Chemicals of Concern in the Building and Construction Sector

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Feedback and contact The United Nations Environment Programme encourages interested readers of this report to engage and share their views about the report.

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List of Acronyms

ABS	Acrylonitrile butadiene styrene
ACQ	Ammonium copper quaternary
ACZA	Ammonical copper zinc arsenate
ATH	Aluminium (tri)hydroxide
BBP	Benzyl butyl phthalate
C&D	Construction and demolition
CASRN	Chemical abstract service registry number
CBA	Copper boron azole
CCA	Chromated copper arsenates
CDP	Cresyl diphenyl phosphate
CEPA	Canadian Environmental Protection Act
CFC	Chlorofluorocarbon
CFL	Compact fluorescent lamps
CP	Chlorinated paraffins
DBDPE	Decabromodiphenyl ethane
DBP	Dibutyl phthalate
DEGBE	2-(2-butoxyethoxy)ethanol;diethylene glycol monobutyl ether
DEGME	2-(2-methoxyethoxy)ethanol;diethylene glycol monomethyl ether
DEHP	Bis(2-ethylhexyl) phthalate
DIBP	Diisobutyl phthalate
DMPP	Dimethyl propane phosphate
EBTBP	Ethylene bis(tetrabromophtalimide)
ECHA	European Chemicals Agency
EDC	Endocrine-disrupting chemicals
EPS	Expanded polystyrene
FCR	Fibre reinforced composite
FEP	Fluorinated ethylene propylene
FGD	Flue gas desulfurization
GCO-II	Global Chemicals Outlook II
GEF	Global Environment Facility
GHS	Globally harmonized system
HBB	Hexabromobiphenyl
HBCD	Hexabromocyclododecane
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HIPS	high impact polystyrene

IARC	International Agency for Research on Cancer
IPPDPP	Isopropylphenyl diphenyl phosphate
LCCP	Long-chain chlorinated paraffins
LED	Light emitting diode
MCCP	Medium-chain chlorinated paraffins
MDH	Magnesium (di)hydroxide
MDI	methylenediphenyl diisocyanate
MEA	Multilateral environmental agreements
ODS	Ozone depleting substances
OLED	Organic ligt emitting diode
PAH	Polyaromatic hydrocarbon
PAN	Polyacrylonitrile
PBDE	Polybrominated diphenyl ethers
PBT	Persistent, bioaccumulative and toxic
PC	Polycarbonate
PCB	Polychlorinated biphenyls
PCN	Polychlorinated naphthalenes
PCP	Pentachlorophenol
PCT	Polychlorinated terphenyls
PE	Polyethylene
PFA	Perfluoroalkoxy alkane
PFBS	Perfluorobutane sulfonate
PFHxS	Perfluorohexanesulfonic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOS-F	Perfluorooctane sulfonyl fluoride
PIR	Polyisocyanurate
POP	Persistent Organic Pollutant
POPRC	Persistent Organic Pollutant Review Committee
PP	Polyproylene
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PU	Polyurethane
PUR	Polyurethane
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
RDP	resorcinal bis(diphenylphosphate)
REACH	European Union Regulation (EC) No. 1907/2006 concerning the Registration, Evaluation Authorization and Restriction of Chemicals
RME	Risk management evaluation
SAICM	Strategic Approach to International Chemicals Management
SBR	Styrene butadiene rubber

SCCP	Short-chain chlorinated paraffins
SVHC	Substance of very high concern
TBBPA	Tetrabromobisphenol A
TBPDPP	Tertbutylphenyl diphenyl phosphate
TCEP	Tris(2-chloroethyl)phosphate
TCEP	tri-chloroethyl phosphate
TCP	tricresyl phosphate
TCPP	tris-chloropropyl-phosphate
TDCPP	tris-dichloropropyl-phosphate
TPP	triphenyl phosphate
TSCA	United States Toxic Substances Act
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UPR	Unsaturated polyester resin
US EPA	United States Environmental Protection Agency
UV	ultraviolet
VOC	Volatile organic compound
XPS	Extruded polystyrene
ZHS	Zinc hydroxystannate
ZS	Zinc stannate

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1 Background, aims and scope

Chemicals in products has been a longstanding emerging policy issue under the Strategic Approach to International Chemicals Management (SAICM) [1]. To further advance this issue, a GEF-funded project on "Global best practices on emerging chemical policy issues of concern under SAICM" has been launched in 2019. Amongst others, the activities under the project aim at increasing the ambition of different stakeholders to track and control chemicals along the value chains of the building and construction sector. In order to contribute to the current discussion on emerging policy issues and to provide a basis for further activities related to chemicals of concern in the building and construction sector, the project foresees the development of a report on chemicals of concern and alternatives in the construction sector, which is provided in this document.

This report aims at providing an overview of the challenge that chemicals of concern pose in the context of products relevant for the building and construction sector. It outlines the relevance and linkages of chemicals of concern with regards to a building life cycle and highlights existing gaps, challenges and opportunities regarding the imperative of increasing circularity in the building and construction sector.

Furthermore, the report aims at identifying selected chemicals of concern that have relevance in the context of products of the building and construction sector. The scope of the analysis covers chemicals that have documented applications in products (including building materials) and formulations intended for incorporation in the built environment in a permanent manner and may be of concern during at least one life-cycle stage of a building. This also includes chemicals and formulations used for installation of building products, such as glues for the installation of floor tiles. The scope of the report does not cover electric installations that may be found in the built environment, such as wiring or technologies for heating, ventilation or air conditioning.

However, given the sector's complexity and its considerable diversity of products, the range of chemicals of concern and their applications in the building sector identified within this report is not intended to serve as an exhaustive list. Rather, the goal is to provide the reader with a first overview of how certain chemicals of concern link to products of the building and construction sector and to provide starting points for further activities under the project as well as for future sector-specific activities. For chemicals that are currently addressed under multilateral environmental agreements (MEAs), such as the Stockholm Convention on Persistent Organic Pollutants, factsheets summarizing information on chemical identities, relevant applications and potential alternatives are provided as an annex to the report. For Chemicals that are currently addressed by national regulatory action relevant for the building and construction sector an overview table is presented.

2 The building life cycle through the lens of chemicals of concern

Building and construction is one of the most chemical-intensive sectors downstream of the chemical industry. It is the largest end market for chemicals and the sector generating the highest chemical revenue [2]. Driven by rapidly accelerating urbanization , the global construction sector is expected to grow by 3.5% annually with its chemicals market estimated to grow by 6.2% annually between 2018 and 2023 [2]. Many of the sector's products are relatively chemical-intensive and some of the chemicals used in products of the building and construction sector can cause severe harm to human health and the environment.

Compared to other consumer products, such as textiles, electronics or toys, products relevant for the building and construction sector (i.e. building products) are used solely in the context of the built environment and therefore their uses are directly linked to the life cycle of buildings. The typical life cycle of building products is illustrated in Figure 1. After raw material extraction and feedstock production, building products are designed and manufactured. Shipped to installation sites, building products are installed into the built environment during building construction or renovation and are in use during a building's operation phase. After removal from a building, either during renovation or building demolition, the product enters its end-of-life stage as construction and demolition (C&D) waste and is either disposed or reused or recycled.

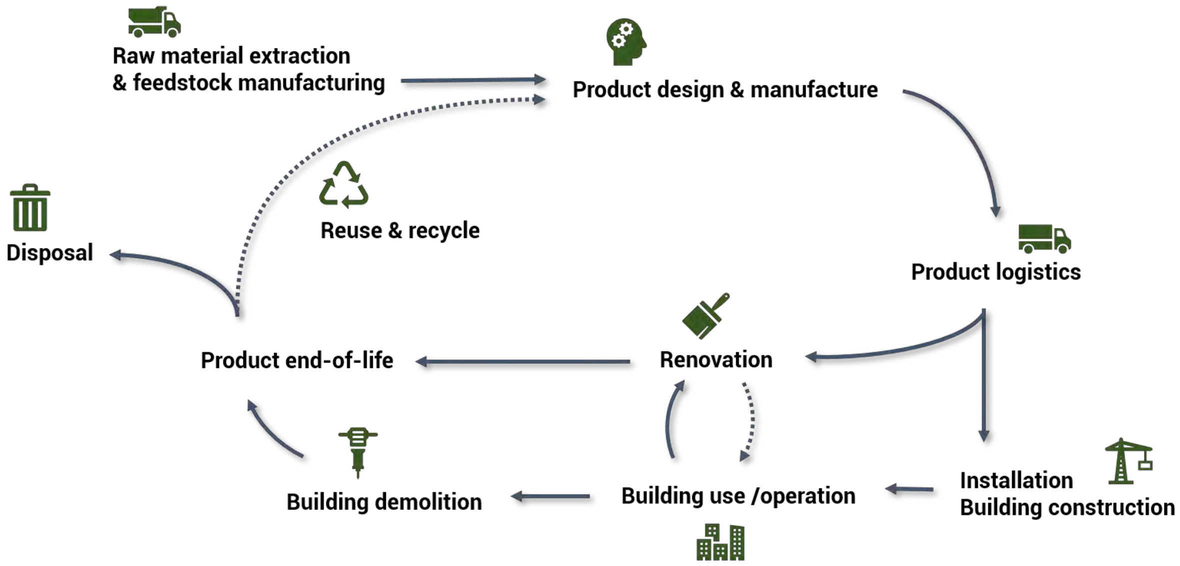

Figure 1: Life cycle of a building product.

The life cycle of a building, especially the use phase can be very long, often spanning several decades sometimes up to centuries. Due to this, the life cycles of building products are much longer compared to other products, such as toys or electronics. During this long lifetime, a variety of different actors may use and come into contact with different building products. These actors include construction workers, renovators with professional or non-professional backgrounds, and demolition workers, as well as building inhabitants that may come into contact with certain building products and material during a building's use phase (e.g. with flooring material). The life cycle of building products is closely linked to potential impacts and challenges of chemicals of concern in the sector are important to consider in the discussion of this issue.

Generally, chemicals of concern in products of the building and construction sector can impact human health or the environment at all stages of a building's life cycle. However, potential impacts may differ significantly between individual life cycle stages, as exposure can differ for actors at different life cycle stages of the product. For example, the type of products and chemicals of concern that a construction worker encounters may differ from the type of products and chemicals of concern that a building inhabitant comes into contact with during a building's use phase. Similarly, potential releases of chemicals of concern into the environment may vary considerably at different life cycle stages. The differences in exposures to chemicals of concern at different stages of the life cycle can thus strongly influence the potential for adverse impacts on human health and the environment. It is also possible, that chemicals of concern only impact human health or the environment at certain stages of the life cycle and not in others.

At end of life, building and construction products enter the waste stream as construction and demolition (C&D) waste. Due to chemicals of concern contained, such waste products may fulfill the criteria for being considered hazardous waste on national or international level, such as for example, under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal [3]. C&D waste often represents the largest proportion of total waste generated in a country and following the rapid pace of infrastructure development across the world, the volume of C&D waste is increasing. If not managed in a sound manner, chemicals of concern in hazardous C&D waste may pose a considerable risk for environmental pollution and impacts on human health and the environment [4].

Another important characteristic of a building life cycle is its long timescale. Unlike other products, such as toys or electronics, the service-lives of construction products can span several decades, and sometimes up to centuries. This long service life can lead to a considerable lag between the design and manufacturing stage of a construction product and its end-of-life stages. Yet, our knowledge on chemicals, their hazards and potential impacts on human health and the environment is ever increasing and the identification of chemicals of concern and the development of risk management action is a constantly developing field. This can lead to the situation where, by the time risk management action is taken for a chemical of concern, the chemical has already been used in products and sold on markets sometimes for extended periods of time.

The long service lives of building products can therefore lead to the accumulation of large stocks of chemicals of concern incorporated into the built environment, which may reach their end-of-life stages not until long after they have been addressed by risk management actions. The issue of legacy chemicals[1] is therefore an important aspect to consider when discussing chemicals of concern in building products. This can be illustrated by the case of polychlorinated biphenyls (PCBs) in Switzerland, whose use in "open-system" applications, such as coatings and joint sealants, was initially widespread but was banned under Swiss law in 1972. Due to the long lifetime of these products in the built environment, PCBs are still present in such "open-system" applications and are routinely found in buildings during refurbishing or demolition operations almost 50 years after their ban.

3 Selected chemicals of concern relevant for products of the building and construction sector

3.1 Method

The identification of chemicals of concern that are relevant for products of the building and construction sector followed a multi-step approach. As a first step, an initial list of chemicals documented in products and applications relevant for the building and construction sector was compiled. Chemicals were identified by means of their CAS number and this basic set of chemicals was subsequently screened for chemicals of concern. Details on the screening approach are further outlined in sections 3.1.1 and 3.1.2. This initial screening was further refined by grouping individual chemicals, associating individual chemical or chemical groups with functional uses and applications, and strengthening the evidence for their past or present relevance in products of the construction sector through literature research.

[1] Chemicals that have been regulated or banned a considerable time ago and whose production and use in (new) products has usually seized.

3.1.1 Identification of chemicals relevant for products of the building and construction sector

To obtain an initial list of chemicals that are relevant for products of the construction sector, the US EPA Chemical and Products Database (CPDat) [5] was queried by filtering for all chemicals associated with the Product and Use categories of "construction", "building" and "home maintenance" and falling under the product scope outlined in chapter 1. This initial list comprised almost 5000 unique chemicals which were subsequently screened for chemicals of concern according to the approach and criteria outlined in section 3.1.2.

