NC	NC
Carcinogenicity	NC	NC	NC	NC	NC	NC	NC	NC
Specific target organ toxicity - single (STOT-SE)	3	NC	NC	NC	NC	NC	NC	1
Specific target organ toxicity - repeated (STOT-RE)	NC	NC	NC	NC	NC	NC	NC	1

NC	Not classified according to CLP criteria
Cat.	Classified according to CLP criteria - Hazard category

Table S-8. Final classification of Environmental hazards (Step 1).

Environmental hazard	Raw materials							
	Manufacturing stage				Operation stage			
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
PBT/vPvB	No PBT	N/A	No PBT	No PBT	N/A	N/A	N/A	No PBT
PMT/vPvM	NC	NC	NC	NC	NC	NC	NC	NC
Aquatic toxicity (acute)	NC	NC	NC	NC	NC	NC	NC	NC
Aquatic toxicity (long-term)	NC	NC	NC	2	NC	NC	NC	2
Ozone layer	NC	NC	NC	NC	NC	NC	NC	NC

NC	Not classified according to CLP criteria
Cat.	Classified according to CLP criteria - Hazard category
No PBT	The substance is not PBT/vPvB
N/A	PBT assessment does not apply

Table S-9. Final classification of Physical hazards (Step 1).

Physical hazards	Raw materials							
	Manufacturing stage				Operation stage			
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Explosives	NC	NC	NC	NC	NC	NC	NC	NC
Flammable gases and chemically unstable gases	NC	NC	NC	NC	NC	NC	NC	NC
Aerosols	NC	NC	NC	NC	NC	NC	NC	NC
Oxidising gases	NC	NC	NC	NC	NC	NC	NC	NC
Gases under pressure	NC	NC	NC	NC	NC	NC	NC	NC
Flammable liquids	2	NC	2	NC	NC	NC	NC	NC
Flammable solids	NC	NC	NC	NC	NC	NC	NC	NC
Self-reactive substances	NC	NC	NC	NC	NC	NC	NC	NC
Pyrophoric solids	NC	NC	NC	NC	NC	NC	NC	NC
Self-heating substances	NC	NC	NC	NC	NC	NC	NC	NC
Emits flammable gases	NC	NC	NC	NC	NC	NC	NC	NC
Oxidising liquids	NC	NC	NC	NC	NC	NC	NC	NC
Oxidising solids	NC	NC	NC	NC	NC	NC	NC	NC
Organic peroxides	NC	NC	NC	NC	NC	NC	NC	NC
Corrosive to metals	NC	NC	NC	NC	1	1	1	NC
Desensitized explosives	NC	NC	NC	NC	NC	NC	NC	NC

NC	Not classified according to CLP criteria
Cat.	Classified according to CLP criteria - Hazard category

Table S-10. Scoring of criteria according to the JCR report (Step 1).

SSbD Level	Conditions
3	If chemicals or materials that pass all safety criteria in Step 1
2	If chemicals or materials that pass hazard criteria H1 and H2 but do not pass criterion H3
1	If chemicals or materials that pass hazard criterion H1 but do not pass criterion H2
0	If chemicals or materials that do not pass hazard criterion H1

Table S-11. Physico-chemical and fate properties information as input for Chesar tool (Step 2).

Physico-chemical and fate properties		Raw materials							
		Manufacturing stage				Operation stage			
		PMMA	**Rivets**	**Ethanol**	**PEEK**	**NaOH**	**Iron(II)**	**Iron(III)**	**TMAH**
General	Physical state at 20°C and 1013 hPa	Liquid	Solid	Liquid	Solid	Solid	Solid	Solid	Solid
	Molecular weight (for assessment)	100.121	63.54	46.07	218.20	39.997	126.75	162.21	91.15
	Melting point at 101 325 Pa (°C)	-48	1059	-114.15	108	323	674	37	63
	Vapour pressure (Pa)	3700 at 20°C	0 at 20°C	5.73E3 at 20°C	0.005 at 20°C	10E-5 at 25°C	0 at 20°C	0 at 20°C	0 at 25°C
	Partition coefficient (Log Kow)	1.38 at 20°C	No data	-0.35 at 20°C	3.37 at 20°C	Not applicable	Not appropriate	Not appropriate	0.036 at 20°C
	Water solubility	15.3 g/L at 20°C	1000 mg/L at 20°C	7.89E5 mg/L at 20°C	8.757 mg/L at 20°C	1110 g/L at 20°C	650 g/L at 20°C	919 g/L at 20°C	1E9 g/L at 20°C
	Henry's law constant (in Pa m3/mol)	14.7	No data	0.33	0.12 at 20°C	No data	Not relevant	Not relevant	4.4E-11 at 25°C
Biodegradation	Biodegradation in water: screening tests	Readily biodegradable	Not biodegradable	Readily biodegradable	Not biodegradable	Not biodegradable	Rapidly biodegradable	Rapidly biodegradable	Readily biodegradable
	DT50 in freshwater	No data	No data	No data	No data	No data	No data	No data	No data
	DT50 in marine water	No data	No data	No data	No data	No data	No data	No data	No data
	DT50 in freshwater sediment	No data	No data	No data	No data	No data	No data	No data	No data
	DT50 in soil	No data	No data	No data	No data	No data	No data	No data	No data
Bioaccumulation	Bioaccumulation: BCF (aquatic species)	No data	No data	No data	No data	No data	No data	No data	No data
	Bioaccumulation: BMF in fish	No data	No data	No data	No data	No data	No data	No data	No data
	Bioaccumulation: BCF (terrestrial species)	No data	No data	No data	No data	No data	No data	No data	No data
Abiotic degradation	Degradation rate constant with OH radicals	No data	No data	No data	No data	No data	No data	No data	No data
	DT50 for phototransformation in air	No data	No data	38 h	No data	No data	No data	No data	No data
	DT50 for hydrolysis	No data	No data	No data	No data	No data	No data	No data	No data
	DT50 for phototransformation in water	No data	No data	No data	No data	No data	No data	No data	No data
Adsorption coefficients	Adsorption/Desorption: Koc	9.14	No data	No data	810	No data	No data	No data	563
	Log Kp (solids-water in soil) in L/Kg	No data	3.33 at 20°C	No data	No data	No data	No data	No data	No data
	Log Kp (solids-water in sediment) in L/Kg	No data	4.39 at 20°C	No data	No data	No data	4.997 at 12°C	4.997 at 12°C	No data
	Log Kp (solids-water in suspended matter) in L/Kg	No data	4.48 at 20°C	No data	No data	No data	2.34 at 12°C	2.34 at 12°C	No data
	Log Kp (solids-water in raw sewage sludge) in L/Kg	No data	4.48 at 20°C	No data	No data	No data	No data	No data	No data
	Log Kp (solids-water in settled sewage sludge) in L/Kg	No data	4.48 at 20°C	No data	No data	No data	No data	No data	No data
	Log Kp (solids-water in activated sewage sludge) in L/Kg	No data	4.48 at 20°C	No data	No data	No data	No data	No data	No data
	Log Kp (solids-water in effluent sewage sludge) in L/Kg	No data	4.48 at 20°C	No data	No data	No data	No data	No data	No data

Table S-12. Hazard information as input for Chesar tool (Step 2)

