Socio-economic considerations of regulating Dechlorane Plus under the Stockholm Convention

Draft report

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Disclaimer

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Contents

Abbreviations & Acronyms

ABS	Acrylonitrile butadiene styrene
ACEA	European Automobile Manufacturers' Association
ACEM	European Association of Motorcycle Manufacturers
AIA	Automotive Industry Association
AIAC	Aerospace Industries Association of Canada
ASR	Auto shredder residue
BIR	Bureau of International Recycling
CEA	Cost-effectiveness analysis
CfE	Call for Evidence
Cl	Chlorine
CLEPA	European Association of Automotive Suppliers
CM	Control measure
CoP	Conference of the Parties
DAP	Diammonium phosphate
DDT	Dichloro-diphenyl-trichloroethane
decaBDE	Decabromodiphenyl ether
DP	Dechlorane Plus
EAV	Equivalent annual values
ECHA	European Chemical Agency
EEA	European Economic Area
EEE	Electrical and electronic equipment
EiF	Entry-into-force
ELVs	End-of-Life Vehicles
EPDM	Ethylene propylene diene monomer rubber
EPR	Electron Paramagnetic Resonance
ERC	Environmental Release Categories
ESD	Emission Scenario Document
EU	European Union
EVA	Ethylene-vinyl acetate
FEICA	The Association of the European Adhesive and Sealant Industry
GC-MS	Gas chromatography – mass spectroscopy
GC-MS/MS	Gas chromatography – tandem mass spectroscopy
HRMS	High resolution mass spectrometry
ILO	International Labour Office
JAPIA	Japan Auto Parts Industries Association
LOQ	Level of quantification
NEA	Norwegian Environmental Agency
OC	Operational conditions
OECD	Organisation for Economic Co-operation and Development

OEM	Original Equipment Manufacturers
OEMs	Original equipment manufacturers
PA	Polyamide
PBT	Polybutylene terephthalate
PBT	Persistent, Bioaccumulative and Toxic
PCB	Printed Circuit Board
PCBs	Printed Circuit Boards
PFAAs	Perfluoroalkyl acids
PFOS	Perfluorooctane sulfonyl fluoride
POPRC	Persistent Organic Pollutants Review Committee
POPS	Persistent Organic Pollutants
PPP	Purchasing Power Parity
PROC	Process Categories
PRODCOM	Statistics on the production of manufactured goods
PST	Post-shredder treatment
PVC	Polyvinyl chloride
R&D	Research & Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RMM	Risk management measures
SAICM	Strategic Approach to International Chemicals Management
SBR	Styrene butadiene rubber
SMEs	Small and medium-sized enterprises
SPERCs	Specific Environmental Release Categories
STP	Sewage treatment plant
SVHC	Substance of very high concern
t	Tonnes
t/y	Tonnes per year
TPE	Thermoplastic elastomers
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation
US EPA	United States Environmental Protection Agency
USA	United States of America
vPvB	Very persistent and very bioaccumulative
WEEE	Electrical and electronic equipment waste
XRF	X-ray fluorescence spectroscopy

1. Emission sources of Dechlorane Plus

This section presents information on the global manufacture, trade, use and emissions of Dechlorane Plus (DP). The information is gathered from peer-reviewed scientific literature, other publicly available literature including reports and documents shared by the Norwegian Environment Agency.

1.2 Manufacture, use and trade of Dechlorane Plus

1.2.1 Information from literature

Manufacture of DP

As shown in **Table 1.1**, global data on the manufacture of DP is from 2010 or earlier. All source references in the table published post 2010 are referring to older sources. The most recent data are from 2008 to 2010. In this period global production volumes were estimated to be between 4,500 and 5,000 tonnes per year (t/y) (Qiu et al., 2007). Of those, 300 – 1,000 t/y were manufactured in China where the only known manufacturer is and was *Jiangsu Anpon Company Ltd* (ECHA, 2020a; Wang et al., 2010; ECCC, 2019). Since 2011, OxyChem has “withheld” their production volumes. Historic volumes manufactured by this company in the USA range between 450 to 4,500 t/y (US EPA, 2002; Qiu et al., 2007; Ren et al., 2009). When ADAMA entered the European market in 2017 their registered tonnage band was 10 – 100 t/y. After OxyChem exited the EU market in 2017, this likely led to increased demand for DP from ADAMA, which may explain why ADAMA increased their supply to this market, - reported to be 100 – 1,000 t/y in April 2020. However, as detailed in the DP REACH Restriction proposal (ECHA, 2021), the REACH registrant recently (October 2020) downgraded the tonnage band to 10 – 100 t/y in their REACH registration (ECHA, 2020c).

Table 1.1: Global production volumes for DP, t/y

Region	1986 - 2002	2003 - 2008	2008 - 2010	> 2011
USA	450 – 4,500[1]	450 – 4,500[2]	n/a	withheld[2]
China	0	300 – 1,000[3]	300 – 1,000[3]	n/a
Global	**450 – 4,500**	**750 – 5,500**	**4,500 – 5,000**[4]	**n/a**

Note: Global production volumes between 1986 and 2008 are calculated based on production volumes in the USA and China. In the table n/a refers to “not available” but it is known that DP is still manufactured in China.

Publicly available registration data accessed in April 2020, when the Call for evidence (CfE) and stakeholder consultation for the REACH restriction proposal (ECHA, 2021) were launched, indicated that the total volume placed on the EU market is in the range of 100 – 1,000 t/y. This was collaborated by several other studies (ECHA, 2017b, ECHA, 2020b, UNEP, 2019). This is the same total tonnage band for the REACH registered substance as in 2017, showing that the volume of DP produced by registrants has remained relatively constant in the EU (ECHA, 2017b, ECHA, 2020b). It was noted in UK EA (EA, 2018) that “a small number of non-EU companies also offer DP for sale, so there could be a handful of other EU importers of <100 t/y”.

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[1] ECHA, 2020a; Qiu et al., 2007
[2] US EPA, 2016
[3] ECCC, 2019; ECHA, 2020a; Wang et al., 2010
[4] Wang et al., 2010; Feo et al., 2012; Ren et al. (2009)

Global trade volumes of DP

As shown in **Table 1.2**, there are large data gaps in reported trade volumes. Import volumes for the EU/EEA constitute the most recent and most complete dataset, although the majority of the volume estimates are from REACH registrations with corresponding broad tonnage bands. As reported above, between 4,500 and 5,000 tonnes (t) of DP are estimated to have been manufactured per year between 2008 and 2010, but there is hardly any information on import and use of DP for these years. It is therefore not known whether the substance was mainly used within the manufacturing countries, i.e. the USA and China, or if a large share was exported.