3.1.2 Identification of chemicals of concern

For the purpose of this research, a set of proxy criteria was developed to screen for and identify chemicals of concern relevant for products of the building and construction sector. To guide this approach, the three categories of hard-hitting pollutants as identified by the recent UNEP report "Towards a Pollution-Free Planet" [6] where used (Table 1). According to this classification, category 1 encompasses chemicals, for which relevant multilateral environmental agreements exist, but where implementation and enforcement needs to be strengthened and scaled up in countries party to the agreements. Category 2 includes chemicals for which scientific evidence exists to advance risk reduction, but policy actions at all levels are required. Category 3 encompasses chemicals, for which scientific evidence concerning human health and the environment warrants a greater understanding of the nature and magnitude of risks [6].

The proxy criteria developed based on these three different categories and used for screening and identifying chemicals of concern for the present analysis are summarized in Table 1. Due to limited resources, the final proxy criteria were limited to targeting categories 1 or 2.

Table 1: Main categories of hard-hitting pollutants as identified by UNEP [6].

Category 1	Category 2	Category 3
Pollutants for which international action already has been agreed on (mainly through multilateral environmental agreements) *Examples*: Persistent Organic Pollutants listed under the Stockholm convention	Pollutants for which evidence exists to advance risk reduction action *Examples*: Heavy metals or selected solvents	Pollutants for which scientific evidence concerning risk to human health and the environment is emerging *Examples*: endocrine-disrupting chemicals (EDCs)
Proxy criteria used for identification of chemicals in the present analysis		
Chemicals listed for global action under the following MEAs: - Stockholm Convention on Persistent Organic Pollutants - Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade - Minamata Convention on Mercury - Montreal Protocol on Substances that Deplete the Ozone Layer	**(a)** chemicals proposed by parties or recommended by the Persistent Organic Pollutant Review Committee (POPRC) for listing under the Stockholm convention **(b)** chemicals recommended by the Chemical Review Committee for inclusion into Annex III of the Rotterdam Convention **(c)** Chemicals that have been prohibited or restricted for their use in products or applications relevant for the building and construction sector under at least	Not considered for the present analysis.

	one of the following regulatory frameworks: - Canadian Environmental Protection Act, 1999 (CEPA) - European Union Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) - United States Toxic Substances Control Act (TSCA)	

3.1.3 Methodological limitations of the present analysis

The methodology used for the present analysis does come with several limitations. Firstly, the basic set of chemicals from which the screening and identification of chemicals of concern was conducted, is based on the US EPA Chemical and Products Database (CPDat) [2], which maps more than 49'000 chemicals according to their use or function in consumer products. It is based on data from EPA databases and publicly available product compositions. While it is one of the largest databases mapping this type of information, its use introduces certain limitations in the present analysis. Most notably, a chemical must occur in this database for it to be potentially captured as chemical of concern. As the database is largely focused on consumer products, it is possible that certain chemicals only occurring in products intended for professional uses are not captured in the analysis.

Furthermore, the product range of the building and construction sector is very broad and chemicals relevant for the sector can have multiple functions and, with this, multiple applications in different product groups. In addition, detailed information on product composition are often unavailable in the public domain. Therefore, it is possible that, although a chemical occurs in the US EPA Chemical and Products Database, its application in products of the building sector may not be documented and thus it would not be captured in the present analysis.

This complexity of potential multiple functions and multiple applications of one individual chemical also extends to the literature research which was conducted on applications of identified chemicals of concern that are potentially relevant for the building and construction sector. As information on chemical functions and product composition is limited, it cannot be excluded that for individual chemicals of concern, other applications exist which could not be identified during this research.

Lastly, the set of proxy criteria used to screen for and identify chemicals of concern only reflects a reduced range of hard-hitting pollutants as identified in the respective UNEP report [6]. For category 1 chemicals, the analysis does not consider chemicals addressed by international action other than under the MEAs listed as proxy criteria (Table 1). For category 2, the analysis also does not consider chemicals for which scientific evidence for risk to human health and the environment exists, but different approaches for risk reduction than the ones outlined in the proxy criteria have been taken. Such other approaches include, for example, the identification of a chemical as SVHC under the EU REACH regulation. The present analysis also does not consider chemicals, for which risk reduction action have been taken in countries other than Canada, the EU and the US, or chemicals for which risk reduction action has not yet been taken at national levels.

3.2 Identified chemicals of concern relevant for the building and construction sector

Based on the methodology outlined in section 3.1, 13 category 1 and 16 category 2 chemicals or chemical groups were identified as relevant for products of the building and construction sector. The category 1 chemicals include several substances addressed by the Stockholm Convention on Persistent Organic Pollutants, the Rotterdam Convention on Prior Informed Consent, the Minamata Convention on Mercury and the Montreal Protocol on Substances that Deplete the Ozone Layer. Table 2 provides an overview of these chemicals of concern in alphabetical order. Factsheets summarizing information on chemical identities, associated concerns, applications relevant for the building and construction sector and, where available, potential alternatives are provided as an annex to the report and the respective page numbers are indicated in Table 2.

Table 2: Chemicals and chemical groups for which international action has been agreed on (category 1) that were identified according to the outlined methodology and that are relevant for products of the building and construction sector.

Chemical / groups	**Basis for inclusion**	**Relevance for the building and construction sector**	**Further information**
Amphibole Asbestos	Listed in Rotterdam Convention	Used in a variety of insulation materials	Annex p. 28
Hexabromobiphenyl (HBB)	Listed in Stockholm Convention	Used as flame retardant in relevant polymer products	Annex p.32
Hexabromocyclododecane (HBCD)	Listed in Stockholm Convention	Used as flame retardant in relevant polymer products	Annex p. 34
Mercury compounds	Listed in Minamata Convention	Used in lamps and as catalyst in PU elastomers. May occur as unintentional contaminant in products containing fly ash fillers.	Annex p. 36
Ozone depleting substances	Listed in Montreal Protocol	Used as blowing agent in insulation products	Annex p. 38
Pentachlorophenol and related compounds	Listed in Stockholm Convention	Used as wood preservative in wood and timber products	Annex p. 41
Perfluorooctane sulfonic acid (PFOS) and related substances	Listed in Stockholm Convention	Used in carpet impregnation, coatings, coating additives paints and varnishes	Annex p. 44
Perfluorooctanoic acid (PFOA) and related substances	Listed in Stockholm Convention	Used in paints, lacquers and sealants	Annex p. 47
Polybrominated diphenyl ethers (PBDE)	Commercial mixtures listed in Stockholm Convention	Used as flame retardants in relevant polymer products	Annex p. 49
Polychlorinated biphenyls (PCB)	Listed in Stockholm Convention	Used in various products, such as caulks/ sealants, paints, plasters, adhesives, floor finishes, anti-corrosion coatings	Annex p. 52
Polychlorinated naphthalenes (PCN)	Listed in Stockholm Convention	Similar open applications as PCB, for example paints and coatings for building and construction	Annex p. 53
Short-chain chlorinated Paraffins (SCCPs)	Listed in Stockholm Convention	Used as plasticisers and flame retardants in in paints, adhesives and sealants	Annex p. 54
Tributyltin compounds	Listed in Rotterdam Convention	Used as biocides in anti-fouling paints, and preservatives for wood and other applications. Can also be present as impurities in organotin stabilizers used for PVC processing	Annex p. 57

Table 2 provides an overview of the identified category 2 chemicals in alphabetical order, including the basis for their identification, the associated concern and a summary of applications and uses relevant for the building and construction sector. The substances identified include metals and metal compounds as well as a selection of organic compounds. Besides being subject to national regulatory action, many of these chemicals have been identified as issues of concern posing risk to human health and the environment by UNEP's GCO-II. These include lead, arsenic, cadmium, organotin compounds phthalates and polyaromatic hydrocarbons (PAHs, component of certain tar compounds) [2], [7] .

As outlined in previous chapters, due to methodological and capacity constraints, the range of chemicals of concern identified within this chapter is not intended to serve as an exhaustive list. For example, the list does not include chemicals for which scientific evidence concerning risks to human health or the environment is emerging (category 3). Rather, the goal of this report is to provide the reader with a first overview of how certain chemicals of concern link to products of the building and construction sector and to provide starting points for further activities under the project as well as for future sector-specific activities.

Table 3: Chemicals and chemical groups for which evidence exists to advance risk reduction action and which are relevant for the building and construction sector (alphabetical order)

Name / identity	Basis for inclusion	Associated concerns	Applications and uses relevant for the building & construction sector	Ref.
Acrylamide (CASRN 79-06-1)	EU - restricted for the use in grouting applications	Concerns for the environment due to toxic effects on aquatic ecosystems and concerns for human health due to potential for carcinogenic, mutagenic, reprotoxic and neurotoxic effects. Identified as substance of very high concern due to potential for carcinogenic and mutagenic effects	Uses include as grouting agents in acrylamide grouts, in coatings and paints	[8]–[10]
Arsenic compounds	EU: - restriction on use in wood treatment applications, with certain exemptions for professional uses as structural timber for certain non-residential infrastructure.	Human health concerns related to carcinogenic and genotoxic effects and the potential of arsenic compounds to cause adverse effects in aquatic environments.	Uses include wood preservatives (chromated copper arsenates, CCA)	[11], [12]
Cadmium and its compounds	EU: - restriction on use in a variety of polymers, paints and painted articles. Certain exceptions apply for recovered PVC.	Human health concerns related to carcinogenicity, mutagenicity, toxicity to reproduction and other systemic toxicity effects.	Applications include as stabilizer or pigments in a variety of polymers, such as PVC, PE, or epoxy resins with a variety of uses, such as in profiles and rigid sheets for building applications, doors, windows, shutters, walls, blinds, fences, roof gutters, decks, terraces and pipes. Further applications include as pigment or anti-corrosion agent in paints.	[8], [13], [14]
Chromium (VI) compounds	EU: - restriction on use in hydrated cement and cement-containing mixtures above 2 mg soluble Cr (VI) per kg of total dry weight of cement, based. - Uses of 14 compounds subject to authorization.	- Potential to cause allergic reactions upon direct and prolonged contact with human skin - Identification of several chromium (VI) compounds as Substances of Very High Concern (SVHC) subject to Authorization due	Applications include as biocides or as fixing agents in wood preservatives. Other potentially relevant applications may include - surface-treatment and anti-corrosion agents for (metal) surfaces,	[15]–[30]

		to their identification as carcinogenic, mutagenic or toxic to reproduction or a combination thereof.	- as pigments in (industrial) paints, vinyl and cellulose acetate plastics, in linoleum and in varnishes and similar coatings, rubber and flooring compounds. May occur as unintentional contaminants in cement	
Chrysotile Asbestos	**Global** - Recommended for inclusion in Annex III of the Rotterdam Convention. **CA:** - prohibition of import, sale and use of asbestos and prohibition of manufacture, import, sale and use of products containing asbestos **EU:** - prohibition of manufacture, placing on the market and use of these fibres and mixtures and articles where these fibres are intentionally added **USA:** - prohibition of five specific asbestos-containing product types (corrugated paper, rollboard, commercial paper, specialty paper, flooring felt) and any application for which manufacture, importation or processing was initiated after August 25, 1989. - prohibition of placing on the market of certain asbestos-containing products without prior review by authorities.	Concerns for human health related to asbestosis, mesothelioma and lung cancer.	Uses may include in insulation spray coating, thermal insulation elements for pipes, boilers, and pressure vessels, millboard, insulating boards, paper, ropes and yarns, gasket and washers, cement profiled sheets, bitumen products, flooring, reinforced PVC and other plastic and resin composites.	[8], [31]–[36]
Dechlorane Plus (CASRNs: 13560-89-9, 1358 21-74-8, 135821-03-3)	**Global** - Proposed for listing under the Stockholm Convention	Concerns for human health and the environment related to multiple adverse effects, including indications	Used as additive flame retardant in polymers (alternative/replacement for c-deca-BDE). Applications include	[37]

		of neurotoxicity, potential for endocrine modulating effects, liver impairments, and indication of immune modulating effects. Additionally, there are high indications for bioaccumulation and persistence in the environment.	plastic roofing materials and occurrences were reported in various other building materials, such as non-woven PVC wallpaper, latex paint, laminated floorboards, fiber board, solid wood boards, glue, sealants, PVC line pipes, sound absorbing foam and expanded polystyrene panels.	
Diisocyanates	**EU** - restriction on professional and industrial uses (concentration limits for applications and stipulation of mandatory training of users) - restriction on the use of methylenediphenyl diisocyanate (MDI) in products for the general public including requirements for information of end users on associated hazards and mandatory supply of protective equipment with respective products.	Concerns for human health related to respiratory, dermal and eye irritation, skin and respiratory sensitization and occupational asthma	Applications include as cross-linking agent in polyurethane-based products, such as rigid and flexible foams (incl. spray foams and assembly foams, such as insulation panels), paints, lacquers and varnishes, adhesives and glues and sealants	[8], [38], [39]
Lead and its compounds	**CA**: - restriction on use in paints, with certain exemptions for outdoor uses and anti-corrosive paints. **EU:** - Restriction of lead carbonates and lead sulphates in paint **USA**: - restriction of lead in paint for consumer uses.	Human health concerns related to developmental neurotoxicity, cardiovascular, renal and reproductive effects.	Pigments in paints. Further potential applications include as stabilizers in PVC products, such as in window profiles, pipes, fittings, flooring, and roofing. Other documented applications include lead sheeting for wall cladding, noise attenuation and damp proofing, as well as lead pipes	[8], [40]–[43]
Certain nonylphenol and octylphenol ethoxylates	**EU**: - All uses are subject to authorization by the authorities	Concerns for the environment due to potential for endocrine disruption	Uses include for paints, varnishes, adhesives, sealants, putties and solvents. Other potential uses in the construction industry include as foaming agents for concrete, mould release agents on construction sites, emulsifiers in bitumen/wax emulsions	[8], [44], [45]