Hazards		Raw materials							
		Manufacturing stage				Operation stage			
		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Physico-chemical	Flash point	10 °C	No data	286 °K	152 °C	No data	No data	No data	No data
	Autoflammability/Self-ignition temperature	435 °C	No data	636 °K	597 °C	No data	No data	No data	No data
	Flammability	Flammable	Non flammable	Flammable	Non flammable	Non flammable	Non flammable	Non flammable	Not classified
	Explosiveness	Non explosive	No data	Non explosive	Non explosive	No data	Non explosive	Non explosive	Non explosive
	Oxidising properties	Non oxidising	No data	Non oxidising	Non oxidising	No data	Non oxidising	Non oxidising	Non oxidising
Environment	PBT assessment	The substance is not PBT / vPvB	PBT assessment does not apply	The substance is not PBT / vPvB	The substance is not PBT / vPvB	PBT assessment does not apply	PBT assessment does not apply	PBT assessment does not apply	The substance is not PBT / vPvB
	Freshwater	0.94 mg/L	6.3 µg/L	0.96 mg/L	0.002 mg/L	No data	No hazard identified	No hazard identified	0.5 µg/L
	Sediment (freshwater)	10.2 mg/kg	87 mg/kg	3.6 mg/kg	0.182 mg/kg	No data	No hazard identified	No hazard identified	30 µg/kg
	Marine water	0.094 mg/L	5.2 µg/L	0.79 mg/L	0 mg/L	No data	No hazard identified	No hazard identified	0.05 µg/L
	Sediment (marine water)	1.02 mg/kg	676 mg/kg	2.9 mg/kg	0.018 mg/kg	No data	No hazard identified	No hazard identified	3 µg/kg
	Sewage treatment plant (STP)	10 mg/L	230 µg/L	580 mg/L	No emission to STP expected	No data	No hazard identified	No hazard identified	5 mg/L
	Air	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No data	No hazard identified	No hazard identified	No hazard identified
	Soil	1.48 mg/kg	65 mg/kg	0.63 mg/kg	0.035 mg/kg	No data	No hazard identified	No hazard identified	5.7 µg/kg
	Predator's prey (freshwater)	No potential	No potential	0.38 g/kg	No potential	No potential	No potential	No potential	No potential
	Predator's prey (marine water)	No potential	No potential	0.38 g/kg	No potential	No potential	No potential	No potential	No potential
	Top predator's prey (marine water)	No potential	No potential	0.38 g/kg	No potential	No potential	No potential	No potential	No potential
	Predator's prey (terrestrial)	No potential	No potential	0.38 g/kg	No potential	No potential	No potential	No potential	No potential
Workers-Inhalation	Systemic effects - long term exposure	348.4 mg/m³	No hazard identified	380 mg/m³	No hazard identified	No hazard identified	Insufficient hazard data available	Insufficient hazard data available	0.164 mg/m³
	Systemic effects - acute exposure	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified	Low hazard	Low hazard	High hazard
	Local effects - long term exposure	208 mg/m³	other toxicological threshold 1 mg/m³	No hazard identified	No hazard identified	1 mg/m³	Insufficient hazard data available	Insufficient hazard data available	High hazard

Hazards		Raw materials							
		Manufacturing stage				Operation stage			
		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
	Local effects - acute exposure	416 mg/m³	other toxicological threshold 1 mg/m³	No hazard identified	No hazard identified	No hazard identified	Low hazard	Low hazard	High hazard
Workers-Dermal	Systemic effects - long term exposure	13.67 mg/kg bw/day	137 mg/kg bw/day	No hazard identified	No hazard identified	No hazard identified	2.8 mg/kg bw/day	2.8 mg/kg bw/day	33.33 µg/kg bw/day
	Systemic effects - acute exposure	No hazard identified	273 mg/kg bw/day	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified	High hazard
	Local effects - long term exposure	1.5 mg/cm²	No hazard identified	No hazard identified	No hazard identified	High hazard	Low hazard	Low hazard	3.75 µg/cm²
	Local effects - acute exposure	1.5 mg/cm²	No hazard identified	No hazard identified	No hazard identified	High hazard	Low hazard	Low hazard	High hazard
Workers-Eyes	Local effects	No hazard identified	No hazard identified	Medium hazard	No hazard identified	High hazard	Medium hazard	Medium hazard	High hazard
Consumers-Inhalation	Systemic effects - long term exposure	74.3 mg/m³	No hazard identified	114 mg/m³	No hazard identified	No hazard identified	Insufficient hazard data available	Insufficient hazard data available	0.029 mg/m³
	Systemic effects - acute exposure	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified	Low hazard	Low hazard	High hazard
	Local effects - long term exposure	104 mg/m³	Other toxicological threshold 1 mg/m³	No hazard identified	No hazard identified	1 mg/m³	Insufficient hazard data available	Insufficient hazard data available	High hazard
	Local effects - acute exposure	208 mg/m³	Other toxicological threshold 1 mg/m³	No hazard identified	No hazard identified	No hazard identified	Low hazard	Low hazard	High hazard
Consumers - Dermal	Systemic effects - long term exposure	8.2 mg/kg bw/day	137 mg/kg bw/day	No hazard identified	No hazard identified	No hazard identified	1.4 mg/kg bw/day	1.4 mg/kg bw/day	16.67 µg/kg bw/day
	Systemic effects - acute exposure	No hazard identified	273 mg/kg bw/day	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified	High hazard
	Local effects - long term exposure	1.5 mg/cm²	No hazard identified	No hazard identified	No hazard identified	High hazard	Low hazard	Low hazard	1.875 µg/cm²
	Local effects - acute exposure	1.5 mg/cm²	No hazard identified	No hazard identified	No hazard identified	High hazard	Low hazard	Low hazard	High hazard
Consumers - Oral	Systemic effects - long term exposure	8.2 mg/kg bw/day	Other toxicological	No hazard identified	No hazard identified	High hazard	0.28 mg/kg bw/day	0.28 mg/kg bw/day	8.33 µg/kg bw/day

Hazards		Raw materials							
		Manufacturing stage				Operation stage			
		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
			threshold 0.041 mg/kg bw/day						
Consumers - Eyes	Local effects	No hazard identified	Low hazard	Medium hazard	No hazard identified	High hazard	Medium hazard	Medium hazard	High hazard

Table S-13. Generic Exposure Scenarios (GES) for the use of solvents on industrial sites reported by European Solvents Industry Group (ESIG).