Besides the EU/EEA, only Canada has reported imports of DP after 2011. That is not to say that other countries do not use DP, but information on imports was not identified within the literature reviewed. Between 2011 and 2016, the combined import volumes of Canada and South Korea were below 20 t/y. For the period between 2017 and 2019, only EU/EEA import volumes are available, reported to be below 1,000 t/y.

Table 1.2: Global trade volumes of DP, t/y

Region	2000	2003-2006	2008	2011	2014	2015	2016	2017	2018	2019	2020
Sweden		4 - 11[5]	0[6]								
Finland			0[6]								
Norway			0[6]								
UK											
EU/EEA	800[6]		200[7] – 5,000[8]					100-1,000[9]	100-1,000[10]	<300[11]	10-100[12]
Canada			1-10[13]	1-10[13]			1-10[13]				

Note:

- Only years for which data was available are included.
- Blank cells indicate that no data on import volumes was found for the country/region in the specific year.

Uses of DP

DP is an additive chlorinated flame retardant that is used in a variety of polymeric systems (ECHA, 2019a; ECHA, 2020c). It has been used as an alternative to Dechlorane ("Mirex") and decabromodiphenyl ether (decaBDE) since the 1960s (ECHA, 2019a; ECHA, 2020c; POPRC, 2021). The market for DP is reported as being mature and presumably relatively stable (ECHA, 2017a; ECHA, 2019a). Reported benefits of DP include its stability to ultraviolet light, its positive impact on the heat distortion temperature and that it does not affect electrical and physical properties. For several polymers, DP is reported to be more efficient than brominated additives, while it is preferable to decabromodiphenyl ether (decaBDE) for use with polyolefin compositions due to a lower production of smoke (ECHA, 2017a).

[5] IVL, 2010; ECHA, 2020a
[6] IVL, 2010
[7] EA, 2018
[8] ECHA, 2021
[9] ECHA, 2017a
[10] ECHA, 2019a
[11] ComRef, 2019
[12] ECHA, 2020c
[13] ECCC, 2019b

Available information on uses of DP in literature is mostly qualitative, which makes it difficult to assess the relative importance of sectors and uses of DP. **Table 1.3** provides a summary of uses of DP identified in publicly available sources.

Table 1.3: Summary of uses of DP found in literature

Industry	Sector	Article / Component
Automotive	Electrical and electronic equipment	Wires and cable plastic coatings, coil bobbins[14], cable straps
		Switches, and small electronic appliances including cameras, computers (motherboards, chargers and hard-plastic connectors)
	Engines	2-part epoxy-void fillers
	Other	Bodywork parts
Aviation	Electrical and electronic equipment	Wires and cable plastic coatings, coil bobbins[14], cable straps
		Switches, and small electronic appliances including cameras, computers (motherboards, chargers and hard-plastic connectors)
	Engines	2-part epoxy-void fillers
Electrical / electronic equipment	Wires and cables	Wire and cable plastic coatings not used in the automotive or aviation industry, including cable insulation and nuclear power plant control cables
	Electronic devices	Electronic devices not used in the automotive or aviation industry, including mobile phones, lamps, refrigerators, computer and washing machines
Building / manufacturing materials	Plastic products	Plastic roofing materials, wallpaper, paint, pipes, flooring, power tool housing and wall plates
Other consumer products	Plastic products	(Plastic) toys
		Food packaging
	Textiles	Clothing, mattresses, curtains, carpets and (textile) toys
	Adhesives	Adhesives and binding agents, syntactic foams and potting compounds

Source: POPRC (2021), ComRef (2019), ECHA (2020c) and OxyChem (2007).

In the EU, DP is not used as an intermediate during industrial manufacturing processes according to the REACH registration dossier[15]. In contrast, information from US EPA (2002) suggests DP is also used as an intermediate, and in production processes in various industries including e.g. in chemical manufacturing, production of metals, the cosmetics industry, and for production of a variety of products (US EPA, 2002).

A main use of DP is as a non-plasticizing flame retardant for various **polymeric systems** (ECHA, 2017a; ECHA, 2020c; ECCC, 2019; POPRC, 2021). Typically, these polymers systems are either thermoplastics, whose curing process is reversible, or thermosets, whose curing process is irreversible (ECHA, 2020c; ECCC, 2019; POPRC, 2021). Examples of thermoplastics commonly containing DP are:

- Acrylonitrile butadiene styrene, also referred to as ABS[16];

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[14] A coil bobbin refers to the plastic containers used to keep wire enabling it to retain shape and rigidity. Additionally, coil bobbins are used to ease assembly of the windings into or onto a magnetic core.

[15] The registrant of a substance needs to compile all the required information in a registration dossier, which consists of a technical dossier and chemical safety report. For more information, see https://echa.europa.eu/regulations/reach/substance-registration/the-registration-dossier

[16] ECHA, 2017a; ECHA, 2020c; ECCC, 2019; UNEP 2019.

- Natural rubber[16];
- Nylon[16];
- Polybutylene terephthalate, also referred to as PBT[16];
- Polyester[16];
- Polypropylene[16]; and,
- Styrene butadiene rubber (SBR) block copolymer[16].

Examples of relevant thermosets are:

- Epoxy resins[16];
- Ethylene propylene diene monomer rubber, also referred to as EPDM[16];
- Neoprene[16];
- Polyester resins[17];
- Polyethylene[16];
- Polyurethane foam[17];
- Polyurethane rubber[16]; and,
- Silicon rubber[16].

The concentration of DP used in different polymers is provided in **Table 1.4**.

Table 1.4: Concentration of DP in thermoplastics and thermosets, based on information from 2007 and 2009

Type of polymeric system	Polymer type	Concentration of DP	Reference
Thermoplastic	ABS	16.9%	OxyChem (2007)
	Natural rubber	18.7%	
	Nylon	0 – 35%	KEMI (2007); Weil and Levchik (2009)
	PBT	8 – 18%	OxyChem (2007)
	Polyester	0 – 16%	KEMI (2007)
	Polypropylene	20 – 35%	OxyChem (2007)
	SBR block copolymer	30%	
Thermoset	Epoxy resins	25.5%	
	EPDM	33%	
	Neoprene	10%	
	Polyester resins, unsaturated	n/a	
	Polyethylene, cross-linked	25.5%	
	Polyuretane foam	17.5 – 35%	
	Polyurethane rubber	20 – 30%	
	Silicon rubber	18.8 – 40%	

Other relevant polymer systems for DP referred to in OxyChem product literature as of 2007 were:

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[17] ECHA, 2020c; ECCC, 2019; POPRC, 2021.