			for painting /sealing of concrete, metal working fluids and oils for lubrication or hydraulic devices	
Certain organotin compounds	**EU:** - All organotin compounds restricted as biocides in free association paint. - selected groups of organotin compounds restricted for use in mixtures and articles for supply to the general public.	Toxic effects to the aquatic environment and human health concerns related to immunotoxicity, reproductive effects and potential endocrine disruption.	Uses include paints, coatings, sealants, PVC products, fabrics for outdoor applications, outdoor rainwater pipes, gutters and fittings, covering materials for roofing and façades, as well as floor and wall coverings	[8], [46]–[48]
Perfluorohexanesulfonic acid (PFHxS), its salts and PFHxS-related compounds	**Global:** - Recommended for inclusion into Annex A of the Stockholm convention without specific exemption **USA**: - New uses are subject to authorization by the authorities	Concerns for human health and the environment related to multiple adverse effects, including indications of liver effects, developmental effects, potential for endocrine modulating effects, and indication for effects on the immune system. Additionally, concerns were identified related to bioaccumulation and high persistence in the environment.	Occurrences have been reported in wood board, plastic façade materials, foam insulation, textile floor covering, textile insulation, paper insulation, plastic insulation, drywall, paint, plaster, polishing agents, damp proofing / impregnation products	[49]–[52]
Certain phenolic benzotriazoles	**Global:** - UV-328 (CASRN 25973-55-1) has been proposed for listing under the Stockholm Convention. **EU**: - All uses are subject to authorization by the authorities	Concerns for the environment due to persistency, potential for bioaccumulation and toxicity.	Uses include as UV-absorber in polymeric construction materials, fillers surface treatments, adhesives, paints, lacquers, varnishes, wood coatings	[8], [53]–[56]
Certain ortho-phthalates	**EU**: - Restriction of DEHP, DBP, DIBP and BBP in all articles with certain exceptions for articles exclusively used for industrial or agricultural uses, vehicles, or aircrafts - All uses of 13 phthalates are subject to authorization by the authorities	Concerns for human health related to toxicity for reproduction and potential for endocrine disruption	Uses include as plasticizer in plastic articles, such as flooring and wall covering, in adhesives, sealants, paints and varnishes	[8], [57], [58]

Certain solvents and volatile organic compounds (VOC)	**CA:** - VOC concentration limits for 53 categories of architectural coatings - Restriction on the use of 2-Butoxyhexanol in selected consumer products for indoor uses **EU:** - VOC concentration limits in paints and varnishes - Restriction of certain solvents, such as DEGME, DEGBE, dichloromethane or toluene in certain applications, such as paints, paint strippers, or adhesives. **USA:** - National VOC emission standards for architectural and aerosol coatings, including concrete curing and sealing compounds, glazing, coatings, lacquers, primers, adhesives and wood stains. - National formaldehyde emission standards for composite wood products	- Concerns related to human health, including potential for carcinogenic and reprotoxic effects, neurotoxic effects and irritation of eyes and the respiratory system. - Concerns for environmental health and human health effects due to the potential of certain VOC for the formation of ground-level ozone and formation of smog	Uses include paints, lacquers, varnishes, coatings, adhesives, engineered wood products. VOC can also be released from polymer products, such as insulation or fibreboard sheeting in the form of monomers or additives.	[8], [59]–[65]
Certain tar compounds	**EU:** - Restriction for the treatment of wood with certain exceptions - Certain tar compounds require authorization by the authorities before use	Concerns for human health and the environment related to potential for carcinogenic effects, persistency and bioaccumulation	Uses include paints, protective coatings, roofing and wood preservatives	[66]–[68]
Tris(2-chloroethyl) phosphate (TCEP) CASRN: 115-96-8	**EU:** - All uses are subject to authorization by the authorities	Concerns for human health related to toxicity for reproduction	Uses include as flame retardant plasticizer in polymeric products, such as roofing, insulation foams, paints, varnishes, coatings, adhesives and resins, back-coatings for carpets	[8], [69], [70]

4 Challenges, gaps, and opportunities

4.1 Challenges and gaps

The building and construction sector is one of the largest end markets for chemicals and the sector's product range reflects the full diversity of outputs from the chemical industry, ranging from commodity chemicals such as plastic resins (e.g. PVC, PE, PP) to specialty chemicals, such as paints, coatings, adhesives, sealants, advanced polymers and additives [2]. These specialty chemicals can either occur as stand-alone formulations, such as paints or adhesives, or be incorporated into articles relevant for the sector, such as for example an adhesive that is used within engineered wood products.

This complexity is an important challenge in discussions of chemicals of concern in products of the building and construction sector. **One chemical may be used in multiple different applications throughout the sector, leading to a large number of different chemical-product combinations with sometimes very different fields of use.** For example, certain short chain chlorinated paraffins, may be used as plasticizers in flexible PVC material used for wood panel ceilings, flooring, wall coverings or in plumbing, but also as flame retardants in paints for metal surfaces, interior walls or swimming pool coatings. **In addition, information on composition of individual products or product groups are often not readily available in the public domain. These information gaps combined with such a complex product landscape can make identifying and addressing chemicals of concern in specific applications and products challenging for practitioners up- and downstream of the value chain of the construction sector**.

Where information on occurrences of chemicals of concern in building products is available in the public domain, **it is often unclear how much of a chemical of concern is present in a given material. Without information on concentration it is challenging to estimate how relevant some materials and products are as a source of exposure for humans and the environment**.

Furthermore, available information on uses of chemicals of concern in building products often reflect the context of their application and industries in developed countries. This applies to both, the identification of potential risk of chemicals of concern and their application in specific products. As these two aspects can, at least partially, be influenced by local practices and economies**, the current results and available knowledge might not fully reflect the situation in developing countries and economies in transition**.

The current analysis focussed on chemicals for which concern has been identified by the international community or by selected regulatory authorities. This focus already covers a considerable range of chemicals and chemical groups, yet, **there may be many more chemicals relevant for products of the building and construction sector for which evidence for potential concern is emerging**. Continued research and collaborative action will be needed to adequately address these concerns and to further protect human health and the environment from impacts of chemical pollution by the building and construction sector. Substitution of chemicals of concern with regrettable alternatives must be avoided and a precautionary approach should be considered for situations where evidence of concern is emerging, or data gaps on hazards and potential impacts exist.

4.2 Opportunities

As concluded in the GCO-II, **the sound management of chemicals and waste is integral to and cuts across the 17 SDGs of the 2030 Agenda for Sustainable development**. While SDG targets 12.4 and 3.9 are directly relevant in the context of chemicals management, many other SDGs and targets cannot be achieved without the sound management of chemicals and wastes [2]. Besides direct impacts on human health and the environment, the **content of certain chemicals can, for example hinder the recycling of products and thus constitute a barrier to circularity and more sustainable consumption**

and production patterns. Addressing chemicals of concern can remove such barriers and, for example, support the creation of conditions for increased resource efficiency.

Given the construction and building sector's importance as an end market for chemicals and its expected growth following the rapidly increasing urbanization, **advancing on the issue of chemicals of concern in the building and construction sector provides significant opportunities for sustainable development**. Such action requires a **holistic perspective and needs to combine addressing legacies with innovations in chemistry and material sciences, design practices, and targeted regulation in order to contribute to chemical safety, increase resource efficiency and reduce the sector's health and environmental impacts** [2]. For this, complementary approaches could be considered by different stakeholders, including the following:

Increase information transparency on chemicals and ensure information flow along the entire life cycle of building products

Information on the use and concentration levels of chemicals of concern in products of the building and construction sector is still scarce in the public domain and can pose a challenge for many actors along the building product value chain to address this issue. Transparency of chemical contents in products of the building and construction sector must be further increased and be available in appropriate form to different value chain actors. Action on increasing transparency could build on existing initiatives, such as health product declarations developed under voluntary building certification schemes (e.g. LEED) or databases providing occupational safety information for construction workers, such as the German GISBAU initiative. Given the long service life of building and construction products, ensuring the flow of information along the entire product life cycle can be especially challenging. Information on materials and chemical composition, which may be available at the time of construction, is often lost by the time a building gets refurbished or demolished. As unknown material composition is a considerable and potentially costly challenge at the end-of-life stages of building products, future activities should include the **development of systems that ensure the flow of relevant information across different life cycle stages of building products**. This could include approaches like the development of material passports and their integration into existing information management systems, which have recently been suggested [71]. Considering that scientific knowledge on chemicals and their potential impact on human health and the environment keeps evolving, it is important that comprehensive information on chemical composition of materials is included in such approaches.

Design for circularity

New building products should be designed to support the sector's transition to circular models. Such **design approaches must ensure that products can retain the highest possible value at their end of life and chemicals-related barriers to circularity are therefore minimized**. This should include the evaluation of potential chemicals-related impacts of materials along the entire life cycle of buildings and products already at their design stage, as well as the development of benign chemicals and recyclable materials through green and sustainable chemistry innovation. In the case where chemicals of concern cannot be avoided for technical reasons, their use must be minimized, and contaminated materials should be easily separable from uncontaminated materials at end-of-life. The concept of designing for circularity should also be extended from the level of individual products to the level of development of building projects, including material and product choice in architectural design, as well as to the development of construction and deconstruction methods that ensure retention of the highest possible value of all construction materials at their end-of-life. As including circularity into design processes requires a holistic approach considering the entire life cycle of a product, **such design practices should be based on a collaborative approach involving stakeholders along the entire building products value chain.** To facilitate this collaborative approach, platforms for exchange amongst value-chain actors in the sector could be established.

For existing buildings, minimizing impacts of legacy chemicals while developing new technologies for recycling

Besides minimizing barriers to circularity in new building products, efforts should also include addressing chemicals-related barriers for circularity in the context of products that are currently in use within the built environment. The environmentally sound management of C&D waste containing chemicals of concern, such as POPs, is paramount in order to ensure that the impacts of legacy chemicals on human health and the environment are minimized. This includes the identification of material stocks in the built environment containing chemicals of concern, as well as separation of C&D waste streams containing chemicals of concern from other C&D waste streams at their end-of-life [72], [73]. In order to increase material recycling and to avoid unintentional re-introduction of chemicals of concern into secondary raw materials, research and development of technologies for sound recycling of building products that contain chemicals of concern should be advanced, and their applicability at scale considered. Recent examples for such technologies include the development of a recycling process for polystyrene insulation foam containing HBCD [74].

Targeted regulatory action

Continued regulatory action will be needed to identify, assess, and address chemicals of concern in building products based on emerging scientific knowledge in order to ensure adequate protection of human health and the environment at all stages of the life cycle. This should also include advancing the knowledge on applications and potential occurrences of identified chemicals of concern, such as POPs, in products relevant to the building and construction sector, as well as mandating and incentivising phasing out of individual chemicals of concern from products of the sector. Where substitution of chemicals of concern in products of the sector is technically not feasible, regulators must ensure adequate training and protection of professional users (e.g. construction workers) as well as the protection of the general public. Furthermore, regulators should evaluate if regulatory requirements for the building and construction sector may have (potentially unintended) consequences on chemical use or material choices that, in turn, can cause adverse effects on human health or the environment. In some countries, for example, fire-safety standards mandated by building codes for polymeric insulation material cannot be met without the addition of chemical flame retardants to the product. Other countries have stipulated fire-safety requirements for such products that can be met without the addition of chemical flame retardants, for example through thermal barriers, such as gypsum drywall [75], [76]. Such evaluation of regulatory requirements for the building and construction sector mandate an interdisciplinary approach involving experts from various fields, such as engineering, material science and toxicology to ensure reliable scientific and technical bases for decisions.

5 Conclusion

The present research has identified almost 30 chemicals of concern relevant in the context of products of the building and construction sector. Yet the number of chemicals for which evidence for potential concern is emerging likely is higher. Continued collaborative research and action will be needed to address the identified gaps and challenges in order further protect human health and the environment from potential harmful impacts of chemicals of concern used in the sector and to shift the sector towards more sustainable patterns of consumption and production. Given the current trends in the building and construction sector and the increased focus on environmental concerns, including energy efficiency, the use of resources and health considerations, should be used a springboard to address the issue of chemicals of concern and to seize the opportunity this offers for sustainable development.

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approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations (creosote), vol. OJ L283/41. 2001.
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Annex I: Factsheets Category 1 Chemicals

Chemicals of concern addressed by global action under selected MEAs

Amphibole Asbestos

Chemical identity

The term "asbestos" refers to six naturally occurring fibrous minerals, namely crocidolite, amosite, tremolite, actinolite, anthophyllite and chrysotile. Based on their chemistry and fibre morphology, asbestos minerals are categorized into the two groups of amphibole and serpentine asbestos. The fibres of the amphibole group are all straight and needle-like in their microscopic appearance and includes crocidolite, amosite, tremolite, actinolite and anthophyllite asbestos. [1]. Table 1 summarizes the names and chemical identities of the five amphibole asbestos minerals. In addition to these minerals, there are other fibrous minerals that are structurally, similar but not technically classified as asbestos. These are referred to as "asbestiform minerals".

Table 1: Summary of names and chemical identities of the five amphibole asbestos minerals [1], [2].