Contributing activity (CA) type	CA name and descriptor		
Manufacture			
Environment	CS 1	Manufacture of the substance	ERC1
Workers	CS 2	General exposures (closed systems)	PROC 1
	CS 3	General exposures (closed systems) with sample collection	PROC 2
	CS 4	General exposures (closed systems) batch process	PROC 3
	CS 5	General exposures	PROC 4
	CS 6	Process sampling	PROC 8b
	CS 7	Laboratory activities	PROC 15
	CS 8	Bulk transfers, closed systems	PROC 8b
	CS 9	Bulk transfers	PROC 8b
	CS 10	Equipment cleaning and maintenance	PROC 8a
	CS 11	Storage	PROC 1
	CS 12	Storage	PROC 2
Formulation			
Environment	CS 1	Distribution of substance	ERC 2
Workers	CS 3	General exposures (closed systems)	PROC 1
	CS 4	General exposures (closed systems) with sample collection	PROC 2
	CS 5	General exposures (closed systems) batch process	PROC 3
	CS 6	General exposures	PROC 4
	CS 7	Batch process, elevated temperature, use in contained systems	PROC 3
	CS 8	Process sampling	PROC 9
	CS 9	Laboratory activities	PROC 15
	CS 10	Bulk transfers, dedicated facility	PROC 8b
	CS 11	Mixing operations	PROC 5
	CS 12	Manual, transfer from/pouring from containers, non-dedicated facility	PROC 8a
	CS 13	Drum/batch transfers, dedicated facility	PROC 8b
	CS 14	Tabletting, compression, extrusion or pelletisation	PROC 14

	CS 15	Drum and small package filling	PROC 9
	CS 16	Equipment cleaning and maintenance	PROC 8a
	CS 17	Storage	PROC 1
	CS 18	Storage	PROC 2
On-site use			
Environment	CS 1	Use in Process Chemicals	ERC 4
Workers	CS 2	General exposures (closed systems)	PROC 1
	CS 3	General exposures (closed systems) with sample collection	PROC 2
	CS 4	General exposures (closed systems) batch process	PROC 3
	CS 5	General exposures	PROC 4
	CS 6	Laboratory activities	PROC 15
	CS 7	Process sampling	PROC 9
	CS 8	Equipment cleaning and maintenance	PROC 8a
	CS 9	Storage	PROC 1
	CS 10	Storage	PROC 2

Table S-14. Risk Characterization Ratios (RCRs) for the environment and man via the environment (Step 2).

Protection target	RCR quantification							
	PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
ERC 1								
Fresh water	RCR = 60.07	-	RCR = 65.72	RCR = 679.6	-	-	-	RCR = 1.21E5
Sediment (freshwater)	RCR = 24.99	-	RCR = 75.16	RCR = 631.8	-	-	-	RCR = 1.21E5
Marine water	RCR = 60.07	-	RCR = 7.987	-	-	-	-	RCR = 1.21E5
Sediment (marine water)	RCR = 24.99	-	RCR = 9.331	RCR = 638.8	-	-	-	RCR = 1.21E5
Sewage Treatment Plant	RCR = 56.47	-	RCR = 1.088	Qualitative risk	-	-	-	RCR = 120.9
Air	-	-	-	-	-	-	-	-
Agricultural soil	RCR < 0.01	-	RCR < 0.01	RCR < 0.01	-	-	-	RCR = 1.32E5
Man via environment - Inhalation	RCR < 0.01	-	RCR < 0.01	-	RCR < 0.01	Qualitative risk	Qualitative risk	RCR < 0.01
Man via environment – Oral	RCR < 0.01	-	-	-	-	-	-	RCR = 291.7
Man via environment - combined routes	RCR < 0.01	-	-	-	-	-	-	RCR = 291.7
ERC 2								
Fresh water	RCR = 3.004	-	RCR = 3.286	RCR = 45.31	-	-	-	RCR = 6.05E3
Sediment (freshwater)	RCR = 1.25	-	RCR = 3.758	RCR = 42.12	-	-	-	RCR = 6.03E3
Marine water	RCR = 3.004	-	RCR = 0.399	-	-	-	-	RCR = 6.05E3
Sediment (marine water)	RCR = 1.25	-	RCR = 0.467	RCR = 42.59	-	-	-	RCR = 6.03E3
Sewage Treatment Plant	RCR = 2.824	-	RCR = 0.054	Qualitative risk	-	-	-	RCR = 6.05
Air	-	-	-	-	-	-	-	-
Agricultural soil	RCR < 0.01	-	RCR < 0.01	RCR = 0.756	-	-	-	RCR = 0.801
Man via environment - Inhalation	RCR < 0.01	-	RCR < 0.01	-	RCR < 0.01	Qualitative risk	Qualitative risk	RCR = 0.066
Man via environment – Oral	RCR < 0.01	-	-	-	-	-	-	RCR = 20.11
Man via environment - combined routes	RCR < 0.01	-	-	-	-	-	-	RCR = 20.18
ERC 4								
Fresh water	RCR = 3.004	-	RCR = 3.286	RCR = 33.98	-	-	-	RCR = 6.05E3
Sediment (freshwater)	RCR = 1.25	-	RCR = 3.758	RCR = 31.59	-	-	-	RCR = 6.05E3
Marine water	RCR = 3.004	-	RCR = 0.399	-	-	-	-	RCR = 6.05E3
Sediment (marine water)	RCR = 1.25	-	RCR = 0.467	RCR = 31.94	-	-	-	RCR = 6.05E3
Sewage Treatment Plant	RCR = 2.824	-	RCR = 0.054	Qualitative risk	-	-	-	RCR = 6.05
Air	-	-	-	-	-	-	-	-
Agricultural soil	RCR < 0.01	-	RCR < 0.01	RCR < 0.01	-	-	-	RCR = 0.02
Man via environment - Inhalation	RCR < 0.01	-	RCR < 0.01	-	RCR < 0.01	Qualitative risk	Qualitative risk	RCR < 0.01
Man via environment – Oral	RCR < 0.01	-	-	-	-	-	-	RCR = 0.694
Man via environment - combined routes	RCR < 0.01	-	-	-	-	-	-	RCR = 0.694

Table S-15. Risk Characterization Ratios (RCRs) in human health for processes in all life cycle (Step 2).

Process	Manufacture	Formulation	On-site use	Route of exposure and type of effects	RCR quantification							
					PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
PROC 1	CS 2 CS 11	CS 3 CS 17	CS 2 CS 9	Inhalation, systemic, long term (mg/m³)	RCR < 0.01	-	RCR < 0.01	Exposure assessment and risk characterisation are not required for workers as no hazard has been identified for human health.	RCR = 0.01	Qualitative risk	Qualitative risk	RCR = 0.061
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR < 0.01	RCR = 0.01	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR < 0.01	RCR = 0.04	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR < 0.01	RCR < 0.01	-		-	RCR = 0.012	RCR = 0.012	RCR = 1.02
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 2.644
				Dermal, local, short term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR < 0.01	-	-		-	-	-	RCR = 1.081
PROC 2	CS 3 CS 12	CS 4 CS 18	CS 3	Inhalation, systemic, long term (mg/m³)	RCR = 0.06	-	RCR = 0.025		RCR = 1	Qualitative risk	Qualitative risk	RCR = 6.098
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.1	RCR = 1	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 4	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR < 0.01	RCR < 0.01	-		-	RCR = 0.024	RCR = 0.024	RCR = 2.055
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 2.664
				Dermal, local, short term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.065	-	-		-	-	-	RCR = 8.153
PROC 2	-	-	CS 10	Inhalation, systemic, long term (mg/m³)	RCR = 0.012	-	RCR < 0.01		RCR = 0.2	Qualitative risk	Qualitative risk	RCR = 1.22
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.02	RCR = 0.2	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 4	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR < 0.01	RCR < 0.01	-		-	RCR = 0.024	RCR = 0.024	RCR = 2.055
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 2.664
				Dermal, local, short term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.013	-	-		-	-	-	RCR = 3.275
PROC 3	CS 4	CS 5	CS 4	Inhalation, systemic, long term (mg/m³)	RCR = 0.12	-	RCR = 0.051		RCR = 1	Qualitative risk	Qualitative risk	RCR = 6.098
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.201	RCR = 1	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.401	RCR = 4	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR < 0.01	RCR < 0.01	-		-	RCR = 0.012	RCR = 0.012	RCR = 1.035
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 2.683
				Dermal, local, short term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk

				Combined routes, systemic, long-term	RCR = 0.122	-	-		-	-	-	RCR = 7.133
PROC 3	-	CS 7	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.06	-	RCR = 0.025		RCR = 0.1	Qualitative risk	Qualitative risk	RCR = 0.61
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.1	RCR = 0.1	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 0.4	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR < 0.01	RCR < 0.01	-		-	RCR = 0.012	RCR = 0.012	RCR = 1.035
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 2.683
				Dermal, local, short term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.062	-	-		-	-	-	RCR = 1.645
PROC 4	CS 5	-	CS 5	Inhalation, systemic, long term (mg/m³)	RCR = 0.168	-	RCR = 0.071		RCR = 17.5	Qualitative risk	Qualitative risk	RCR = 106.7
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.281	RCR = 17.5	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.562	RCR = 70	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.025	RCR < 0.01	-		-	RCR = 0.123	RCR = 0.123	RCR = 10.29
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.33
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.193	-	-		-	-	-	RCR = 116.9
PROC 4	-	CS 6	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.024	-	RCR = 0.01		RCR = 2.5	Qualitative risk	Qualitative risk	RCR = 15.24
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.04	RCR = 2.5	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.08	RCR = 10	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.025	RCR < 0.01	-		-	RCR = 0.123	RCR = 0.123	RCR = 10.29
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.33
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.049	-	-		-	-	-	RCR = 25.53
PROC 5	-	CS 11	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.06	-	RCR = 0.025		RCR = 2.5	Qualitative risk	Qualitative risk	RCR = 15.24
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.1	RCR = 2.5	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 10	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.05	RCR < 0.01	-		-	RCR = 0.245	RCR = 0.245	RCR = 20.56
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.067	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 26.65
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.067	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.11	-	-		-	-	-	RCR = 35.81
PROC 8a	CS 10	CS 12 CS 16	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.06	-	RCR = 0.025		RCR = 5	Qualitative risk	Qualitative risk	RCR = 30.48
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.1	RCR = 5	-		-	Qualitative risk	Qualitative risk	Qualitative risk

Exposure assessment and risk characterisation are not required for workers as no hazard has been identified for human health.

				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 20	-	Exposure assessment and risk characterisation are not required for workers as no hazard has been identified for human health.	-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.05	RCR < 0.01	-		-	RCR = 0.245	RCR = 0.245	RCR = 20.56
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.32
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.11	-	-		-	-	-	RCR = 51.05
PROC 8a	-	-	CS 8	Inhalation, systemic, long term (mg/m³)	RCR = 0.042	-	RCR = 0.025		RCR = 3.5	Qualitative risk	Qualitative risk	RCR = 21.34
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.07	RCR = 3.5	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.14	RCR = 14	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.05	RCR < 0.01	-		-	RCR = 0.245	RCR = 0.245	RCR = 20.56
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.32
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.092	-	-		-	-	-	RCR = 41.90
PROC 8b	CS 6 CS 8 CS 9	CS 10 CS 13	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.299	-	RCR = 0.126		RCR = 25	Qualitative risk	Qualitative risk	RCR = 152.4
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.501	RCR = 25	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 1.003	RCR = 100	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.05	RCR < 0.01	-		-	RCR = 0.245	RCR = 0.245	RCR = 20.56
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.32
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.349	-	-		-	-	-	RCR = 173.0
PROC 9	-	CS 8	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.599	-	RCR = 0.253		RCR = 20	Qualitative risk	Qualitative risk	RCR = 30.48
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 1.003	RCR = 20	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 2.006	RCR = 80	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.025	RCR < 0.01	-		-	RCR = 0.123	RCR = 0.123	RCR = 10.29
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.33
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.624	-	-		-	-	-	RCR = 132.2
PROC 9	-	CS 15	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.06	-	RCR = 0.025		RCR = 2	Qualitative risk	Qualitative risk	RCR = 12.19
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.1	RCR = 2	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 8	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.025	RCR < 0.01	-		-	RCR = 0.123	RCR = 0.123	RCR = 10.29
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.33

				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-	Exposure assessment and risk characterisation are not required for workers as no hazard has been identified for human health.	Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.085	-	-		-	-	-	RCR = 22.48
PROC 9	-	-	CS 7	Inhalation, systemic, long term (mg/m³)	RCR = 0.599	-	RCR = 0.253		RCR = 20	Qualitative risk	Qualitative risk	RCR = 121.9
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 1.003	RCR = 20	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 2.006	RCR = 80	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.025	RCR < 0.01	-		-	RCR = 0.123	RCR = 0.123	RCR = 10.29
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 13.33
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.033	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.624	-	-		-	-	-	RCR = 132.2
PROC 14	-	CS 14	-	Inhalation, systemic, long term (mg/m³)	RCR = 0.06	-	RCR = 0.025		RCR = 1	Qualitative risk	Qualitative risk	RCR = 6.098
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.1	RCR = 1	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.201	RCR = 4	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR = 0.013	RCR < 0.01	-		-	RCR = 0.061	RCR = 0.061	RCR = 5.146
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR = 0.017	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 6.669
				Dermal, local, short term (mg/cm² bw/day)	RCR = 0.017	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.072	-	-		-	-	-	RCR = 11.24
PROC 15	CS 7	CS 9	CS 6	Inhalation, systemic, long term (mg/m³)	RCR = 0.12	-	RCR = 0.051		RCR = 5	Qualitative risk	Qualitative risk	RCR = 30.48
				Inhalation, systemic, short term (mg/m³)	-	-	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, long term (mg/m³)	RCR = 0.201	RCR = 5	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Inhalation, local, short term (mg/m³)	RCR = 0.401	RCR = 20	-		-	Qualitative risk	Qualitative risk	Qualitative risk
				Dermal, systemic, long term (mg/kg bw/day)	RCR < 0.01	RCR < 0.01	-		-	RCR < 0.01	RCR < 0.01	RCR = 0.51
				Dermal, systemic, short term (mg/kg bw/day)	-	-	-		-	-	-	-
				Dermal, local, long term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	RCR = 1.332
				Dermal, local, short term (mg/cm² bw/day)	RCR < 0.01	-	-		Qualitative risk	Qualitative risk	Qualitative risk	Qualitative risk
				Combined routes, systemic, long-term	RCR = 0.121	-	-		-	-	-	RCR = 30.99

Table S-16. Scoring of RCR quantification (Step 2)

SSbD Level	Conditions
3	If total RCR<=1
2	If total RCR>1 but all individual RCRs<1
1	If total RCR>1 but at least 1 individual RCRs>1
0	If total RCR>1 and more than one individual RCRs>1

Table S-17. Scoring of processes involved in the manufacturing stage of each raw material according to the criteria defined in SSbD (Step 2)

	Process	Manufacturing							
		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Environment	ERC 1	0	3	0	0	3	3	3	0
Human health	PROC 1	3	3	3	3	3	3	3	0
	PROC 2	3	3	3	3	3	3	3	0
	PROC 3	3	3	3	3	3	3	3	0
	PROC 4	3	3	3	3	1	3	3	0
	PROC 8a	3	3	3	3	1	3	3	0
	PROC 8b	3	3	3	3	1	3	3	0
	PROC 15	3	3	3	3	1	3	3	0
	Total human health	21	21	21	21	13	21	21	0

SSbD Level	Total score	Safety
3	16-21	Negligible risk
2	10-15	Medium risk
1	5-9	High risk
0	0-4	Very high risk

Table S-18. Scoring of processes involved in the formulation stage of each raw material according to the criteria defined in SSbD (Step 2).