- Chloroprene;
- DAP;
- EEA;
- Phenolics;
- EPR;
- EVA;
- Hypalon®;
- Hytrel®;
- Kraton;
- High Impact Polystyrene; and
- TPE.

According to ECHA (2019c), the concentration of DP in finished **articles** is typically around 20%. However, it is uncertain whether this share refers to the share of DP per mass or per weight of the article (ECHA, 2019c). With respect to phenolics, DP is reported to be used for both industrial phenolic laminates and phenolic resins, while its use in products for consumer use is unknown (ECCC, 2019). DP is according to the manufacturer also used in nylon incorporated in electrical connectors and, secondly, polyolefins applied in commercial wires and cables as the two primary applications of DP with respect to polymers (OxyChem, 2013).

Electric applications are a main area of application of DP containing polymers. Examples of applications for such polymers are as coatings of commercial electrical wires and cables (ECHA, 2017a; ECHA, 2020c; ECCC, 2019; US EPA, 2002; IVL, 2010; POPRC, 2021), as cable insulation (ECHA, 2020c; ComRef, 2019) and coil bobbins (ECCC, 2019). Polymers containing DP are also reported to be used in switches, cable straps, power tool housing and wall plates (ECCC, 2019) as well as in niche applications such as nuclear power plant control cables (ECHA, 2017a). The use of DP in the manufacture of electronic devices and optical products includes electronic equipment of all types, e.g. cameras, computers and phones, as well as electronic components related to the (use of) these devices, e.g. motherboards and chargers (US EPA, 2002). In addition, DP can be found in lamps, refrigerators and washing machines (ECHA, 2020a). The draft POPs risk profile (POPRC, 2021) reiterates the use of DP in wire and cable, and as a flame retardant for electrical connectors used in computers and other electronic devices.

Hard plastic connectors within television and computer monitors are other examples of the application of DP in polymers used in the manufacture of plastic products used within electrical and electronic products (ECHA, 2017a; ECHA, 2020c; ECCC, 2019; IVL, 2010; POPRC, 2021). Information published by ECHA (2020a) points to the use of DP in plastic toys. DP seems to be used as additive or coating to prevent flammability and appears to be relevant in relation to the manufacturing of plastics, plastic additives as well as plastic products (US EPA, 2002). In response to a public consultation by EU authorities, the US company Velsicol Chemical[18] confirmed that DP "has one significant use whereby it is used as a flame retardant within plastic products such as cabling". Additionally, Velsicol Chemical stated that DP is used as a flame retardant in the

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[18] Stakeholder number 3387, information submitted on 5 December 2018

manufacture of fire-resistant plastic articles (ComRef, 2019).

The use of DP in **automobiles, aerospace and defence engines** is reported in relation to its use in articles (ECHA, 2019a; ECHA 2020c). The substance is also used in other aircraft components, including adhesives, binding agents, syntactic foams and potting compounds (ECHA, 2017a; ECHA, 2019a; ECHA, 2020c). The extensive use of DP in the aerospace industry as a flame retardant and in other functions was confirmed by the Aerospace Industries Association of Canada (AIAC) in their input to the consultation on the DP risk profile under the Stockholm Convention. AIAC states that DP is often used as an additive to various formulations and can be found in many aircraft components such as cabin interior panels, ducting, engines and other components (POPRC, 2021). In response to a public consultation by EU authorities, Rolls-Royce PLC[19] also confirmed that DP is used in aerospace and defence engines. It reported that DP is used for its flame-retardant properties in a concentration of <15% in 2-part epoxy void fillers. The void filler formulations are reported to be relevant for both the manufacture and repair of engines. The use of formulations containing DP is reported to be essential for manufacturing the engines due to a lack of suitable alternatives meeting the stringent qualification requirements faced by the industry sector (ECHA, 2019c). The use of DP for automobiles has been reported for Canada and India, where it is used as a flame retardant in automobile manufacturing (ECHA, 2020b; ECCC, 2019; POPRC, 2021), but also for EU countries. Information from the Netherlands reports its use for powertrain, cooling, chassis and bodywork parts (ECHA, 2020b). The Society of Indian Automobile Manufacturers (SIAM), on behalf of their members, reported to the POPRC that dechlorane plus is used as an alternative to c-decaBDE in automobile manufacturing (SIAM, 2020).

Flame retardants are also widely used in ships and offshore installations, however, use of DP has not been confirmed within these sectors.

In the EU, DP can also be found in **food packaging** and storage according to substance information provided on the ECHA web site (ECHA, 2020a). In Canada, in contrast, DP is neither approved as a food additive nor are authorities aware of its use in formulations for producing food packaging material or its presence in such formulations as an impurity (ECCC, 2019).

In China, DP has been identified in various types of **building materials**, e.g. non-woven wallpaper and wallpaper made of PVC and paper, latex paint, PVC line pipes, boards such as laminated flooring, fibre boards and solid wood. The highest concentrations of DP were found in foams and PVC materials in concentrations up to 3,270 ± 5,423 ng/g and 1,425 ± 968.8 ng/g, respectively (Hou et al., 2018). Conversely, lower concentrations of DP were found in paints and wall decoration powders at 42.15 ± 31.99 ng/g and 5.14 ± 2.51 ng/g, respectively (Hou et al., 2018). Examples of foams containing DP are sound absorbing foams and expanded polystyrene panels (ECHA, 2020c). In addition to its use in flooring, wooden building materials and insulation, DP is also reported to be used in caulk, tile, paint and glass (US EPA, 2002). DP is also reported to be used in furniture (ECHA, 2020c; POPRC, 2021). DP is also used in plastic roofing material (ECCC, 2019).

With respect to the use of DP in **adhesives**, US EPA (2002) reports that DP is used in general adhesives as well as binding agents applied in relation to a variety of uses.