Group	Name	CAS-Number
Amphibole asbestos	Crocidolite	12001-28-4
	Amosite	12172-73-5
	Tremolite	77536-68-6
	Actinolite	77536-66-4
	Anthophyllite	77536-67-5

Associated concerns and justification for inclusion

All amphibole asbestos minerals have been classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC) and exposure to asbestos has also been associated with non-malignant diseases, such as asbestos warts or asbestosis [1], [3]. Due to these adverse effects, 67 countries have instituted either partial or complete bans on asbestos (as of 2013) [4] and all five amphibole asbestos minerals have been included in Annex III to the Rotterdam Convention [5].

Relevant applications for the building and construction sector

Amphibole and serpentine asbestos minerals have been used in a wide variety of industrial and consumer products, some of which have been and still are relevant for the building and construction sector. Table 2 provides a non-exhaustive overview of identified asbestos applications relevant for the building and construction sector [6]. Amphibole asbestos accounts for 5-10% of all asbestos that is currently used worldwide. The remaining 90-95% of asbestos uses are in the form of chrysotile asbestos which is not listed under the Rotterdam Convention (see also p. 16 of main report). [1].

Table 2: Non-exhaustive overview of identified asbestos applications relevant for the building and construction sector [6].

Products	Use
Spray coatings	- Thermal and anti-corrosion insulation on underside of roofs and on the sides of industrial buildings - Acoustic insulation in theatre halls, etc. - Fire protection of steel and reinforced concrete beams / columns as well as on underside of floors
Thermal insulation elements, slabs, blocks, pre-moulded	- Thermal insulation of pipes, boilers, pressure vessels, calorifiers etc.
Millboard	- Heat insulation and fire protection
Insulating boards	- Fire protection, thermal, acoustic, and moisture insulation

	- Found in service ducts, firebreaks, infill panels, partitions and ceilings (incl. ceiling tiles), roof underlay, wall linings, soffits, external canopies and porch linings
Insulating board in cores and linings of composite products	- Thermal insulation and acoustic attenuators - Found in fire doors, cladding infill panels, domestic boiler casings, oven linings, suspended floor systems
Paper	- Reinforced bitumen - Facing / lining of floor products
Ropes and yarns	- lagging on pipes - Jointing - Caulking in brickwork
Gasket and washers	- Various pipe systems (from hot water boilers to industrial power and chemical plants)
Cement profiled sheets	- Roofing - Wall cladding
Cement semi- and fully compressed flat sheet and partition board	- Partitioning in farm buildings - Infill panels for housing - Shuttering in industrial buildings - Decorative panels for facings, bath panel, soffits - Linings of walls and ceilings - Composite panels for fire protection - Slates, board cladding, decking and roof slates
Textured coatings	- Decorative / flexible coatings on walls and ceilings
Bitumen products	- Roofing felts and shingles - Semi-rigid bitumen roofing - Gutter linings and flashings - Bitumen damp-proof courses (DPC) - Bitumen mastics and adhesives for floor tiles and wall coverings
Flooring	- Thermoplastic for tiles - PVC vinyl floor tiles and unbacked PVC flooring - Asbestos paper-backed PVC floors - Magnesium oxychloride flooring used in WCs, staircases and industrial flooring
Reinforced PVC	- Panels and cladding
Reinforced plastic and resin composites	- Toilet cisterns - Seats - Banisters - Window seals - Laboratory bench tops

Potential alternatives

Due to the wide variety of uses of asbestos, there is no one single substitute available. Since the use of asbestos is banned in 67 countries, it is assumed that technically feasible substitutes and alternatives exist for all applications. Table 3 provides a non-exhaustive list of identified potential substitutes relevant for the applications of the building and construction sector [4]. It must be emphasised however, that no comparative safety assessment has been conducted for these substitutes within the scope of this report, and therefore, no statement on potential concerns of these substitutes can be made. For some fibrous materials used as asbestos substitutes, human hazard assessments have raised concerns regarding carcinogenicity. For many of the substitute materials, data gaps on potential adverse effects on human health and the environment remain [7], [8].

Table 3: Non-exhaustive list of identified potential asbestos substitutes relevant for the building and construction sector [4]. No statement on potential concerns of these substitutes can be made within the scope of this report.

Products	**Potential substitutes**
Asbestos-cement products	- Aluminium sliding - Ductile iron - Fibrillated polypropylene (PP) - Polyvinyl Alcohol (PVA) fibre - Polyvinyl Chloride (PVC) - Vinyl sliding - Wollastonite - Cellulose fibres - Fibreglass and corrugated fibreglass - Mica - Polyacrylonitrile (PAN) fibre - Pre-stressed and reinforced concrete - Wood
Coatings and composites	- Aramid fibre - Cellulose fibre - Cotton - Mica - Polypropylene fibre - Rubber membrane roofing - Wollastonite - Carbon fibre - Clay - Limestone - Polyethylene (PE) fibre - Particulate mineral fillers - Talc
Gaskets	- Aramide fibre - Cellulose fibre - Cork - Graphite - Metal gaskets - Polytetrafluoroethylene (PTFE) - Carbon fibre - Ceramic fibre - Fibreglass - Mica - Mineral wool - Rubber sheeting
Insulation	- Calcium silicate borate - Ceramic fibre - Mica - Vermiculite - Cement board - Fibreglass - Mineral wool

Flooring	- Ceramic tile - Fibreglass - Silica - Vinyl compositions - Clay - Polyethylene (PE) pulp - Talc
Plastics	- Aramid fibre - Fibreglass - Mica - Potassium titanate - Carbon fibre - Fumed silica powder - PTFE - Wollastonite
Sealing materials	- Aramid fibre - Glass fibre - Graphite - PTFE - Carbon fibre - Glass yarn - Mineral wool

Hexabromobiphenyl

Chemical identity

Hexabromobyphenyl (HBB) is an organic substance consisting of a biphenyl structure with six bromine atoms attached. It is a congener of the wider group of polybrominated biphenyls and exists in 42 different isomeric forms [9]. Figure 1 provides an example structure for one HBB isomer.

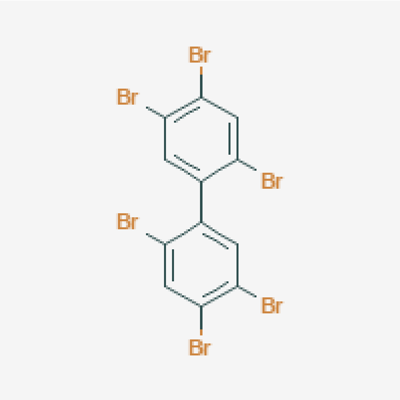


Figure 1: Example of one isomeric structure of HBB (CASRN 59080-40-9) [9], [10].

Associated concerns and justification for inclusion

HBB have been identified as persistent, bioaccumulative and toxic and have been listed in Annex A (elimination) of the Stockholm Convention on Persistent Organic Pollution [11]. The entire group of polybrominated biphenyls has furthermore been listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade [5].

Relevant applications for the building and construction sector

HBB was commonly used as flame retardants and its documented uses include ABS thermoplastics for construction business, coatings and lacquers and in polyurethane foam for auto upholstery. In 2006, research conducted during the assessment of the chemical under the Stockholm Convention concluded that the production and use of HBB as ceased in most, if not all countries [9]. Due to the long lifetimes of building products, it cannot be excluded that HBB can still be present in the built environment.

Potential alternatives

As production and use of HBB as flame retardant likely has ceased several decades ago, alternatives are considered to be widely available and technically feasible. The risk management evaluation (RME) developed during the process of listing HBB under the Stockholm Convention provides several alternatives to HBB. Table 4 provides an overview of these alternatives. In addition to chemical alternatives, the RME also identified several technologies including barrier technologies, graphite impregnating of foam and surface treatments as potential alternatives to the use of HBB. While the listed alternatives are considered to be technically feasible, no assessment of potential impacts or risks for human health and the environment has been conducted under the procedures of the Stockholm Convention. This report can therefore make no statement on the safety of these potential alternatives. Since publication of the RME under the Stockholm Convention, concerns have been raised for some of the listed alternatives, including for TBBP-A, TDCPP, TCPP and TCEP [12]–[15].

Table 4: Examples of potential chemical alternatives for HBB in applications relevant for the building and construction sector [16].

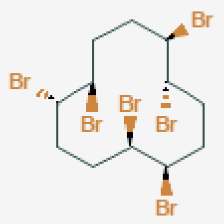
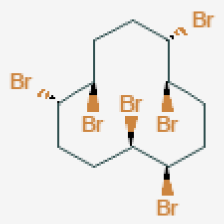
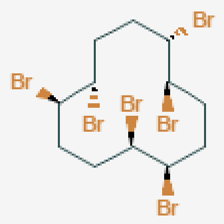
Alternative group	**Example chemicals**	**Application**
Brominated compounds	- Tetrabromobisphenol A (TBBPA)	- ABS polymers
Halogenated organophosphorus compounds	- Tris-dichloropropyl-phosphate (TDCPP) - Tris-chloropropyl-phosphate (TCPP) - Tri-chloroethyl phosphate (TCEP)	- ABS polymers
Non-halogenated organophosphorus, e.g.	- Triphenyl phosphate (TPP) - Tricresyl phosphate (TCP) - Resorcinal bis(diphenylphosphate) (RDP) - Phosphonic acid, (2-((hydroxymethyl)carbamyl)ethyl)-dimethyl ester (Pyrovatex®) - Phosphorus and nitrogen constituents for thermosets	- ABS polymers, - high impact polystyrene (HIPS) - polycarbonate (PC) - polyurethane (PU) foams
Inorganic compounds	- Aluminium trihydroxide - Magnesium hydroxide - Ammonium polyphosphate - Red phosphorus - Zinc borate	- Coatings and lacquers
Nitrogen containing compounds including melamine and melamine derivatives	- Melamine cyanurate - Melamine polyphosphate	- PU foams

Hexabromocyclododecane

Chemical identity

Hexabromocyclododecane (HBCD) is an organic substance consisting of a cycling ring structure with bromine atoms attached. It has commonly been used as flame retardant chemical in polymers. Commercial HBCD consists of a mixture of different stereoisomers, each with a different CAS-number [17]. Table 5 provides an overview of the chemical structures and identity of HBCD.

Table 5: Chemical structures and identity of the different stereoisomers found in commercial HBCD [10], [17].

		
alpha-HBCD, CAS No: 134237-50-6	beta-HBCD CAS No: 134237-51-7	gamma-HBCD CAS No: 134237-52-8

Associated concerns and justification for inclusion

Commercial HBCD was identified to be persistent, bioaccumulative, toxic and to have the potential for long range transport and listed in Annex A to the Stockholm Convention on Persistent Organic Pollutants for global elimination [18]. HBCD is also listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade in 2019 [19].

Relevant applications for the building and construction sector

HBCD is used as flame retardant additive to reduce ignition of flammable polymers and textiles in buildings, vehicles or electric and electronic products. The principal use of HBCD globally is in expanded and extruded polystyrene (EPS and XPS) foams which are widely used in building and construction. The production and use of HBCD in EPS and XPS in buildings is currently listed as exemption from the regulation under the Stockholm Convention. Parties listed in the register of specific exemption can thus still produce and use HBCDs for these applications, given the foams can be easily identifiable throughout their entire life cycle [18]. At the time of writing, China is listed in this registry for production and use, while the Republic of Korea is listed for use only [20].

EPS and XPS materials are used in a variety of applications throughout the construction sector. An overview of identified applications is provided in Table 6. Depending on the flammability standards in a country, HBCD may be used in these identified applications. These flammability standards differ significantly between countries. While in some countries (e.g. the United Kingdom) EPS/XPS applications in construction require flame retardants, other countries (e.g. Sweden) do not require the use of flame retardants in in polystyrene (PS) in construction, but other protection measures against fire [21]. In a recent comprehensive risk assessment, the US EPA has concluded HBCD in XPS/EPS insulation foam to pose unreasonable risks to the environment at all life cycle stages (i.e. manufacture, use, disposal and recycling). The same assessment furthermore concluded HBCD in building and construction materials to pose a risk to workers when no personal protective equipment (such as respirators) is used during construction and demolition operations [22].

Table 6: Non-exhaustive list of identified EPS and XPS applications and products in buildings and construction. Depending on a countries' flammability standards, these applications may contain HBCD [21].

Type of polystyrene (PS)	Applications & products
EPS	Flame-retardant EPS insulation, including - Flat roof insulation - Pitched roof insulation - Floor insulation 'slab-on-ground' insulation - Insulated concrete floor systems - Interior wall insulation with gypsum board ('doublage') - Exterior wall insulation or ETICS (External Insulated Composite Systems) - Cavity wall insulation board - Cavity wall insulation loose fill - Insulated concrete forms (ICF) - Foundation systems and other void forming systems - Load bearing foundation applications - Core material for EPS used in sandwich and stressed skin panels (metal and wood fibreboard) - Floor heating systems - Sound insulation in floating floors - EPS drainage boards
	EPS concrete bricks, EPS concrete
	Soil stability foam (for civil engineering use)
	Seismic insulation
	Other moulded EPS articles, such as ornaments, decorations, logos etc.
XPS	Flame-retarded XPS insulation boards
	Cold bridge insulation floors
	Basement walls and foundations
	Inverted roofs, ceilings, cavity insulation
	Composite panels and laminates

The second most important application of HBCD is in polymer dispersions on cotton or cotton mixed with synthetic blends in the back-coating of textiles. HBCD treated textiles are used in upholstery fabrics but also in draperies, wall coverings and interior textiles. HBCD may also be added to latex binders, adhesives and paints [21].