	Process	Formulation							
		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Environment	ERC 2	0	3	0	0	3	3	3	0
Human health	PROC 1	3	3	3	3	3	3	3	0
	PROC 2	3	3	3	3	3	3	3	0
	PROC 3	3	3	3	3	3	3	3	0
	PROC 3	3	3	3	3	3	3	3	0
	PROC 4	3	3	3	3	1	3	3	0
	PROC 5	3	3	3	3	1	3	3	0
	PROC 8a	3	3	3	3	1	3	3	0
	PROC 8b	3	3	3	3	1	3	3	0
	PROC 9	3	3	3	3	1	3	3	0
	PROC 9	3	3	3	3	1	3	3	0
	PROC 14	3	3	3	3	3	3	3	0
	PROC 15	3	3	3	3	1	3	3	0
	Total human health	36	36	36	36	22	36	36	0

SSbD Level	Total score	Safety
3	27-36	Negligible risk
2	18-26	Medium risk
1	9-17	High risk
0	0-8	Very high risk

Table S-19. Scoring of processes involved in the use stage of each raw material according to the criteria defined in SSbD (Step 2).

	Process	On-site use							
		PMMA	Rivets	Ethanol	PEEK	NaOH	Iron(II)	Iron(III)	TMAH
Environment	ERC 4	0	3	0	0	3	3	3	0
Human health	PROC 1	3	3	3	3	3	3	3	0
	PROC 2	3	3	3	3	3	3	3	0
	PROC 2	3	3	3	3	3	3	3	0

	PROC 3	3	3	3	3	3	3	3	0
	PROC 4	3	3	3	3	1	3	3	0
	PROC 8a	3	3	3	3	1	3	3	0
	PROC 9	3	3	3	3	1	3	3	0
	PROC 15	3	3	3	3	1	3	3	0
	Total human health	24	24	24	24	16	24	24	0

SSbD Level	Total score	Safety
3	18-24	Negligible risk
2	12-17	Medium risk
1	6-11	High risk
0	0-5	Very high risk

Table S-20. Summary of scores for each raw material during the manufacturing, formulation, and on-site use stages (Step 2).

	Manufacturing		**Formulation**		**On-site use**	
	Environment	**Human health**	**Environment**	**Human health**	**Environment**	**Human health**
PMMA	0	3	0	3	0	3
Rivets	3	3	3	3	3	3
Ethanol	0	3	0	3	0	3
PEEK	0	3	0	3	0	3
NaOH	3	2	3	2	3	2
Iron(II)	3	3	3	3	3	3
Iron(III)	3	3	3	3	3	3
TMAH	0	0	0	0	0	0

SSbD Level	**Safety**
3	Negligible risk
2	Medium risk
1	High risk
0	Very high risk

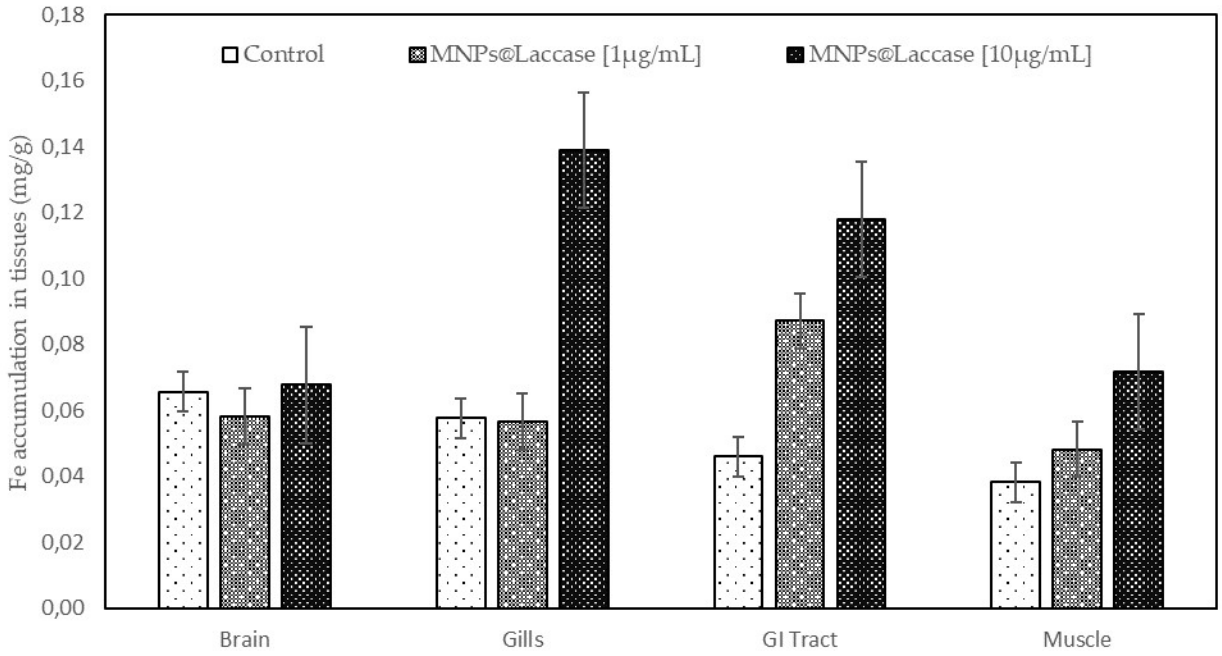

Figure S-2. Tissue-specific accumulation of MNPs@Laccase in Zebrafish at different exposure concentrations. Data adapted from Guillén-Pacheco et al. study.[2]