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[19] Stakeholder number 3382, information submitted on 5 December 2018

In **fabrics, textiles and apparel**, DP is reported to be used as an additive or as a coating to prevent flammability (US EPA, 2002). According to information published by EU authorities, DP can be found in clothing, mattresses, curtains, carpets and textile toys (ECHA, 2020a). A minor application of DP in relation to this article category are military textiles (ECCC, 2019).

While US EPA (2002) identifies the use of DP in the **cosmetics industry in the USA**, no use of DP in cosmetics has been indicated within the EU according to information from REACH registration dossiers or the COSING database. This implies that DP is not used in cosmetics within the EU (EC, 2020a). Similarly, DP seems not to be used in cosmetic products in Canada according to notification submissions to Canadian authorities under the Canadian Cosmetic Regulation (ECCC, 2019).

The manufacture of **fireworks** is an additional, yet minor use, of DP (ECHA, 2020c). Velsicol promotes their DP-containing product *Pyrovex SG* as a chlorine donor for fireworks with produce deeper colours (Impag, 2018). In the public consultation to the "*Draft 9th recommendation for inclusion of substances in Annex XIV of REACH for Dechlorane Plus*", Velsicol states that "*One minor use of Dechlorane Plus is within the development of fireworks. The fireworks made using Dechlorane Plus are not placed on the market and the usage is less than 100 kg per year.*" (ComRef, 2019).

Figure 1.1 below, presents a simplified flow chart of DP from its production and compounding phase throughout some of the use stages found in literature. A more complete list of thermoplastics and thermosets can be found in the REACH restriction proposal for DP (ECHA, 2021).

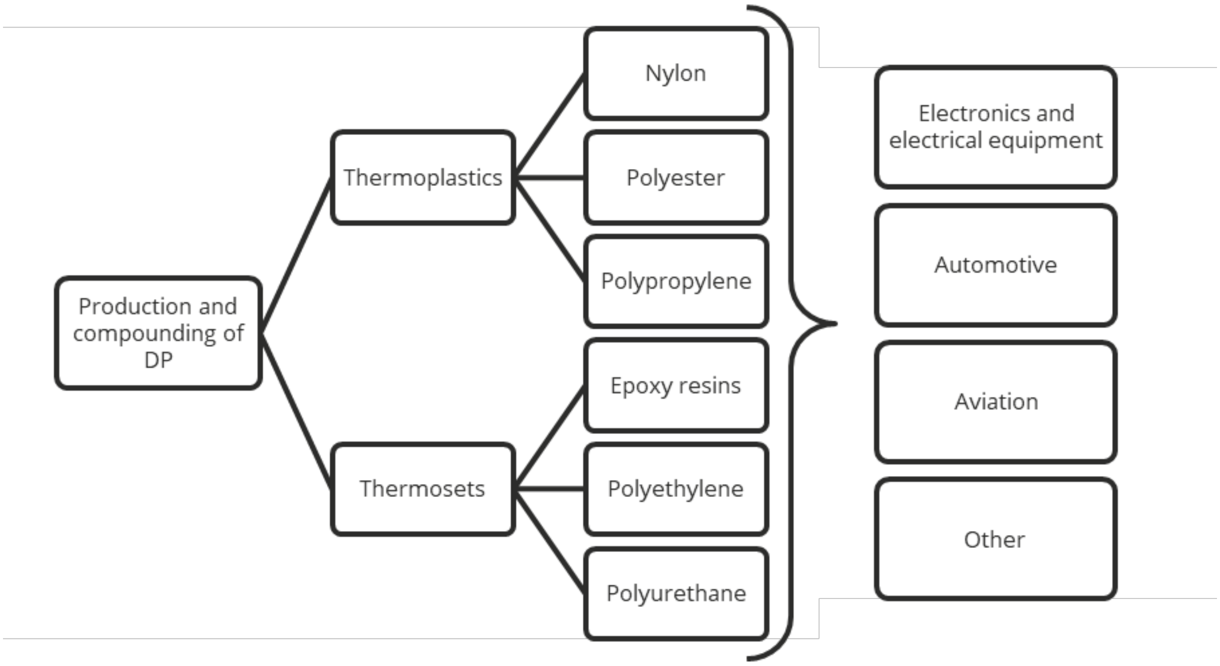

Figure 1.1: Flow chart of DP production and polymer compounding through to end uses identified during the literature review (non-exhaustive).

Historic and future trends

Publicly available data on the global manufacture and trade of DP is not detailed enough to conclude on any historic trends, and no market predictions have been found. DP has however been marketed as an alternative to decaBDE, which means that developments in the market for decaBDE may impact the sales of DP. DecaBDE was listed in Annex A under the Stockholm Convention on POPs which entered into force in 2019, which may lead to an increase in manufacture and trade of DP as substance, in mixtures or in articles in the near future.

Trade volumes of DP in articles

Information on global trade volumes in articles is limited, with available data only covering countries in Europe (EU) where the only available information is that DP is used in articles in volumes >10 t/y. More specifically, the background document for the ninth recommendation for the inclusion of substances in Annex XIV (i.e. ECHA, 2019a) states that "*the substance is used in articles in volumes >10 t/y, e.g. computers, electronics*", referring to the Annex XV SVHC report from 2017 (ECHA, 2017a).

In a Norwegian study of 67 different textile and plastic articles, DP was not detected in any of the consumer products investigated (LoD < 0.1-1.5 µg/g) (NEA, 2019).

1.2.2 Information from stakeholders

Stakeholder consultations constituted an important part of the data gathering for this report and the REACH EU restriction dossier (ECHA, 2021). In this process information was collected through:

- A stakeholder survey;
- Stakeholder interviews;
- An EU-focussed Call for Evidence (CfE) on ECHA's website[20]; and
- Other communications with stakeholders.

Despite significant efforts to engage with potentially affected stakeholders, the overall number of stakeholder responses was limited.

Manufacture of DP

Two stakeholders provided information on the manufacture and supply of DP. OxyChem previously manufactured DP, but their production in the U.S. ceased in 2017. There thus appears to be only one known global manufacturer of DP called ADAMA, which recently acquired the *Jiangsu Anpon Company Ltd*., and its manufacturing site is in China (ADAMA, 2019).

Associations representing the automotive Original Equipment Manufacturers (OEMs) and their supply chain (ACEA[21], CLEPA[22] and JAPIA[23]) all claimed much higher global tonnages than ADAMA – 1,000 t/y globally; which is split between 740 – 800 t/y remaining in Asia and 200 – 260 t/y being imported to the EU, according to information from their supply chain. The volumes have been reassessed three times ACEA, and they are confident that their reported volumes are correct.