Potential alternatives

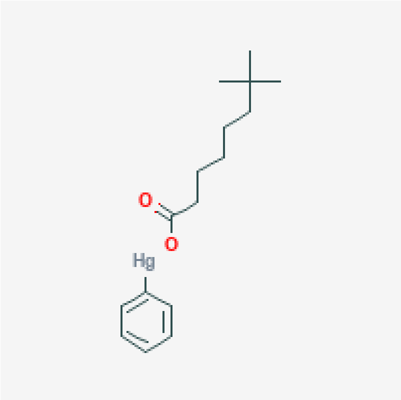
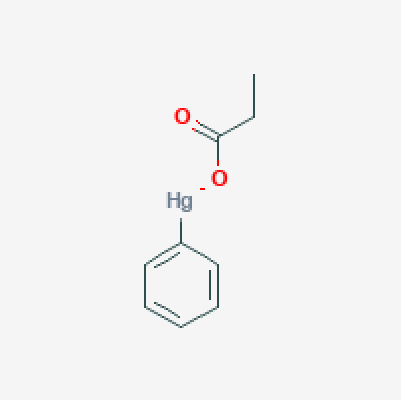
The Guidance on alternatives to HBCD drafted by the Secretariat of the Stockholm Convention lists six chemical alternatives for HBCD in EPS/XPS applications and textiles, including information on trade names, availability and efficacy [23]. For all the chemical alternatives however, there is evidence for certain concerns, such as the potential for bioaccumulation, persistency or suspected toxic effects, and in many cases the available data is insufficient for a comprehensive risk assessment. The guidance also provides information on non-chemical alternatives. These include non-flame retardant EPS/XPS insulation in combination with thermal barriers (e.g. concrete), alternative insulation materials like mineral wools or plant fibers, or intumescent systems for textile back-coatings [23]. The applicability of such non-chemical alternatives strongly depends on individual countries' fire safety regulations.

Mercury compounds

Chemical identity

Mercury is a metallic element, which can occur in its metallic form or bound to organic compounds. An overview of the chemical identity of mercury and some examples of a mercury compounds can be found in Table 7.

Table 7: Chemical identity and structures of mercury and some examples of mercury compounds [10].

Name	CAS-Number	Chemical Structure
Metallic mercury	7439-97-6	-
Phenylmercury neodeconate	26545-49-3	
Phenylmercury proprionate	103-27-5	

Associated concern and justification for inclusion

Mercury is internationally recognized to be of concern due to its potential for long-range atmospheric transport, its persistence in the environment its potential for bioaccumulation in ecosystems and its toxic properties [24]. Various international conventions address mercury, including the decisions and recommendations of the contracting parties to the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), and the Protocol of 24 June 1998 on Heavy Metals (Aarhus Protocol on Heavy Metals), and a protocol to the Convention on Long-range Transboundary Air Pollution (Geneva Convention on Air Pollution) of the UN Economic Commission for Europe (UNECE). In additions to these, the Minamata Convention on Mercury was established to protect human health and the environment from anthropogenic releases of mercury and mercury compounds and entered into force in 2017 [24]. Mercury compounds, including inorganic mercury compounds, alkyl mercury compounds and alkyloxyalkyl and aryl mercury compounds are listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade [5].

Relevant applications for the building and construction sector

Mercury and mercury compound have been used in a variety of products, some of which are relevant for the building and construction sector. One major application of mercury is in energy efficient mercury lamps including fluorescent lamps (tubes and compact fluorescent lamps (CFLs)), high-intensity discharge (HID) lamps (mercury vapour, metal halide, (most) high-pressure sodium, low-pressure mercury discharge, etc.), and cold cathode (ultraviolet and (some) "neon") light sources [25]. Other documented applications relevant for the building and construction sector include the use of mercury compounds as catalysts in PU elastomers that were used in products like hardeners and resins for plastic materials, plastic flooring materials, or jointing compounds and the use of mercury compounds as biocides in paints [25]. The use of mercury compounds as catalysts in PU elastomers and as biocide in paints is assumed to have seized in the EU and the US [25]. Due to the potentially long service life of these products, their continuing relevance for the building and construction sector cannot be excluded. The Minamata Convention calls for a ban of the import, export and manufacture of mercury-containing lamps by 2020.

Potential alternatives

It is assumed that alternatives exist for all uses of mercury and mercury compounds in lamps, PU elastomers and in paints [25], [26]. Table 8provides an indicative but no exhaustive overview of potential alternatives that have been identified for these uses. It must be emphasised, that no comparative safety assessment has been conducted for these substitutes within the scope of this report, and therefore, no statement on potential concerns of these substitutes can be made.

Table 8: Indicative overview of potential alternatives for the uses of mercury and mercury compounds relevant for the buildings and construction sector [25], [26].

Use	Alternatives
Lamps	- Light emitting diodes (LEDs) - Field emission lamps - High-efficiency incandescents - Organic light-emitting diode (OLED) lighting
Catalyst for PU elastomers	- Bismuth- and zinc-based carboxylates - Zirconium carboxylates - Titanium chelates - Organotin compounds - Amides
Biocide in paints	- Wide array of mercury-free biocides for paint

In addition to these applications, mercury can also be found as unintended contaminant in certain products that contain recycled materials. Most notably, mercury contamination has been found in products containing recycled materials originating from fly ash of coal power plants, such as fillers for carpet backings, cement or synthetic gypsum (FGD gypsum) used for the manufacture of drywall [27], [28]. An assessment by the US EPA has not found any risk for human health or the environment to arise from potential mercury contamination of fly ash concrete and FGD gypsum wallboard [27]. A recent study from Austria also concluded, that while current levels of inclusion of fly ashes in cement production elevate the content of mercury, the concentration of mercury in the final products remain below the respective limit values for Austrian cements. The study however pointed out that a further increase in the use of fly ash could lead to final products exceeding regulatory limit values and inhibition of future recycling of the material [29].

Ozone depleting substances and HFCs

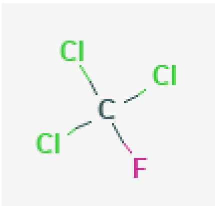
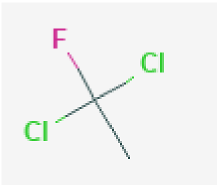
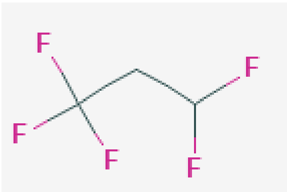
Chemical identity

Ozone depleting substances (ODS) are a group of substances that have the ability to destroy ozone in the earth's atmosphere. All substances in this group are man-made gases and include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrobromofluorocarbons (HBFCs), halocarbon gases (halocarbons), methyl bromide, carbon tetrachloride and methyl chloroform. Table 9 provides an overview of the chemical identity and structures of selected ODS.

Associated concerns and justification for inclusion

To protect the earth's ozone layer, the global community adopted the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987, mandating a global phase-out of ODS [30]. The subsequent progress towards a global phase-out of ODS lead to the substitution of ODS by hydrofluorocarbons (HFCs), which do not contribute to ozone depletion, but which are potent greenhouse gases. To address concern regarding the use of HFCs in the context of global warming, the global community adopted the Kigali Amendment to the Montreal Protocol in 2017 which mandates a global reduction of HFC uses [30]. Table 9 provides an overview of the chemical identity and structures of selected HFC.

Table 9: Overview of chemical identities and structures of selected ozone depleting substances (ODS) and hydrofluorocarbons (HFC) [10], [31].

Ozone depleting substances (ODS)		
Name	CAS-Number	Structure
Trichlorofluoromethane (CFC-11)	75-69-4	
Dichlorofluoroethane (HCFC-141b)	1717-00-6	
Hydrofluorocarbons (HFC)		
PubChem 1,1,1,3,3-Pentafluoropropane (HCF-245fa)	460-73-1	

Relevant applications for the building and construction sector

Amongst other applications, ODS and HFC have been widely used as blowing agents for foam products, some of which are relevant for the building and construction sector. The blowing agents are liquid or gaseous substances which produce a closed cellular structure via a foaming process. The foam blowing agent often is retained within the final foam product until its end of life [32]. A non-exhaustive list of foam applications relevant for the building and construction sector for which the use of ODS or HFC as blowing agents have been documented is provided in Table 10.

Table 10: Non-exhaustive list of foam applications relevant for the building and construction sector for which the use of ODS or HFC as blowing agents have been documented [31], [33].

Material	Foam type	Application areas
Polyurethane (PU)	Injected / P-i-P	Wall & roof insulation Floor insulation Pipe insulation
	Boardstock	Wall & roof insulation
	Panels	Wall & roof insulation
	Spray	Wall & roof insulation Pipe insulation
	One-component	Wall & roof insulation
Extruded Polystyrene (XPS)	Board	Wall & roof insulation Floor insulation
Phenolic	Boardstock	Wall & roof insulation
	Panels	Wall & roof insulation
Polyisocyanurate (PIR/Polyiso)	Boardstock	Wall & roof insulation

Potential alternatives

Alternatives for ODS blowing agents have been researched since the early 1990s and a variety of substitutes have been identified. As mentioned, initial substitute blowing agents (so-called 2nd generation) included HFC [33], which since then have come under scrutiny for their global warming potential and whose global use is currently being reduced. In addition, material alternatives have also been identified. Table 11 provides a non-exhaustive overview of identified potential substitutes and alternatives to ODS and HFC blowing agents for foam products relevant to the building and construction sector. It must be emphasised that no comparative safety assessment has been conducted for these alternatives within the scope of this report, and therefore, no statement on potential concerns of these alternatives can be made. For hydrocarbon blowing agents, concerns and requirements regarding flammability have shown to be a limiting factor for adoption. Very recently, concerns have arisen regarding the use of HFOs and their potential breakdown to short-chain fluorinated alkyl acids (a group of highly mobile and persistent substances) in the environment [34].

Table 11: identified potential substitutes and alternative materials to ODS and HFC blown foam products relevant to the building and construction sector [31], [35], [36].

Foam type	Substitute blowing agent	Alternative material
Rigid polyurethane, polyisocyanurate and phenolic	- Hydrocarbons (HCs; n-pentanes & cyclopentane) - Hydrofluoroolefins (HFOs) & hydrochlorofluoroolefins (HCFOs) - In limited applications, CO2 (water), methyl formate and formic acid in blends with HFC 134a - Blowing agents with proprietary chemical structures	- Mineral (glass) fibres
Extruded polystyrene (XPS)	- CO2 or CO2 with co-blowing agents, such as ethanol, HCs, acetone, and isopropanol - Hydrofluoroolefins (HFOs) & hydrochlorofluoroolefins (HCFOs)	- Glass and mineral fibres - wood - cellular glass - other polymeric (urethane and phenolic) foams

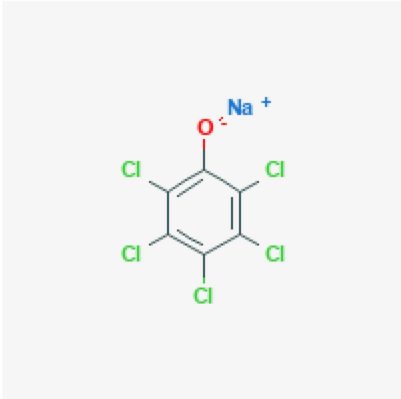
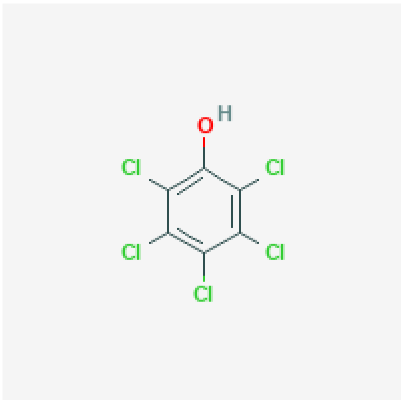
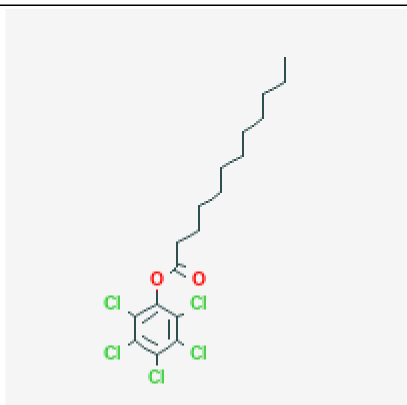
	- DME, ethanol, butanes - Methyl formate	
Spray-foams	- CO_2 (water) - Methyl formate - HFOs	- n/a
One-component	- DME, ethanols, butanes - Hydrocarbons	- Caulk

Pentachlorophenol and its related compounds

Chemical identity

Pentachlorophenol (PCP) is a chlorinated aromatic hydrocarbon consisting of a chlorinated benzene ring and a hydroxyl group. Table 12 provides an overview of the identities and chemical structure of PCP, its salts and esters, which are considered as PCP-related compounds.

Table 12: Overview of identities and chemical structure of PCP and its related compounds [10], [37].

Substance name	CAS-Number	Chemical structure
Pentachlorophenol (PCP)	87-86-5	
sodium pentachlorophenate (incl. its monohydrate form) (Na-PCP)	131-52-2 and 27735-64-4	
pentachlorophenyl laurate (L-PCP)	3772-94-9	

Associated concerns and justification for inclusion

PCP and its related compounds have been internationally recognized as persistent, bioaccumulative, toxic and to have the potential for long range transport and have been listed in Annex A (Elimination) to the Stockholm Convention on Persistent Organic Pollutants with specific exemption for the use of PCP for utility poles and cross-arms in 2015 [37]. PCP and its salts and esters are also listed in Annex

III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade [5].