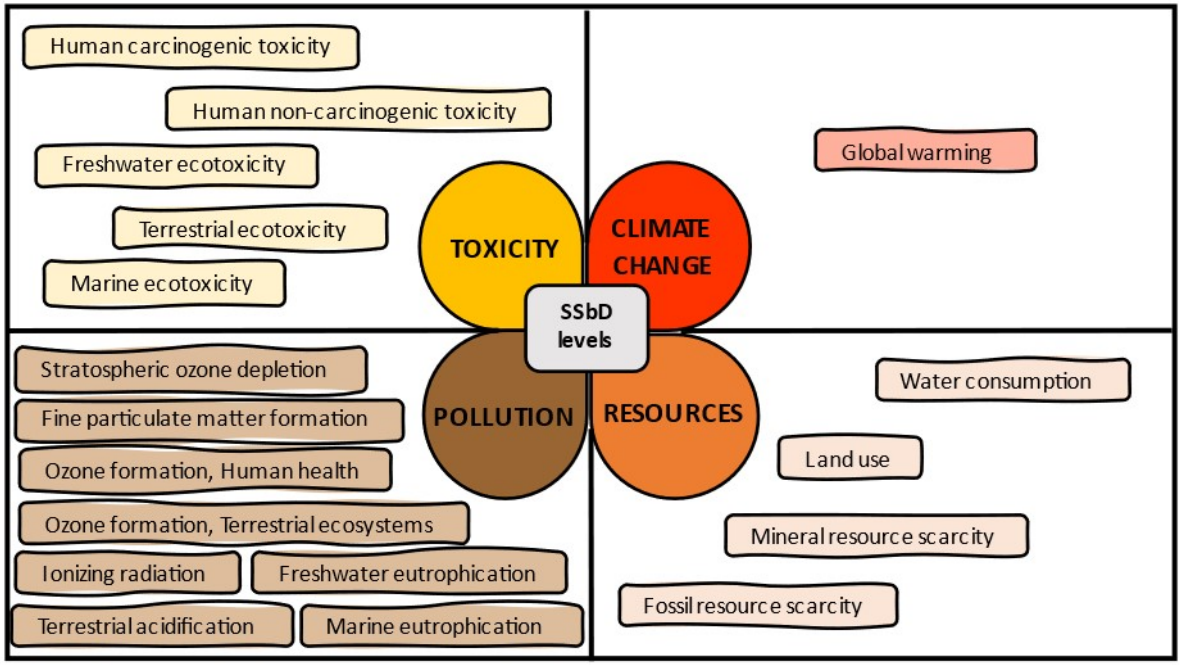

Figure S-3. Impact categories of the ReCiPe 2016 midpoint (H) method aligned with the SSbD framework (Step 4).

Table S-21. Scores to be applied for each impact category (Step 4).

SSbD score	Conditions
3	Improvement ≥ 20%
2	Improvement ≥ 5% to 20%
1	Improvement > 0% to 5%
0	No improvement

Table S-22. Impact assessment results of the reference process with rivets fittings in the manufacturing stage. Adapted from Fuentes et al.[3] (Step 4).

	Impact categories	Electricity	Ethanol	PMMA	Rivets	PEEK Tubing	Deionized water	Lorry	Ship
Reference	Fine particulate matter formation	1,129E+00	7,183E-01	2,477E+00	3,833E+01	7,370E-01	7,440E-04	2,324E-01	1,274E+00
	Fossil resource scarcity	2,528E+02	6,115E+01	6,596E+02	1,024E+03	2,446E+02	8,114E-02	5,716E+01	7,388E+01
	Freshwater ecotoxicity	3,006E+01	5,743E+00	8,108E+00	4,895E+03	1,108E+01	9,383E-03	2,327E+00	1,570E+00
	Freshwater eutrophication	3,145E-01	7,723E-02	8,004E-02	2,727E+01	1,472E-01	1,573E-04	1,317E-02	3,133E-02
	Global warming	8,136E+02	2,596E+02	2,070E+03	3,473E+03	5,162E+02	3,206E-01	1,620E+02	2,331E+02
	Human carcinogenic toxicity	2,574E+01	8,133E+00	4,200E+01	1,205E+03	1,517E+01	3,707E-02	3,427E+00	4,825E+00
	Human non-carcinogenic toxicity	5,179E+02	2,232E+02	1,949E+02	1,851E+05	2,992E+02	2,381E-01	9,585E+01	4,061E+01
	Ionizing radiation	3,037E+00	8,527E+00	8,399E-01	7,355E+02	1,934E+01	2,529E-02	3,050E+00	9,346E+00
	Land use	3,078E+00	6,508E+01	7,056E-01	8,374E+01	1,872E+00	1,598E-03	6,751E+00	5,510E-01
	Marine ecotoxicity	3,923E+01	7,388E+00	1,108E+01	7,148E+03	1,396E+01	1,308E-02	4,318E+00	2,436E+00
	Marine eutrophication	1,997E-02	3,073E-01	1,145E-01	1,675E+00	9,568E-03	1,254E-05	1,102E-03	2,293E-03
	Mineral resource scarcity	7,687E-01	8,548E-01	2,591E-01	4,398E+02	9,019E-01	1,380E-03	2,966E-01	2,835E-01
	Ozone formation, Human health	1,726E+00	8,570E-01	4,096E+00	2,001E+01	1,108E+00	7,638E-04	8,582E-01	3,011E+00
	Ozone formation, Terrestrial ecosystems	1,738E+00	8,787E-01	4,483E+00	2,046E+01	1,226E+00	7,737E-04	8,750E-01	3,034E+00
	Stratospheric ozone depletion	4,481E-04	2,130E-03	1,711E-05	5,876E-03	9,341E-05	2,528E-07	7,112E-05	1,096E-04
	Terrestrial acidification	3,203E+00	2,331E+00	7,936E+00	1,111E+02	1,459E+00	1,191E-03	5,317E-01	3,887E+00
	Terrestrial ecotoxicity	7,397E+02	8,458E+02	3,539E+02	7,414E+05	9,546E+02	6,553E-01	2,338E+03	4,384E+02
	Water consumption	1,591E+00	4,747E+01	7,655E+00	5,294E+01	5,929E+00	2,116E-01	4,787E-01	6,902E-01

Table S-23. Impact assessment results of the alternative process with PEEK fittings in the manufacturing stage. Adapted from Fuentes et al.[3] (Step 4).

	Impact categories	Electricity	Ethanol	PMMA	PEEK fittings	PEEK Tubing	Deionized water	Lorry	Ship
Alternative	Fine particulate matter formation	1,129E+00	7,183E-01	2,477E+00	1,73E-02	7,370E-01	7,440E-04	2,324E-01	1,274E+00
	Fossil resource scarcity	2,528E+02	6,115E+01	6,596E+02	5,75E+00	2,446E+02	8,114E-02	5,716E+01	7,388E+01
	Freshwater ecotoxicity	3,006E+01	5,743E+00	8,108E+00	2,60E-01	1,108E+01	9,383E-03	2,327E+00	1,570E+00
	Freshwater eutrophication	3,145E-01	7,723E-02	8,004E-02	3,46E-03	1,472E-01	1,573E-04	1,317E-02	3,133E-02
	Global warming	8,136E+02	2,596E+02	2,070E+03	1,21E+01	5,162E+02	3,206E-01	1,620E+02	2,331E+02
	Human carcinogenic toxicity	2,574E+01	8,133E+00	4,200E+01	3,57E-01	1,517E+01	3,707E-02	3,427E+00	4,825E+00
	Human non-carcinogenic toxicity	5,179E+02	2,232E+02	1,949E+02	7,04E+00	2,992E+02	2,381E-01	9,585E+01	4,061E+01
	Ionizing radiation	3,037E+00	8,527E+00	8,399E-01	4,55E-01	1,934E+01	2,529E-02	3,050E+00	9,346E+00
	Land use	3,078E+00	6,508E+01	7,056E-01	4,40E-02	1,872E+00	1,598E-03	6,751E+00	5,510E-01
	Marine ecotoxicity	3,923E+01	7,388E+00	1,108E+01	3,28E-01	1,396E+01	1,308E-02	4,318E+00	2,436E+00
	Marine eutrophication	1,997E-02	3,073E-01	1,145E-01	2,25E-04	9,568E-03	1,254E-05	1,102E-03	2,293E-03
	Mineral resource scarcity	7,687E-01	8,548E-01	2,591E-01	2,12E-02	9,019E-01	1,380E-03	2,966E-01	2,835E-01
	Ozone formation, Human health	1,726E+00	8,570E-01	4,096E+00	2,61E-02	1,108E+00	7,638E-04	8,582E-01	3,011E+00
	Ozone formation, Terrestrial ecosystems	1,738E+00	8,787E-01	4,483E+00	2,88E-02	1,226E+00	7,737E-04	8,750E-01	3,034E+00
	Stratospheric ozone depletion	4,481E-04	2,130E-03	1,711E-05	2,20E-06	9,341E-05	2,528E-07	7,112E-05	1,096E-04
	Terrestrial acidification	3,203E+00	2,331E+00	7,936E+00	3,43E-02	1,459E+00	1,191E-03	5,317E-01	3,887E+00
	Terrestrial ecotoxicity	7,397E+02	8,458E+02	3,539E+02	2,24E+01	9,546E+02	6,553E-01	2,338E+03	4,384E+02
	Water consumption	1,591E+00	4,747E+01	7,655E+00	1,39E-01	5,929E+00	2,116E-01	4,787E-01	6,902E-01