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[20] Note that the CfE covers both EU and non-EU actors.
[21] ACEA is the European Automobile Manufacturers' Association
[22] CLEPA is the European Association of Automotive Suppliers
[23] JAPIA is the Japan Auto Parts Industries Association

Global manufacture volumes and volumes supplied to different regions according to different stakeholders are summarised in **Table 1.5**. One possible reason for the discrepancies in the cited tonnage data is that the stakeholders might be referring to different years. It was explained by the Dutch authorities, who participated in the open commenting round for the draft risk profile on DP under the Stockholm Convention on POPs, that the highest volume imported by ADAMA to the EU was 300 - 400 t/y, and that the import volumes were below 100 t in 2019 (POPRC, 2021). This implies that the global production volumes have recently been above 300 t/y. In October 2020, ADAMA updated their registration dossier reflecting that EU supply is now below 100 t/y (ECHA, 2020c).

Table 1.5: Global manufacture data and volumes placed on the EU market

Stakeholder	Global manufacture volumes (t/y)	Year	Regional supply (t/y)	Year
ADAMA - updated registration dossier	-	-	EU : 10-100	2020
ADAMA (information from the Dutch authorities (POPRC, 2021)	300	2019 and earlier	EU : 100 – 400	2019 and earlier
ACEA, CLEPA and JAPIA	1,000	2019 and earlier	EU: 200 – 260 Asia: 740 – 800	2019 and earlier

Uses of DP

Concerning the use of DP, key stakeholders in the industries affected (e.g., automotive, aviation and wire & cable) provided some information, thereby helping to extend the knowledge available in literature. Nevertheless, some important uncertainties – described further below – remain on tonnages used per application.

Data received from the automotive industry on use of DP in their sector

Stakeholders within the automotive industry reported that they use around 500 t/y globally, comprising 50% of the global volume manufactured. For the EU, the reported use volume was 130 t/y for the automotive industry. On the other hand, using the global volumes reported by the Dutch authorities to POPRC of 300 t/y (POPRC, 2021), the automotive sector use about 150 t/y of DP globally, i.e. less than half of what the industry itself claim to use. As explained above, some of the difference can likely be explained by stakeholders citing tonnage data from different years.

The main uses of DP mentioned by the automotive industry are set out in **Table 1.6**.

Table 1.6: Use of DP in the automotive industry

Use/application	Share of total volume
Electric wire (with wire harnesses being specifically mentioned)	80%
Plastic and rubber parts	8%
Tapes and adhesives	10%

Greases (extreme pressure agent)	2%

DP has two key functions when used in the automotive sector: (i) flame retardance, i.e. DP avoids the start or slows down the growth of fire, and (ii) seizure resistance, i.e. DP prevents seizure of metal parts in sliding parts.

Data received from the aviation industry

Uses of DP reported by aerospace industry stakeholders are:

- Epoxy adhesives;
- Syntactic foams;
- Potting compounds;
- 2-part epoxy void filler;
- Manufactured items for the production and maintenance of aircrafts and aircraft components (e.g. aircraft engines);
- Connectors;
- Wires/cables: and
- Other plastic components made from polypropylene, nylon, ABS etc.

Important substance properties mentioned by AIA / AIAC that make DP suitable for aerospace uses are its "*excellent flame-retardancy performance and thermal stability, along with its unique electrical performance*". The stakeholder, however, also states that "*there is not a clear understanding of DP's key technical functions for these uses as many of the applications or products that contain DP have been in use for several decades.*" Another stakeholder, Rolls Royce, highlights density, compressive strength, operating temperature, fluid resistance and shear strength as important substance properties.

No tonnage estimates for the global aerospace sector were provided but Rolls Royce informed that they use 0.13 t/y of DP, not including use by companies carrying out repair and maintenance for Rolls Royce.

Data received from the wires and cables industry

Wire and cable manufacturers are suppliers for the automotive-, aerospace- and consumer electronics industries. Europacable, the leading association for European wire and cable producers, stated that only one of its members uses DP, as most of the members do not supply wires and cables for use in vehicles. Europacable did not have any specific information on why DP is used, but the educated guess was that the harness dimensions needed to be small, whilst being flame retardant and highly flexible.

Data received from the consumer electronics industry

Bose Corporation stated that they imported articles containing DP in volumes of < 1 t/y, for the use in professional audio equipment. While it was stated that DP was important for their products, no other information like the function of DP in these products and the availability of any alternatives was provided.

Data received from the explosives industry

A respondent manufacturing or supplying manufacturers of explosives informed that > 90 % of DP used for explosives falls under the category *formulation*. The respondent also mentioned that product(s) containing DP are being phased out in the EU, with an expected decline of more than 10 % per year. However, globally, they expect an increase in the use of DP in explosives of between 0 and 2 % per year. No information on the function of DP was provided.

It was not stated what the explosives were used for but based on information from other sources (see Annex A.2.2. of ECHA, 2021); it seems likely that it relates to fireworks. This aligns with the information found in literature, detailed in Section 1.2.1.

Data received on end-of-life

The vehicle manufacturers associations ACEM (European Association of Motorcycle Manufacturers) and JAPIA (Japan Auto Parts Industries Association) and Rolls Royce have all indicated that they provide guidance on end-of-life disposal. ACEM indicated in their response that they provide guidance to end users on end-of-life disposal of each type of product containing DP, while JAPIA stated that their guidance is provided by the final product manufacturers. Rolls Royce stated that they dispose of aviation parts reaching their end-of-life via the use of licensed third parties, in accordance with industry best practice and environmental protection laws.

Data received on recycling

Important information on recycling was provided by the Bureau of International Recycling (BIR). BIR (directly or indirectly) represents over 30,000 recyclers in more than 70 countries around the world, including 36 associations. Company members of BIR collect, sort and process recyclables including plastics, e-scrap, rubber and tyres. According to BIR, the main issues for recyclers in terms of hazardous chemicals in wastes are:

- A lack of knowledge on which chemicals are present in products or in wastes; and
- A lack of economic means to identify and separate the waste containing hazardous chemicals, as well as removing the chemicals or materials containing it from the waste stream before recycling.

The industry does not support any derogations for manufacturers and downstream users of DP, as this pushes problems into the future and harms the prospects of recyclers. Legacy issues from chemicals already on the market were stressed in this respect.