Relevant applications for the building and construction sector

Pentachlorophenol was widely used as pesticide and disinfectant. PCP is one of three major industrial wood preservative and its uses have been documented for a variety of wood products, including utility poles, cross-arms, indoor and outdoor construction timber, pilings and railway ties [38]. Historic uses of PCP as a preservative has also been documented in a variety of other applications which are relevant to the building and construction sector, including paints, stains, wood joinery products, glues, adhesives, joint sealants, casting compounds, varnishes, asbestos shingles, roof tiles, brick walls, concrete blocks, insulation, pipe sealing compounds, and wallboard [38].

At the time of listing PCP in the Stockholm Convention, due to its properties of concern, many countries have banned the use of PCP and its related products even before its listing in the Stockholm Conventions. Due to the long service life of construction products, PCP containing building products may, however, be relevant for up to several decades after its phase out. For example, the service life for a PCP treated wood pole has been estimated at 60-70 years in Canada and in buildings, the service life of PCP treated timber can be eve longer. In tropical countries, PCP treated wood is estimated to have a life span of 20 years [38].

Potential alternatives

The risk management evaluation (RME) developed under the process of listing PCP under the Stockholm Convention provides several alternatives to PCP. At the time of listing PCP, parties to the convention indicated that the only remaining active application of PCP was as wood preservative with a key use for utility poles and cross-arms, thus only alternatives for this application were considered for the RME. Table 13 provides an overview of these alternatives for PCP for wood preservation [39] . It must be emphasised however, that no chemical safety assessment has been conducted for these alternatives under the procedures of the Stockholm Convention and for almost all the listed chemical alternatives, concerns exist regarding their safety for human health and the environment. Furthermore, not all alternatives are suitable to all applications for wood protection.

In addition to the chemical alternatives, the RME developed under the processes of the Stockholm Convention and the draft guidance on inventories and alternatives for PCP also identify material substitutes for PCP-treated wood, including concrete, steel or fibre reinforced composite (FCR), heat treated wood or hardwood alternatives [39], [40]. Studies on life cycle impacts for these alternative materials compared to PCP-treated wood have drawn different conclusions, with some showing that life time costs and environmental profiles of alternative materials are better and others showing them as worse compared to PCP-treated wood [39].

For a more detailed overview on technical feasibility of the provided alternatives as well as information related to concerns for human health and the environment, the reader is referred to the original RME and the Stockholm Convention draft guidance on inventories and alternatives for PCP provides further technical details on the identified alternatives [39], [40].

Table 13: Overview of chemical alternatives for PCP as wood preservatives as compiled by the risk management evaluation of the Stockholm Convention [39].

Alternative	Concern	Comments
Chromated Copper Arsenate (CCA)	- Contains chemicals of concern identified in category 2 of this report (ref. section 3.2 of main report)	- Voluntarily phased out by industry for domestic / residential uses in Canada and USA

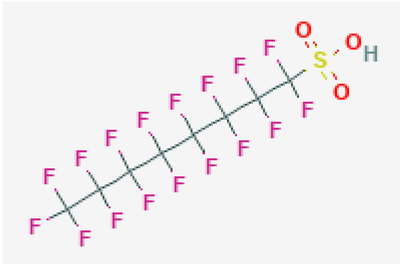
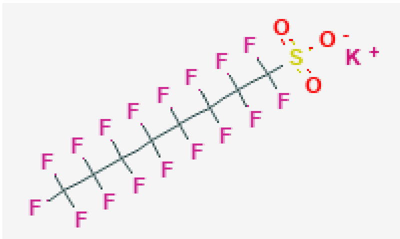
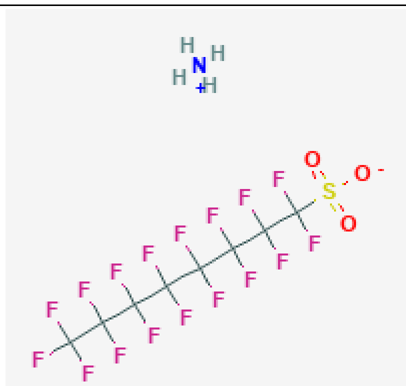
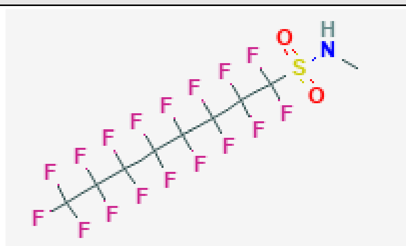
		- No longer authorized for use in the EU under the Biocidal Products Regulation
Creosote based products	- Contain a large number of hazardous substances, such as polycyclic aromatic hydrocarbons (PAHs), phenol and cresols, which have been identified as chemicals of concern in category 2 of this report (ref. section 3.2 of main report)	- Restricted to industrial applications in the USA and Canada - Restricted to industrial installations and professional applications in the EU with a ban on domestic uses.
Copper Naphthenate	- Toxicity poorly characterized	- Approved for domestic and industrial use in the USA
Ammonical Copper Zinc Arsenate (ACZA)	- Contains toxic metals, some of which have been identified as chemicals of concern in category 2 of this report (ref. section 3.2 of main report)	- Restricted to industrial applications in the USA, only used within closed systems in Canada
Ammonium Copper Quaternary (ACQ) – type C and type D	- Copper is highly toxic to aquatic organisms - Copper released from ACQ-treated wood in landfill leachates raises concerns for environmental contamination	- Used for domestic applications in Canada
Copper Azoles	- Tebuconazole (the non-metal biocide ingredient in copper azoles) has been identified to meet Persistent, Bioaccumulative and Toxic (PBT) criteria under the EU Biocidal Products regulation	- Approved for domestic applications in Canada
Sodium Borates	- Borate compounds are classified as toxic for reproduction according to UN GHS criteria	- Reserved specifically for use within indoor applications or above ground
Copper boron azole (CBA)	- Copper highly toxic to aquatic organisms - Copper released from CBA-treated wood in landfill leachates raises concerns for environmental contamination	- n/a
Silicone polymers	- Not specified	- Appear to be untested for widescale industrial use.

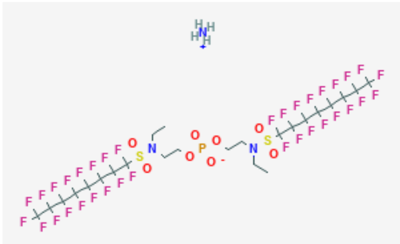
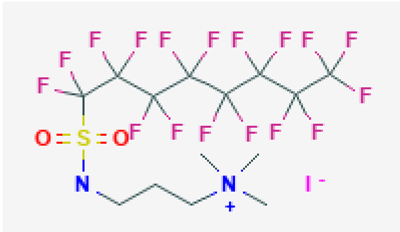
Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F)

Chemical identity

Perfluorooctane sulfonic acid (PFOS) is an organic substance consisting of a fully fluorinated chain of eight carbon atoms and a sulfonic acid functional group. Apart from the PFOS parent acid, the PFOS anion can also form salts with different cations. Furthermore, there are many PFOS-related substances, such as structurally very similar molecules (so-called PFOS derivatives) or substances that can degrade to PFOS (PFOS precursors). A report by the United Kingdom contains a draft list of 98 compounds that have the potential to degrade to PFOS in the environment, while a Chinese report indicates 66 PFOS-related chemicals have been identified in a national inventory in China in 2009 [41]. Table 14 provides an overview of the structure of PFOS, some of its salts and examples of its derivatives [41].

Table 14: Overview of the structure of PFOS, some of its salts and examples of its derivatives [10], [41].

PFOS Substance	CAS Number	Chemical structure
Perfluorooctane sulfonic acid	1763-23-1	
Potassium perfluorooctane sulfonate	2795-39-3	
Ammonium perfluorooctane sulfonate	29081-56-9	
Example PFOS derivative	**CAS Number**	**Chemical structure**
N-Methyl perfluorooctane sulphonamide (MeFOSA)	31506-32-8	

Ammonium bis[2-N-ethyl perfluorooctane sulfonamidoethyl] phosphate	30381-98-7	
3-[[(Heptadecafluorooctyl)- sulfonyl]amino]-N,N,N-trimethyl-1-Propanaminium dide/perfluorooctyl sulfonyl quaternary ammonium iodide (Fluorotenside-134)	1652-63-7	

Associated concerns and justification for inclusion

PFOS, its salts and perfluorooctane sulfonyl fluoride (PFOS-F) have been internationally recognized as persistent, bioaccumulative, toxic and to have the potential for long range transport and have been listed in Annex B to the Stockholm Convention on Persistent Organic Pollutants for restriction in 2009. This listing restricts the use of PFOS and PFOS-related substances to a set of defined acceptable purposes and specific exemptions [42]. Although the listing does not specifically mention more complex PFOS derivatives, these derivatives are covered through the listing of PFOS-F, which is the basic material for their manufacture [41]. In 2019, the Conference of the Parties to the Convention revised the listing of PFOS and PFOS-related substances in the Annex B and significantly reducing the number of acceptable purposes and specific exemptions for the uses of PFOS[1] [43]. Perfluorooctane sulfonic acid, perfluorooctane sulfonates, perfluorooctane sulfonamides and perfluorooctane sulfonyls are listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade in 2013 [44] .

Relevant applications for the building and construction sector

PFOS and PFOS-related substances have historically been used as surfactants and surface treatment in a variety of applications including some that are relevant for the building and construction sector [41], [45]: PFOS and PFOS-related substances have been widely used for carpet impregnation. They have also been used in coatings, coating additives paints and varnishes to reduce surface tension. Information from suppliers suggest, that due to their high cost, fluorosurfactants, including PFOS, are in general much more expensive than other alternative surfactants and are therefore only used in paints and varnishes where very low surface tension is needed. Low volume uses of PFOS are also documented for sealant and adhesive products [41]. During a relatively recent screening of building materials, PFOS have also been found in engineered wood insulation materials, plastic and foam insulation and plastic façade materials [46]. However, the authors of the study were not able to determine the function of PFOS in these products.

Potential alternatives

The Stockholm Convention's Persistent Organic Pollutants Review Committee compiled a guidance document summarizing the available knowledge on alternatives to PFOS and PFOS-related

[1] From December 2020, the acceptable purposes of PFOS and PFOS-related substances only cover insect baits with sulfuramid as an active control of leaf-cutting ants for agricultural use and the specific exemptions cover metal-plating in closed-loop systems as well as fire-fighting foams for liquid fuel vapour suppression and liquid fuel fires.

substances [41]. Table 15 provides a summary of the identified alternatives for applications that may be relevant to the building and construction sector. It must be emphasised however, that no chemical safety assessment has been conducted for these alternatives under the procedures of the Stockholm Convention. For a variety of identified alternatives, the chemical identity of the alternatives used for PFOS and PFOS-related substances furthermore are trade secrets and have not been disclosed publicly. According to a variety of scientific studies and the Madrid Statement [47], an international scientific consensus statement, perfluorinated compounds with shorter alkyl chain lengths (so-called “short-chain PFASs) used as alternatives to PFOS have raised concerns with regards to their persistency and bioaccumulation and should not be regarded as acceptable alternatives considering the criteria of the Alternatives Guidance document established under the Stockholm Convention [48], [49].

Table 15: Alternatives to PFOS and PFOS-related substances identified in a guidance document by the Stockholm Convention’s Persistent Organic Pollutant Review Committee that may be relevant for applications in the building and construction sector

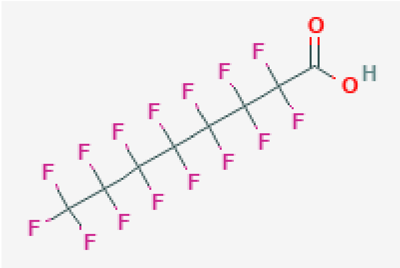
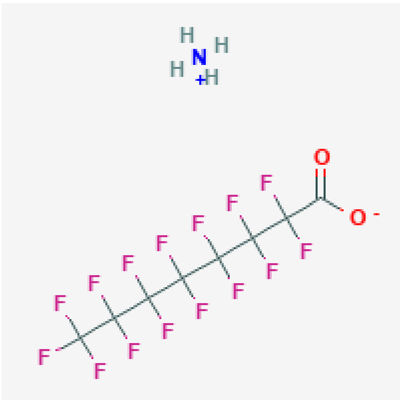
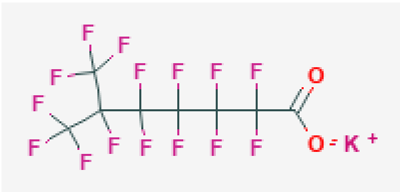
Application	**Potential alternatives**
Impregnation for textiles (carpets)	- Other polyfluorinated compounds with shorter alkyl chain lengths, such as: (i) substances based on perfluorobutane sulfonate (PFBS) or (ii) fluorotelomer-based substances incl. polymers - Silicone-based products - Mixture of silicones and stearamidomethyl pyridine chloride, sometimes combined with carbamide (urea) and melamine resins
Surface coatings, paints and varnishes	- Fluorotelomer-based surfactants (e.g. Capstone™ products) - C4-compounds based on perfoluorobutane sulfonate - Fluorinated polyethers (PolyFox™) - Sulfosuccinates for use in wood primers and printing inks - Silicone polymers - Polyproylated naphtalenes and polyproylated biphenyls - Fatty alcohol polyglycol ether sulfate

Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds

Chemical identity

Perfluorooctanoic acid (PFOA) is an organic substance belonging to the group of per- and polyfluorinated alkyl substances (PFASs). It consists of a fully fluorinated chain of seven carbon atoms with a carboxylic acid functional group. Similar to PFOS, the anion of the PFOA parent acid can form a variety of salts and there are many PFOA-related substances, i.e. substances that can degrade to PFOA (PFOA precursors). A non-exhaustive list of PFOA and PFOA-related compounds compiled under the procedures of the Stockholm Convention on Persistent Organic Pollutants identified a total of 175 individual chemical identities, consisting of 42 PFOA isomers, 15 salts of PFOA and 118 PFOA-related substances [50]. Table 16provides an overview of the chemical structure and identity of PFOA and a few examples of its salts.