Table S-24. Impact assessment results of the reference process with TMAH in the operation stage. Adapted from Fuentes et al.[3] (Step 4).

	Impact categories	Electricity	Iron (II)	Iron (III)	NaOH	TMAH	Deionized water	Lorry	Ship
Reference	Fine particulate matter formation	2,00E+01	5,64E+01	2,63E+02	4,39E+02	1,82E+01	6,18E+01	9,11E+01	4,84E+02
	Fossil resource scarcity	4,48E+03	5,69E+03	2,87E+04	4,81E+04	4,02E+03	6,74E+03	2,24E+04	2,80E+04
	Freshwater ecotoxicity	5,33E+02	1,73E+03	9,58E+03	6,71E+03	1,86E+02	7,79E+02	9,12E+02	5,96E+02
	Freshwater eutrophication	5,57E+00	1,72E+01	1,00E+02	1,10E+02	2,33E+00	1,31E+01	5,16E+00	1,19E+01
	Global warming	1,44E+04	2,22E+04	1,10E+05	1,91E+05	1,04E+04	2,66E+04	6,35E+04	8,85E+04
	Human carcinogenic toxicity	4,56E+02	1,68E+03	9,30E+03	9,21E+03	3,17E+02	3,08E+03	1,34E+03	1,83E+03
	Human non-carcinogenic toxicity	9,18E+03	5,66E+04	3,11E+05	1,92E+05	5,78E+03	1,98E+04	3,76E+04	1,54E+04
	Ionizing radiation	5,38E+01	2,58E+03	2,32E+04	2,22E+04	3,80E+02	2,10E+03	1,20E+03	3,55E+03
	Land use	5,46E+01	1,82E+02	9,40E+02	1,17E+03	4,47E+01	1,33E+02	2,65E+03	2,09E+02
	Marine ecotoxicity	6,95E+02	2,48E+03	1,37E+04	9,42E+03	2,67E+02	1,09E+03	1,69E+03	9,25E+02
	Marine eutrophication	3,54E-01	1,07E+00	7,37E+00	1,06E+01	2,17E+00	1,04E+00	4,32E-01	8,71E-01
	Mineral resource scarcity	1,36E+01	2,10E+02	1,15E+03	5,50E+02	1,85E+01	1,15E+02	1,16E+02	1,08E+02
	Ozone formation, Human health	3,06E+01	6,74E+01	3,37E+02	4,82E+02	3,06E+01	6,34E+01	3,36E+02	1,14E+03
	Ozone formation, Terrestrial ecosystems	3,08E+01	6,83E+01	3,41E+02	4,87E+02	3,13E+01	6,42E+01	3,43E+02	1,15E+03
	Stratospheric ozone depletion	7,94E-03	1,02E-02	9,15E-02	2,05E-01	1,95E-02	2,10E-02	2,79E-02	4,16E-02
	Terrestrial acidification	5,68E+01	1,06E+02	5,62E+02	7,38E+02	4,33E+01	9,89E+01	2,08E+02	1,48E+03
	Terrestrial ecotoxicity	1,31E+04	1,84E+05	1,00E+06	5,66E+05	1,91E+04	5,44E+04	9,17E+05	1,66E+05
	Water consumption	2,82E+01	1,63E+02	2,10E+03	4,83E+03	8,22E+01	1,76E+04	1,88E+02	2,62E+02

Table S-25. Impact assessment results of the reference process with sodium metasilicate in the operation stage (Step 4).

	Impact categories	Electricity	Iron (II)	Iron (III)	NaOH	Sodium metasilicate	Deionized water	Lorry	Ship
Alternative	Fine particulate matter formation	2,00E+01	5,64E+01	2,63E+02	4,39E+02	2,04E+01	6,18E+01	9,11E+01	4,84E+02
	Fossil resource scarcity	4,48E+03	5,69E+03	2,87E+04	4,81E+04	9,40E+02	6,74E+03	2,24E+04	2,80E+04
	Freshwater ecotoxicity	5,33E+02	1,73E+03	9,58E+03	6,71E+03	1,54E+02	7,79E+02	9,12E+02	5,96E+02
	Freshwater eutrophication	5,57E+00	1,72E+01	1,00E+02	1,10E+02	1,84E+00	1,31E+01	5,16E+00	1,19E+01
	Global warming	1,44E+04	2,22E+04	1,10E+05	1,91E+05	3,49E+03	2,66E+04	6,35E+04	8,85E+04
	Human carcinogenic toxicity	4,56E+02	1,68E+03	9,30E+03	9,21E+03	1,73E+02	3,08E+03	1,34E+03	1,83E+03
	Human non-carcinogenic toxicity	9,18E+03	5,66E+04	3,11E+05	1,92E+05	4,77E+03	1,98E+04	3,76E+04	1,54E+04
	Ionizing radiation	5,38E+01	2,58E+03	2,32E+04	2,22E+04	3,08E+02	2,10E+03	1,20E+03	3,55E+03
	Land use	5,46E+01	1,82E+02	9,40E+02	1,17E+03	2,73E+01	1,33E+02	2,65E+03	2,09E+02
	Marine ecotoxicity	6,95E+02	2,48E+03	1,37E+04	9,42E+03	2,20E+02	1,09E+03	1,69E+03	9,25E+02
	Marine eutrophication	3,54E-01	1,07E+00	7,37E+00	1,06E+01	1,54E-01	1,04E+00	4,32E-01	8,71E-01
	Mineral resource scarcity	1,36E+01	2,10E+02	1,15E+03	5,50E+02	1,59E+01	1,15E+02	1,16E+02	1,08E+02
	Ozone formation, Human health	3,06E+01	6,74E+01	3,37E+02	4,82E+02	9,20E+00	6,34E+01	3,36E+02	1,14E+03
	Ozone formation, Terrestrial ecosystems	3,08E+01	6,83E+01	3,41E+02	4,87E+02	9,33E+00	6,42E+01	3,43E+02	1,15E+03
	Stratospheric ozone depletion	7,94E-03	1,02E-02	9,15E-02	2,05E-01	2,75E-03	2,10E-02	2,79E-02	4,16E-02
	Terrestrial acidification	5,68E+01	1,06E+02	5,62E+02	7,38E+02	1,35E+01	9,89E+01	2,08E+02	1,48E+03
	Terrestrial ecotoxicity	1,31E+04	1,84E+05	1,00E+06	5,66E+05	1,77E+04	5,44E+04	9,17E+05	1,66E+05
	Water consumption	2,82E+01	1,63E+02	2,10E+03	4,83E+03	6,15E+01	1,76E+04	1,88E+02	2,62E+02

Table S-26. List of considered stakeholder categories, impact subcategories and indicators. Adapted from Caldeira et al. (2022).