Concentrations of DP in products/components

Information on concentrations of DP in relevant products/articles/materials provided by stakeholders is presented in **Table 1.7**.

Table 1.7: Concentration of DP in components in cars, motorcycles and explosives

Stakeholder name	Product/Application	Concentration (%)	Comment
JAPIA	Wire coating	13 - 20 %	< 0.1 % in final products
Rolls Royce	Individual component articles	< 0.1 - 6.5 %	-

ACEA	Wire coating and wire printed circuit board housing. Often but not exclusively used in PA 66[24].	13 – 20 %	Average purchase price for the materials: € 6 - 11 per kg
	Plastic and rubber parts (connector, board, case, bobbin)	13 – 20 %	Average purchase price for the materials: € 6 - 11 per kg
	Grease	20 – 25 %	-
	Tape and adhesive	5 – 30 %	-
ACEM	Electric wire, where DP is contained in the wire coating	13 – 20 %	-
	Plastic and rubber parts	13 – 20 %	-
	Grease	20 – 25 %	-
	Tape and adhesive	5 – 30 %	-
Explosives (unknown)	Explosives	0.1 %	-

1.2.3 Summary of information taken forward for the impact assessment

Due to conflicting information provided by different stakeholders, both at a global level and EU level, it has not been possible to reach a robust conclusion on the tonnage used by each sector and tonnage used in different applications. Instead, two different use patterns have been defined – a low tonnage and a high tonnage scenario – based on the information received. **Table 1.8** presents volume data (low and high) per sector, whilst **Table 1.9** show the breakdown per application. The volume data presented in these tables are used to derive the baseline, i.e. a forward-looking timeline for emission and use, which is set out in Section 2.3.2.

Table 1.8: Global volumes of DP per sector according to the stakeholder consultations

Sectors	Low volume scenario		High volume scenario	
	Share of total	Use volume (t/y)	Share of total	Use volume (t/y)
Automotive	75%	225	57%	565
Aviation	10%	30	10%	100
Other	15%	45	33%	335
All	**100%**	**300**	**100%**	**1,000**

Note: The low- and high-volume scenarios are based on information from different sources, which is why market

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[24] PA 66 refers to a polyamide commonly known as Nylon 66.

share as well as the tonnages of the sectors vary between the two scenarios.

Table 1.9: Global volumes of DP per use application

Uses		Share of total	Low-volume scenario (t/y)	High-volume scenario (t/y)
Polymers	Wire and printed circuit board housing, other plastic and rubber parts	93%	279	930
Adhesives etc.	Tape, adhesives, sealants	5%	15	50
Greases	Lubricant	2%	6	20
All		**100%**	**300**	**1,000**

1.3 Waste and disposal

Article 6 of the Stockholm Convention sets out measures for reducing or eliminating releases from POPs-containing wastes. According to this Article, Parties to the Convention shall take appropriate measures to handle, collect, transport and store such waste in an environmentally sound manner. POPs-containing waste, including products and articles upon becoming wastes, must be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs or otherwise be disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the POP content is low. Handling that may lead to the recovery, recycling, reclamation, direct reuse or alternative uses of POPs is not permitted.

Based on the confirmed uses (see mainly "*Uses of DP*" in Section 1.2.1), the waste streams that will most likely be affected by a regulation of DP under the Stockholm Convention are End-of-Life Vehicles (ELVs) and electrical and electronic equipment waste (WEEE).

Recycling of **ELVs** is a topic receiving global attention. With automobile ownership having increased substantially – at rates higher than global population growth – and having reached a volume of 1 billion vehicles as of 2010, handling of ELVs is becoming ever more important. Specifically, regulated recycling systems for ELVs are known to exist in Europe as well as several Asian countries, e.g. Japan, Korea and China. Other countries, e.g. the United States, regulate the recycling of ELVs under general environmental protection laws. Many of those countries aim for very high reuse, recycling and recovery rates, for example the EU aim for over 95% of the ELV to be reused, recovered or recycled, meaning that a maximum of 5% of the ELV should end up in landfill. The quota achievements must be proven under the Whole Vehicle Type Approval (WVTA) process (ACEA, 2015). Furthermore, as stated in the *Circular Economy Action Plan* (EC, 2020b); *"the Commission will also propose to revise the rules on end-of-life vehicles with a view to promoting more circular business models"*. Thus, the current recycling requirements for ELV recycling rates could increase in the future. However, in an impact assessment evaluation for the announced proposal for a revision of Directive 2000/53/EC on end-of-life vehicles the provisional conclusions are that the ELV Directive has largely delivered on its initial objectives (notably elimination of hazardous substances from cars, attainment of the recovery and recycling targets, increase in collection points for end-of-life vehicles). An important problem identified was however the large number of “missing vehicles”, which are not reported, and represent about 35% of estimated ELVs each year, so approximately 4 million vehicles per year[25]. This notwithstanding, in other areas, including those where the increase in automobile ownership is especially high, e.g. Asia, Central and South America, a legal framework for ELV recycling are lacking (Sakai et al., 2014).

The global volume of **electrical and electronic equipment waste (WEEE)**, which reached 44.7 million metric tonnes in 2016, is consistently increasing between 3-4% every year and is projected to reach 52.2 million metric tonnes in 2021 (Baldé et al., 2017). Treatment of this waste is concentrated in areas of the world where it is cheaper to process and recycle materials; at least 50% - 80% of WEEE arising in developed countries is shipped to developing countries (Kumar et al., 2017; ILO, 2012). Around 70% of all electrical and electronics waste is estimated to end up in China, with other common locations being India, Pakistan, countries in South-East Asia, e.g. Sri Lanka and Thailand, as well as West African countries – particularly Ghana and Nigeria (ILO, 2012).

With the objective of transforming waste into useable polymer streams, that only contain one or two polymers, plastics are separated from other waste at the initial stage and then sorted by polymer type and colour. Efficient sorting is crucial for ensuring that the material can be recycled, and that recycling is economically feasible (Shehu, 2017). When recycling plastics, higher purity of the targeted polymer type(s) and fewer impurities (due to other polymers, hazardous additives or impurities) is preferred to attain the maximum output. If polymer types and/or additives are mixed, then the quality of the recycling process will be reduced (EC, 2018). Effective sorting processes are therefore important tools to increase the output value of the recycled materials as well as ensuring compliance with chemicals regulations.