Table 16: Overview of chemical structure and identity of PFOA and a few examples of its salts [10], [50].

PFOA Substance	CAS-Number	Chemical Structure
Perfluorooctanoic acid (PFOA)	335-67-1	
Octanoic acid, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluoro-, ammonium salt (1:1) (APFO)	3825-26-1	
Heptanoic acid, 2,2,3,3,4,4,5,5,6,7,7,7-dodecafluoro-6-(trifluoromethyl)-, potassium salt (1:1)	29457-73-6	

Associated concerns and justification for inclusion

PFOA, its salts and PFOA-related compounds have been internationally recognized as persistent, bioaccumulative, toxic and to have the potential for long range transport and have been listed in Annex A (Elimination) to the Stockholm Convention on Persistent Organic Pollutants with various specific exemptions in 2019 [51].

Relevant applications for the building and construction sector

Like PFOS, PFOA and PFOA-related substances have been widely applied as surfactants and surface protectors in a variety of industrial and consumer products. While the predominant use for PFOA is in the manufacture of fluoropolymers, such as Polytetrafluorethylen (PTFE), fluorinated ethylene propylene (FEP), perfluoroalkoxy alkane (PFA) or polyvinylidene fluoride (PVDF), the use of PFOA-related substances have been identified in a variety of applications, some of which are relevant for the building and construction sector. These include the use of side-chain fluorinated polymers in paints and lacquers to improve flow, wetting and levelling. The use of these PFOA-related substances has been identified in exterior and interior architectural paints. The application of PFOA-related substances appears to mainly occur in water-based paints where a reduction of surface tension of the paint is needed to achieve wetting of the surface the paint is applied to. Other applications of side-chain-fluorinated polymers include sealants for stones and wood [52]. Another potentially PFOA-related group of substances include the so-called "fluorotelomers". Fluorotelomers may be PFOA-related substances, if they contain the chemicals with the respective chain-lengths. The US EPA reported that the use in carpets and carpet care products constituted the second largest share in global consumer uses of fluorotelomers [52].

Potential alternatives

For all identified applications of PFOA and PFOA-related substances relevant for the building and construction sector, potential alternatives have been identified [49], [52]. The available information on alternatives relevant for the building and construction sector is summarized in Table 17. It must be emphasised however, that no risk assessment has been performed with regard to these substances and no statement on the safety of these alternatives can be made within the scope of this report. According to a variety of scientific studies and the Madrid Statement [47], an international scientific consensus statement, perfluorinated compounds with shorter alkyl chain lengths (so-called "short-chain PFASs) used as alternatives to PFOA and PFOA-related substances have raised concerns with regards to their persistency and bioaccumulation and should not be regarded as acceptable alternatives considering the criteria of the Alternatives Guidance document established under the Stockholm Convention [48], [49] .

Table 17: Available information on potential alternatives for PFOA and PFOA-related substances in the building and construction sector [49], [52].

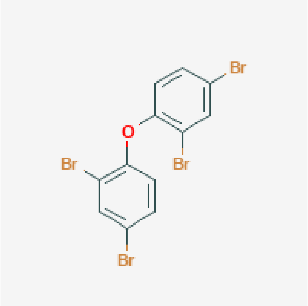
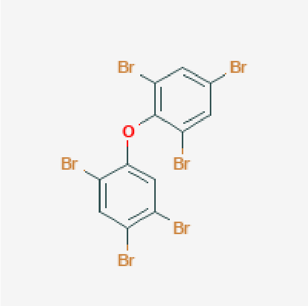
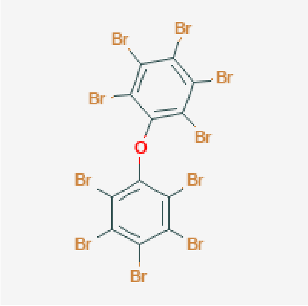
Application	Fluorinated alternatives	Non-fluorinated alternatives
Coating of architectural materials (fabric, metals, stones, tiles, etc.), additives in paints and coatings	Short-chain fluorinated alternatives, including perfluorobutanesulfonate (PFBS) and fluorinated polyethers	- Polyether-modified polydimethyl siloxanes - propylated aromatics - Aliphatic alcohols - Silicone surfactants / silicone polymers - Sulfosuccinates - Telomer-based surfactants
Impregnation of carpets	Short-chain fluorotelomer and PFBS-based substances including polymers	- Paraffins - Alpha olefin modified siloxanes - Fatty-acid modified melamine resins - Fatty-acid modified polyurethanes

Polybrominated Diphenyl Ethers

Chemical Identity

Polybrominated diphenyl ethers (PBDEs) are synthetic mixtures of brominated hydrocarbons in which 2-10 bromine atoms are attached to a diphenyl ether base structure. PBDEs are not a single chemical compound but exist as mixtures of 209 distinct chemicals, so-called congeners. PBDEs have commonly been used as flame retardants in a variety of applications and products [53]. Table 1 provides an overview of the chemical identities and structures included of selected PBDEs.

Table 18: Chemical identities and structures of selected PBDEs [10], [54]–[56]

Congeners	CAS-Numbers	Structures
2,2',4,4'-tetrabromodiphenyl ether (BDE-47)	5436-43-1	
2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154)	207122-15-4	
Decabromodiphenyl ether (BDE-209)	1163-19-5	

Associated concern and justification for inclusion

The three important commercial PBDE mixtures (penta-BDE, octa-BDE and deca-BDE) were identified to be persistent, bioaccumulative, toxic and to have the potential for long range transport and listed in Annex A to the Stockholm Convention on Persistent Organic Pollutants for global elimination [54]–[56]. Commercial mixtures of penta-BDE and octa-BDE are also listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade in 2013 [57], [58]. Deca-BDE will be considered for listing in Annex III to the Rotterdam Convention in 2021 [59].

Relevant applications for the building and construction sector

PBDEs were commonly used as additive flame retardants in polymers, textiles, adhesives, coatings and inks with a variety of end uses. A non-exhaustive list of identified applications relevant for the building sector are summarized in Table 19 (identified applications not relevant for the building sector as per the scope of this report are excluded).

Table 19: Identified applications of PBDEs relevant for the building sector [60], [61].

PBDE mixture	Materials / polymers /resins	Applications	Articles
c-Penta-BDE	Polyurethane (PUR)	Cushioning materials, padding, construction	Sound insulation, padding panels, PUR foam constructions
	Textiles	Coatings	Back coatings and impregnation for carpets
	Polyvinylchloride (PVC)	n/a	Floor mats
c-Octa-BDE	Polyamide-Polymers	Construction	Pipes and plastic foils
c-Deca-BDE	Polyurethane (PUR)	Construction	Insulation foams
	Extruded Polystyrene (XPS)	Construction	Insulation foams
	Polypropylene (PP)	Construction	Roofing membranes, cladding panels
	Polyethylene (PE)	Construction	PE/Wood composites, PE films
	Unsaturated Polyester Resin (UPR)	Construction	Modular building parts, roofing materials, porch canopies, decorative moldings, fiber reinforced plastics
	Styrene Butadiene Rubber (SBR)	Construction, interior design	Latex, carpet reinforcements, interior decorations
	Emulsions /coatings PVC, Ethylene Vinyl Chloride emulsion acrylic	Adhesives, protective coatings, saturation of fibrous materials	Wall coverings, flooring, paper, textiles
	n/a	Construction	Facing laminates for insulation panels
	n/a	Construction	Film for under the roof and protection of building areas
	n/a	Construction	Electrical ducts and fittings
	n/a	Construction	Piping insulation and pipes

For many of these products, the service life is considered to span several decades up to a century. This implies that despite the listing of these PBDE mixtures in the Stockholm Convention in 2009 (Penta- and Octa-BDE) and in 2017 (deca-BDE), respectively, a large share of PBDE-containing polymers may still be in use in the built environment [62].

Potential alternatives

The risk management evaluation prepared for the three PBDE mixtures under the procedures of the Stockholm Convention prepared by the POPs Review Committee (POPRC) as well as the guidance on alternatives for penta- and deca-BDE drafted by the Secretariat of the Stockholm Convention list a variety of potential alternatives for PBDE flame retardants for different polymers, including other brominated flame retardants as well as organophosphorus and mineral based flame retardants and non-chemical / material alternatives [61], [63]–[65]. Table 20 provides examples for the alternatives identified in these documents. While all listed alternatives are considered to be technically feasible, no assessment of potential impacts or risks for human health and the environment has been conducted under the procedures of the Stockholm Convention for the provided chemicals. This report can therefore make no statement on the safety of these potential alternatives. Since the publication of these documents under the convention, concerns have been raised for some of the listed alternatives, such as for DBDPE, which is considered to be persistent and to contribute the formation of persistent, bioaccumulative and inherently toxic substances in the environment [66].

Table 20: Examples of potential chemical and non-chemical alternatives for the applications of PBDEs relevant for the building and construction sector [61], [63]–[65].

Mixture	**Application**	**Potential chemical alternative**	**Potential non-chemical alternative**
Penta-BDE	PUR	- Ammonium poly phosphate - Red phosphorous - Reofos (non-halogen flame retardant) - Melamine - Dimethyl propane phosphate (DMPP) - Tetrabromophenolic anhydride - Tris(chloroethyl)phosphate (TCPP)	- Intumescent systems
	PVC	- Aluminium hydroxide (ATH) - Zinc borate - Zinc molybdenum compounds (combined with phosphate esters) - Zinc hydroxystannate (ZHS), Zinc stannate (ZS) & ZHS/ZS-coated ATH - Tricresyl phosphate - Tris (dichloropropyl) phosphate	- n/a
Octa-BDE	Thermoplastic elastomers	- Bis (tribromophenoxy) ethane - Tribromophenyl allyl ether	- n/a
Deca-BDE	PU-foam	- Magnesium hydroxide (MDH) - Aluminium trihydroxide (ATH) - Ethylene bis(tetrabromophtalimide) (EBTBP) - Substituted amine phosphate mixture (P/N intumescent systems) - Red phosphorous - Decabromodiphenyl ethane (DBDPE)	- Stone wool - Glass wool (fibre-glass insulation) - Phenolic foams - Natural fibre-based insulation materials

Polychlorinated Biphenyls

Chemical identity

Polychlorinated biphenyls are a synthetic group of chlorinated organic compounds, consisting of a double-ring (biphenyl) carbon base structure with 1-10 chlorine atoms attached. Figure 2 [67] provides the general structure of a PCB congener.

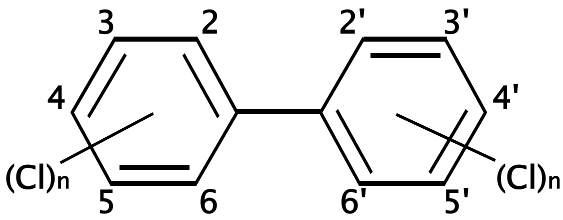


Figure 2: General chemical structure of a PCB congener [67]. Each side of the carbon ring structure can have 1-5 chlorine atoms attached

Associated concerns and justification for inclusion

PCBs have been identified as persistent, bioaccumulative and toxic and have been listed as one of the 12 initial POPs in the Stockholm Convention on Persistent Organic Pollutants in Annex A (elimination) and Annex C (unintentional production). PCBs are also listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, along with polychlorinated terphenyls (PCT) [5].

Relevant applications for the building and construction sector

Apart from their primary use as dielectric fluids, PCBs were also used as flame retardants, plasticizers, anti-corrosion coatings and impregnating agents in a variety of products relevant to the construction sector, such as caulks/ sealants, paints, plasters, adhesives, floor finishes, anti-corrosion coatings and fluorescent lights. Adding PCBs to these building products greatly enhanced their physical and chemical resistance, improved the flexibility, fire resistance or impregnating qualities and extended their lifetime [68]. It is estimated that approximately 25% of the total world production (approx. 375'000 tonnes) was used in such open applications.

It is generally believed that open applications of PCBs were phased-out in the early 1980s. Due to the long lifetimes of these products however, PCBs are still present in the built environment.

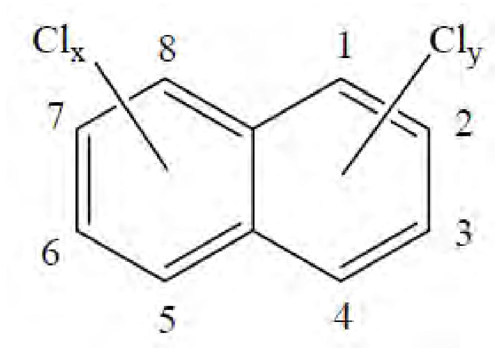
Potential alternatives

There is currently no comprehensive compilation available for alternatives to PCBs in open applications. As these alternatives have been used for more than 40 years, their technical suitability for all applications is no longer an issue. However, there is a lack of information on the extent of environmental performance assessments conducted for these alternatives. One major substitute of PCBs in sealants, paints and as flame retardants appear to be chlorinated paraffins [69]. Short-chain chlorinated paraffins have also been listed as persistent organic pollutants in the Stockholm Convention (see p. 53).