Stakeholder categories	Impact subcategories	PSILCA indicators	Reference unit
Workers	Child labor	Child Labour | Female	CL med risk hours
		Child Labour | Male	CL med risk hours
		Child Labour | Total	CL med risk hours
	Discrimination	Discrimination | Gender wage gap	GW med risk hours
		Discrimination | Men in the sectoral labour force	M med risk hours
		Discrimination | Women in the sectoral labour force	W med risk hours
	Fair Salary	Fair Salary	FS med risk hours
	Forced Labour	Forced Labour | Frequency of forced labour	FL med risk hours
		Forced Labour | Goods produced by forced labour	GFL med risk hours
		Forced Labour | Trafficking in persons	TP med risk hours
	Freedom of Association and Collective Bargaining	Freedom of Association and Collective Bargaining | Association and bargaining rights	ACB med risk hours
		Freedom of Association and Collective Bargaining | Trade unionism	TU med risk hours
	Health and Safety	Health and Safety | DALYs due to indoor and outdoor air and water pollution	DALY med risk hours
		Health and Safety | Fatal accidents	FA med risk hours
		Health and Safety | Non-fatal accidents	NFA med risk hours
		Health and Safety | Safety measures	SM med risk hours
		Health and Safety | Workers affected by natural disasters	ND med risk hours
	Social benefits, legal issues	Social benefits, legal issues | Social security expenditures	SS med risk hours
		Social benefits, legal issues | Violations of employment laws and regulations	VL med risk hours
	Working Time	Working Time | Weekly hours of work per employee	WH med risk hours

Table S-27. Social inventory of MNPs production (100 ton/year).

Process activity	Amount	Unit	PSILCA dataset
Materials	21.950.966,40	USD	Manufacture of chemicals and chemical products - CO
Electricity	9.680,70	USD	Electric power - CO
Water	14.830,10	USD	Water - CO
Transport	116.036,0	USD	Land transport - CO

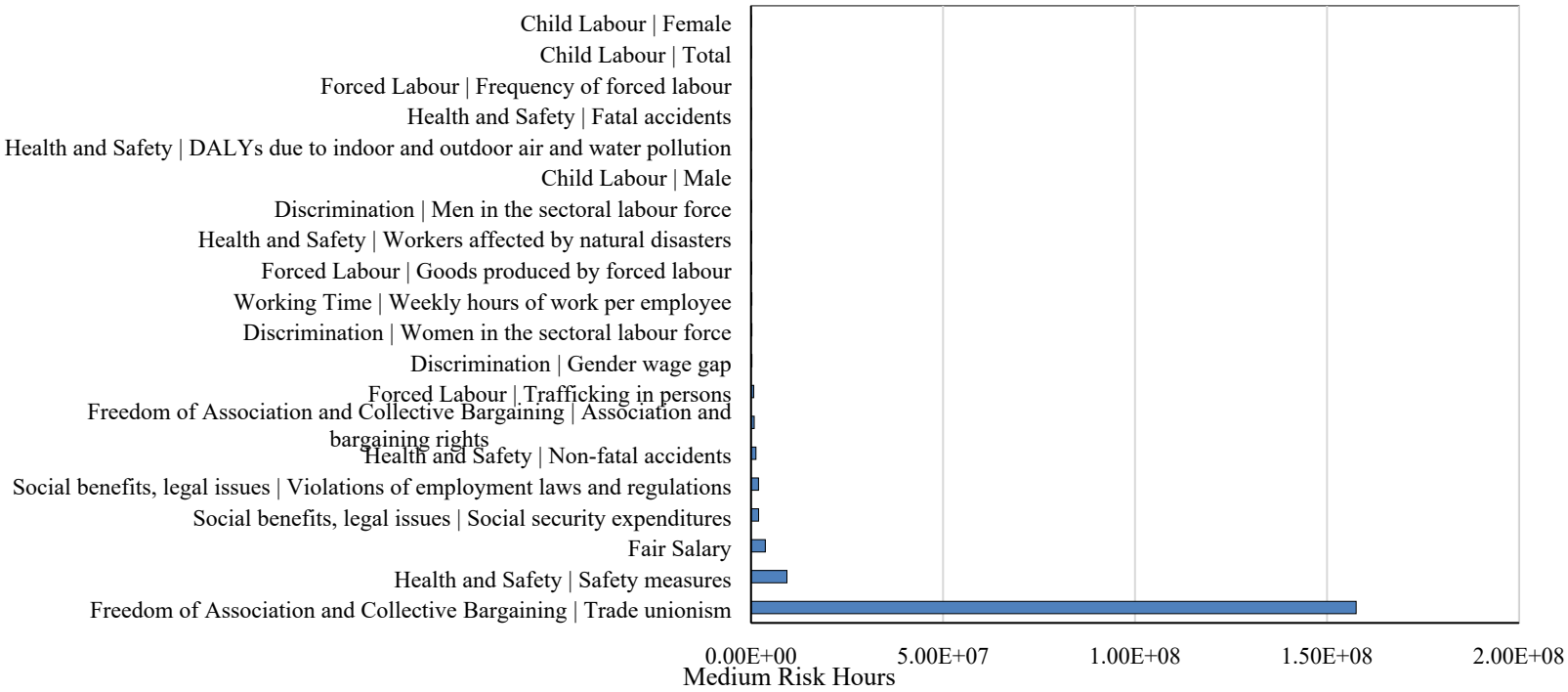

Figure S-4. Social impact risks related to workers (expressed in medium risk work hours).

REFERENCES

(1) Peñaranda, P. A.; Noguera, M. J.; Florez, S. L.; Husserl, J.; Ornelas-Soto, N.; Cruz, J. C.; Osma, J. F. Treatment of Wastewater, Phenols and Dyes Using Novel Magnetic Torus Microreactors and Laccase Immobilized on Magnetite Nanoparticles. *Nanomaterials* **2022**, *12* (10). https://doi.org/10.3390/nano12101688.

(2) Guillén, A.; Ardila, Y.; Noguera, M. J.; Campaña, A. L.; Bejarano, M.; Akle, V.; Osma, J. F. Toxicity of Modified Magnetite-Based Nanocomposites Used for Wastewater Treatment and Evaluated on Zebrafish (Danio Rerio) Model. *Nanomaterials* **2022**, *12* (3). https://doi.org/10.3390/nano12030489.

(3) Fuentes, O. P.; Cruz, J. C.; Mignard, E.; Sonnemann, G.; Osma, J. F. Life Cycle Assessment of Magnetite Production Using Microfluidic Devices: Moving from the Laboratory to Industrial Scale. *ACS Sustain Chem Eng* **2023**, *11* (18), 6932–6943. https://doi.org/10.1021/acssuschemeng.2c06875.