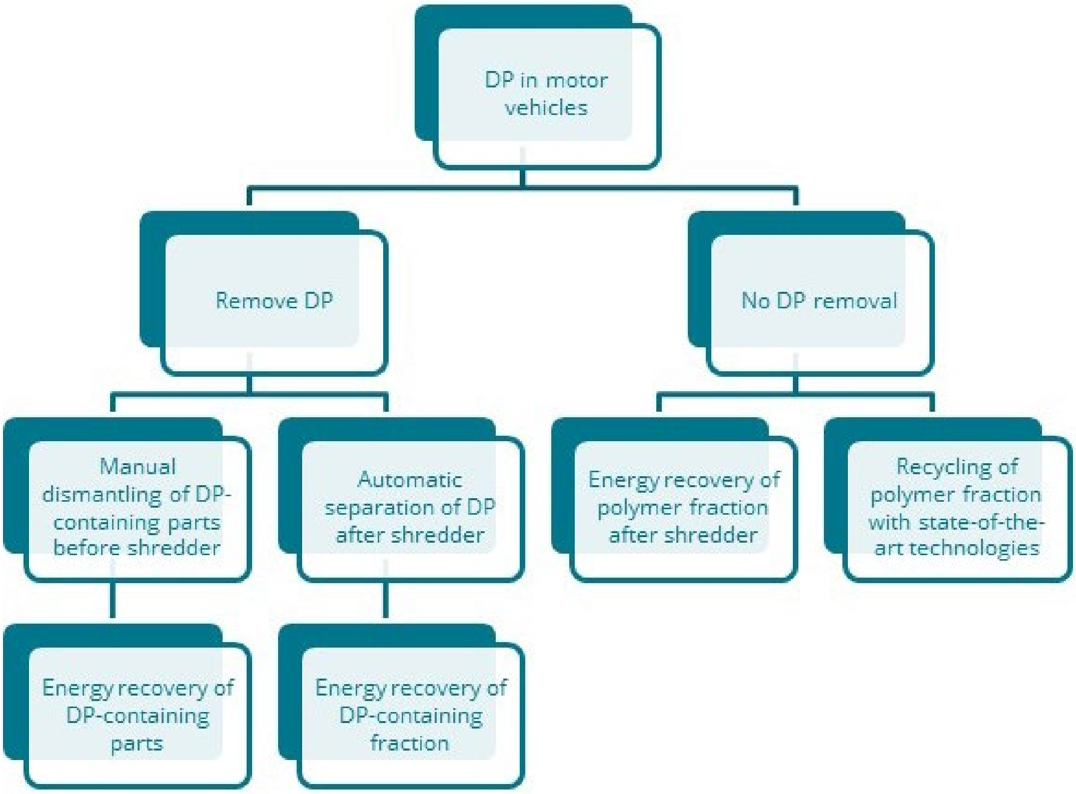
Within both aforementioned waste streams, ELVs and WEEE, plastic is the most likely material to contain DP. Global plastic use has increased rapidly since its introduction in 1950; 359 million tonnes of plastic was used in 2018. Although plastic use in Europe has stabilised at around 61.8 million tonnes (used in 2018), it is still rapidly increasing in other parts of the world (EEA, 2021). According to the European Strategy for Plastics in a Circular Economy, the most important plastic waste streams in the EU is by far plastic packaging (59%), followed by the category others (14%), electrical and electronic equipment (EEE) (9%), agriculture (5%), automotive (5%), construction and demolition (4%), and non-packaging household waste (4%) (EC, 2018).

The recycling process typically involves similar stages and techniques for plastics contained in both ELVs and WEEE, and consists of four general stages, i.e. (i) pre-treatment and dismantling, (ii) shredding, (iii) post-shredder treatment and (iv) recycling and recovery (Plastics Market Watch, 2016). Not all recycling processes undertaken globally are, however, undergoing such a sophisticated process. As mentioned above, a large share of WEEE is shipped from developed to developing countries and recycling is commonly undertaken in Asia and West Africa (ILO, 2012). After dismantling, primitive (often mechanical) methods are used to recover resources according to Wang et al. (2020). Those methods include open-burning, shredding and grinding, and are followed by final open dumping of residual materials (Wang et al., 2020). Recycling activities using such simple methods tend to be concentrated in small workshops (ILO, 2012). As a result,

[25] End-of-life vehicles – revision of EU rules*:* https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12633-Revision-of-EU-legislation-on-end-of-life-vehicles

and due to the often-limited regulation of the sector, strong concerns about the implications of recycling activities on human health and the environment exist (ILO, 2012). Developing countries are seen as "*shouldering a disproportionate burden of a global problem without having the technology to deal with it*" (ILO, 2012, p.9). As a result of often inadequate environmental awareness, regulations or monitoring, significant releases of DP might occur in these countries. However, due to the increased awareness of the environmental challenges posed by plastics waste, formal recycling activities is increasing in many countries and advanced large scale recycling facilities today also exist in some of these countries.

Information on options available for recycling ELVs and WEEE containing DP can be drawn from a presentation delivered by ACEA, the European Automobile Manufacturers Association, in relation to a regulation of decaBDE under the Stockholm Convention. At the 11th meeting of the POPRC in 2015, the association presented the waste treatment options shown in **Figure 1.2**. Given the similarity of uses of decaBDE and DP, it is likely that the available recycling options presented in relation to decaBDE and potential challenges encountered by the industry are broadly similar to the situation for DP.



Source: Figure adapted from figure in ACEA (2015)

Figure 1.2: Waste treatment options for motor vehicles

As shown in **Figure 1.2**, DP can be removed either during the dismantling stage where DP-containing plastics (e.g. wire harnesses) are separated from the parts not containing DP, or after the shredding of the vehicle where the auto shredder residue (ASR) goes through post-shredder treatment (PST). PST to remove DP from the waste material can involve a number of different techniques including separation technologies, such as float-sink tanks, magnetic separation, eddy current separators, or laser and infra-red systems. Sorting technology using x-ray fluorescence spectroscopy (XRF) is, as opposed to laser and infra-red technology, independent of the colour of the input plastics (TOMRA, 2019) and is used to separate polymers containing halogenated flame retardants from halogen-free polymers. The described steps and techniques are relevant to both the recycling of ELVs and WEEE. A more detailed description of commonly applied sorting and separation steps for WEEE and ELV waste can be found in a recent study on substances of concern in post-consumer plastics performed by Ramboll Deutschland on behalf of the Dossier Submitter (Ramboll, 2021 (in prep)).