Polychlorinated Naphthalenes

Chemical identity

Polychlorinated naphthalenes (PCNs) are a synthetic group of chlorinated organic compounds, consisting of a double-ring carbon base structure with 2-8 chlorine atoms attached. Figure 2Figure 3 provides the general structure of a PCN congener.



x + y = 2 to 8

Figure 3: General chemical structure of a PCN congener [70].

Associated concerns and justification for inclusion

PCNs have been identified as persistent, bioaccumulative and toxic and have been listed in Annexes A (elimination) and C (unintentional production) of the Stockholm Convention on Persistent Organic Pollutants [71].

Relevant applications for the building and construction sector

Because of their structural similarities, PCNs were often used for the same applications as PCBs, although the overall production volume of PCNs is estimated to be lower than of PCBs [72]. PCNs have been used in a variety of products relevant for the building and construction sector including in waterproof sealants, anti-corrosion paints and lacquers, caulks and putty, and as wood preservative [72]. While most applications of PCN seem to have been phased out in the 1970 and 1980, there is some evidence of their use in sealants until ca. 2000 in East Asia. Since then, it is assumed that global production and use of these substances have ceased. Due to their long lifetimes, a considerable share of PCN containing products, such as woods or sealants, may however still be in use and present in the built environment [72].

Potential alternatives

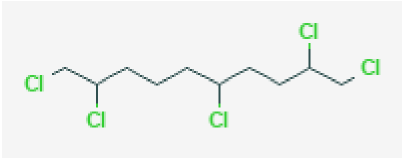
There is currently no comprehensive compilation available for alternatives to PCN in applications relevant for products of the building and construction sector. As PCNs seem to have been phased out of use on a global scale, it is assumed that technically feasible alternatives exist [73].

Short-Chain Chlorinated Paraffins

Chemical identity

Chlorinated paraffins (CP) are complex mixtures of polychlorinated n-alkanes, consisting of a carbon-chain backbone with varying chain length to which a varying number of chlorine atoms can be attached. CPs are generally characterised by the length of their carbon-chain backbone (chain-length) and their degree of chlorination. According to their chain length, they are categorized in short-chain CPs (SCCPs, 10-13 carbon atoms), medium-chain CPs (MCCPs, 14-17 carbon atoms), and long-chain CPs (LCCPs, 10-30 carbon atoms) [74]. Table 18 provides an example for the structure of a short-chain chlorinated paraffin and CAS-Numbers of example substances [74].

Table 21: Example for the structure of a short-chain chlorinated paraffin [10].

Example substance identity	Example substance structure
1,2,5,9,10-Pentachlorododecane CAS-Nr: 1637297-61-0	

Associated concerns and justification for inclusion

Short-chain chlorinated paraffins with a chain length ranging from 10-13 carbon atoms and a content of chlorine greater than 48% have been identified to be persistent, bioaccumulative, toxic and to have the potential for long range transport and listed in Annex A to the Stockholm Convention on Persistent Organic Pollutants for global elimination [75]. This listing includes several specific exemptions for production and certain uses of SCCP. SCCPs are also listed in Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade in 2017 [76].

Relevant applications for the building and construction sector

Due to their versatile chemical structure and properties, the range of applications of SCCPs is wide. Primary uses of SCCP have been as lubricants and coolants in metal working applications and in polyvinyl chloride (PVC) processing. In addition, SCCPs have also been used as plasticizers and flame retardants in a variety of other applications, including in paints, adhesives and sealants, rubber, textiles leather fat liquor and polymeric materials. With this, SCCP have been and may still be used for a wide range of applications relevant to the building and construction sector. Many of these applications are so-called “open-applications”, for some of which, SCCP have been used as substitute for PCBs. Uses have varied between countries and over time depending on the need of products in the respective country and the regulatory framework [74]. Table 22 summarizes a non-exhaustive collection of identified uses relevant to the building and construction sector.

Table 22: Non-exhaustive collection of identified uses of SCCPs relevant for the building and construction sector [74], [77]–[79]. Identified uses not deemed directly relevant for products used in the built environment, are not included.

Application of SCCPs	Products
Secondary plasticiser in flexible PVC materials	- PVC wood panel ceilings - Flooring - Wall covering - Plumbing - Tubes for outdoor decoration

Flame retardant for materials made from natural and synthetic rubber	- Sound insulation - Flooring (rubber-track products)
Plasticizer or flame retardant in paints and coatings e.g. chlor-rubber and acrylic protective coatings and intumescent paints	- Anti-corrosive coatings for metal surfaces - Fire-retardant paints - Swimming pool coatings - Decorative paints for internal and external surfaces - Primers for polysulphide expansion joint sealants
Plasticizer or flame retardant in adhesives and sealants e.g. polysulfide and polyurethane formulations, acrylic and butyl sealants	- Joint sealants e.g. for expansion and movement joints, filling of gaps around doors, windows, arches, water storage applications, underground facilities - Floor adhesives (e.g. parquet, carpets) - Adhesives for use on concrete, tiles bricks and ceramics

The specific exemptions from the provisions of the Stockholm Convention include almost all applications of SCCP relevant for the building and construction sector[2]. At the date of writing, no country has registered for such a specific exemption. Nevertheless, with these exemptions it is possible that SCCPs remain in use in applications relevant for the building and construction sector for up to five years after their listing in the Stockholm Convention. Due to the long service life of products used in the built environment, it is expected that SCCPs will be present in waste streams from construction and demolition for many decades [80].

Potential alternatives

The risk management evaluation prepared under the procedures of the Stockholm Conventions and the preliminary draft guidance on alternatives to SCCP list a variety of alternative products and processes for the different applications of SCCPs [81], [82]. Table 23 provides an overview for some of the applications of SCCP relevant for products of the building and construction sector. It needs to be emphasised however, that none of the listed alternatives been evaluated for their safety under the procedures of the Stockholm Convention or the present work and for some of these alternatives, established or emerging knowledge has raised concern [78], [79], [81].

Table 23: Overview of suggested alternatives for some SCCP applications relevant for products of the building and construction sector [82]. No safety assessment has been conducted for these alternatives as part of the present work.

Application	**Alternative chemicals**	**Alternative materials and techniques**
Secondary plasticizers in flexible PVC	- Inorganic substances: alumina trihydrate, aluminium trihydroxide (ATH) used in conjunction with antimony trioxide, aluminium trioxide, antimony trioxide (or antimony oxide), zinc borate - Organophosphorus flame retardants: Cresyl diphenyl phosphate (CDP), Tertbutylphenyl diphenyl phosphate (TBPDPP), Isopropylphenyl diphenyl phosphate (IPPDPP), Tricresyl phosphate	- Inherently flame-resistant materials or use of flammability barriers, such as PVC solid woven, chloroprene (CR) multi-ply, or silicone-based materials.

[2] The exemptions form the provisions of the Stockholm Convention that are relevant for the building and construction sector include (i) the use of SCCP in tubes for outdoor decoration bulbs, (ii) in waterproofing and fire-retardant paints, (iii) in adhesives and (iv) the use of SCCP as secondary plasticizers in flexible PVC except in toys.

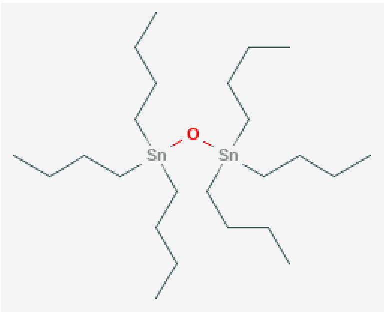
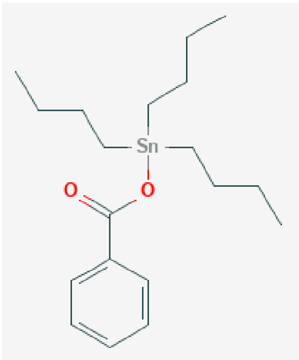
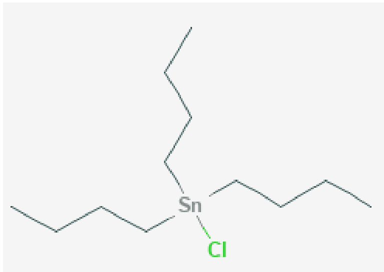
	(TCP), Phosphorus based compounds (in general). - Inorganic alternatives for some applications: Borate and phosphate esters, calcium sulphonates, sulphonated fatty esters, zinc borate, acrylic polymers - Other halogenated alternatives: medium-chain chlorinated paraffins (MCCPs; C14-17), long-chain chlorinated paraffins (LCCPs; C18+), alicyclic chlorinated compounds - Phthalate plasticizers (if only plasticizing properties are required)	
Waterproofing and fire-retardant paints	- Medium-chain chlorinated paraffins (MCCPs; C14-17) - Long-chain chlorinated paraffins (LCCPs; C18+) - Boron- and silicone-based compounds (e.g. phosphorus-boron-nitrogen compounds) - Diisobutyrate compounds - Organophosphorus flame retardants - Phosphate esters - Phosphorus-based compounds - Phthalates (including phthalate esters)	- Epoxy-based paints - For road-markings: thermoplastic products
Adhesives & sealants	- Medium-chain chlorinated paraffins (MCCPs; C14-17) - Long-chain chlorinated paraffins (LCCPs; C18+) - 2,2,4-trimethyl-1,3-pentanediol - Alkyl sulphonic acid esters of phenol or cresol - Di-2-ethylhexyl adipate - Glycolate esters, - Hydrogenated terphenyls - Phosphate esters - Phthalates (generally, including phthalates esters) - Polyacrylate esters - For polyurethane formulations: dibenzoate, dipropylene glycol	- Urethane or silicone sealants as replacement of polysulphide sealants

Tributyltin compounds

Chemical identity

Tributyltin compounds is a group of chemicals which are characterized by three butyl groups being covalently bonded to a tetravalent tin center. They have a general molecular formula of $(n\text{-}C_4H_9)_3Sn\text{-}X$, where X is an anion [83]. Table 24 provides an overview of the structure and chemical identities of a selection of tributyltin compounds.

Table 24: Overview of structures and chemical identities for a selection of tributyltin compounds [10], [84].

		
Tributyltin oxide (TBTO) CASRN: 56-35-9	Tributyltin benzoate (TBTB) CASRN: 4342-36-3	Tributyltin chloride CASRN: 1461-22-9

Associated concerns and justification for inclusion

Due to concerns regarding the persistence, the potential for bioaccumulation and high toxicity of tributyltin compounds to the aquatic environment, many countries have severely restricted or banned the uses of these compounds as biocide in antifouling paints [85]. Based on the notification of a ban on pesticide uses of tributyltin compounds in the EU and Canada, as well as severe restrictions on industrial uses in Canada, tributyltin compounds were listed in Annex III of the Rotterdam Convention on the Prior informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade in 2008 [86]. In 2017, this listing was extended with industrial uses of tributyltin compounds [84], [87].

Relevant applications for the building and construction sector

One of the major applications of tributyltin compounds are as biocides in anti-fouling paints, wood preservatives and preservatives for other applications [88]. Tributyltin compounds can also be present as impurities (concentration <20%) in organotin stabilizers used for PVC processing and catalysts for polymer production [88], [89]. Table 25 provides an overview of documented applications and occurrences of tributyltin compounds in products potentially relevant for the building and construction sector [88]–[90]. The use of tributyltin compounds in anti-fouling paints for ships and hulls was not considered a relevant application for the sector.

Table 25: Overview of documented applications and occurrences of tributyltin compounds in products potentially relevant for the building and construction sector [88]–[90].

Application	**Relevant products**
Wood preservatives	- Paint, stains and waterproofing to be applied to exterior wood, such as decks, shingles, shakes, wood siding, fences, railings, floors, structural lumber, beams, timber, sills, roofs, plywood, clapboards and porches

	- Pressure or vacuum impregnation of wood for industrial uses
Material preservatives / biocide	- Drywall, joint compound, medium density fibre board, particulate board. - Building material adhesives - Polyurethane foams - Polymers used for flooring, tiles and carpeting
Impurity in organotin stabilizers for PVC	- Rigid construction applications including foamed sheeting, for use in external decking and railing, sheeting including foamed panels, vinyl mini-blinds - Pipes and moulding including all pipe types such as sewer pipes, rainwater goods and drinking water pipes - Profile extrusion for windows, door frames, doors and decorative profiles

Potential alternatives

No systematic overview of alternatives for the relevant identified applications of tributyltin compounds are available. As all of the identified applications have been severely restricted in the European Union[3] [91], it can be assumed that technically feasible alternatives for the use of tributyltin compounds exist and are in use. Substitutes for organotin stabilizers for PVC include stabilizers based on lead or mixed metals, such as cadmium and zinc [84]. Lead stabilizers are a low-cost alternative but associated with environmental concerns and are currently being debated for restriction under REACH in the EU. Mixed metal stabilizers are more expensive than their tin-based counterparts and are less effective in stabilization [84].

[3] Entry 20 of Annex XVII of REACH stipulates that all "tri-substituted organostannic compounds such as tributyltin compounds and thriphenyltin compounds shall not be used after 1 July 2010 in articles where the concentration in the article, or part thereof, is greater than the equivalent of 0.1% by weight of tin" and non-conforming articles shall not be placed on the market after 1 July 2010 [91].

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