According to ACEA (2015), selective dismantling before shredding is problematic as not all parts that contain DP can be identified and removed. Dismantling can furthermore cause a significant environmental footprint due to increased transportation of waste (ACEA, 2015). The Bureau of International Recycling (BIR) has also reported difficulties, both technically and economically, in detecting and removing materials containing flame retardants at the dismantling stage in the stakeholder consultation for the restriction proposal on DP under REACH.

The need for elaborated technologies for recycling plastics that contain hazardous substances is confirmed by EC (2018), which also stresses that the presence of hazardous substances can make recycling impossible or limit the share of recycled material contained in new products (with a view of ensuring that concentration thresholds for hazardous substances are not exceeded). The technical and economic feasibility of such technologies would, however, not be the only factors hindering the recycling of plastics. For ELVs, the low effectiveness of collection and pre-sorting and the missing market for recyclates are other factors hindering recycling mentioned by EC (2018). Similarly, EuRIC (2020) reports that the increasing complexity of multi-material vehicle design and a lack of demand for recycled plastics in the automotive sectors result in recycling currently being limited to high-volume polymers (e.g. PP, ABS, PS). Maisel et al. (2020) furthermore stress that recycling of WEEE plastics is not only a challenge due to the presence of harmful additives but also due to the highly complex plastic mixtures, which can consist of more than 15 different polymer types. Given the low quality of recycled plastics resulting from shredding and the possibly high level of contamination, EC (2018) notes that recyclers might rely on manual dismantling to remove parts containing hazardous substances, such as persistent organic pollutants. Furthermore, recycled plastics re-entering the market lose some of their physical properties after processing, and therefore cannot always be used for the same purposes e.g. vehicle manufacturing. The recycled plastics can however be used for other purposes. Recycled plastics from ELVs can, for example, be used for the production of vent tubes (Merkisz-Guranowska, 2018).

The option considered most suitable by ACEA is to use advanced technologies to recycle the polymer fraction. A current technique used for sorting and separation of ASR is the crude sorting by XRF combined with density separation that removes the "heavy" halogenated fraction (Chaqmaqchee et al., 2017). The technical feasibility of advanced polymer recycling will be determined by the allowed concentration limit in the recycled material (ACEA, 2015).

ACEA highlights that the high recycling rates required for end-of-life vehicles under EU law prohibits large-scale incineration. Furthermore, as indicated above the capacity of high-temperature incineration could be an issue for some countries due to the large volumes of wastes from EEE and the automotive sector (ACEA, 2015). The United Nations Industrial Development Organisation (UNIDO) has therefore recommended a variety of effective non-combustion techniques. These include methods suitable for destruction of POPs, e.g. gas phase chemical reduction and ball milling (UNIDO, 2007). The updated general technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with POPs under the Basel Convention lists Gas Phase Chemical Reduction as capable of destroying all POPs in its overview of technologies for the destruction and irreversible transformation of POPs in wastes (UNEP/CHW.14/7/Add.1/Rev.1. Tab 4). Electrochemical oxidation is another technique which has demonstrated the ability to destroy carbon bonds in perfluoroalkyl acids (PFAAs) (AECOM, 2018). In addition, cement kiln co-incineration can be used for high temperature incineration and this infrastructure is present in most countries. Cement kiln co-incineration is indicated as an environmentally sound method for destruction of POPs in the Basel Convention General Technical Guidelines for POPs (Basel Convention, 2020).

Techniques for sorting and separating out plastics containing halogenated POPs are commercially available and in use in several countries. These techniques, such as incineration, can also be used to destroy plastics containing DP. Incineration is the most widely used POP destruction technique due to its versatility and relatively low pre-treatment requirements (Defra, 2020). However, the common municipal waste incinerators operate at a minimum of 850°C, which may be too low for more thermally stable POPs. With respect to DP, it is likely that hazardous waste incinerators (which operate up to 1,200°C) will be required to completely destroy the POP. Moreover, these more specific methods for permanent destruction or irreversible transformation of DP are available but may not be accessible in all countries globally. Sorting and separating out DP containing plastics waste is the preferred option as this will allow for recycling of non-DP containing plastics and reduce the share of waste going to incineration. A careful balance between maximising recycling rates and destroying materials, where safe recycling is not feasible, to avoid releases to the environment should therefore be sought.

1.4 Releases to the environment

1.4.1 Introduction

A summary of the available information on sources of releases to the environment of DP is given in the draft risk profile for DP (POPRC, 2021) and its supporting information, as this was judged to be the most updated literature. This existing information is not reviewed again here, but a brief summary of the main points is provided for completeness.

DP is a very persistent substance and will have a very long residence time in the environment. It will build up over time and can be widespread in various environmental media. Monitoring results show that elevated DP levels can be found in urban areas and near point sources, such as wastewater treatment plants, as well as in humans and wildlife (POPRC, 2021). DP can enter the environment at any point during its lifecycle stages, thus sources of DP are likely to be, but are not limited to: manufacturing facilities; formulation facilities; industrial uses; releases over the service life of articles containing DP and releases from waste, for example e-waste recycling plants. See POPRC (2021) for more precise examples of DP sources in the environment.

The stakeholder consultation, which covered both the EU market and the global market, indicated that there is one current manufacturer of DP globally, located in China, and that globally DP is currently used in the following applications: (i) sealants and adhesives; (ii) use in polymers; and, (iii) use in greases. However, no information is available on releases to the environment from this manufacturing facility. This, notwithstanding, Hansen et al. (2020) estimated the global emissions of DP and its geographical distribution by using the Danish Eulerian Hemispheric Model to compare the resulting predicted concentrations of DP with measured DP levels in air in the Arctic. The authors estimate that emissions to water are larger than emissions to air, and that oceanic transport may be important in the coming decades.

The following sections provides a high-level summary of the global exposure assessments, whilst more details are provided in Section 3.1 (Technical Annex).

1.4.2 Methodology for estimation of releases

There is limited information on releases of DP to the environment that is publicly available. Moreover, no information indicating specific release factors of DP to the environment from the manufacturer or downstream users was received in the stakeholder consultation. As a result of this, generic release factors from ECHA Guidance R.16 (ECHA, 2016a) summarised in **Table 1.10**, were used. The exposure assessment approach is detailed in Section 3.1 (Technical Annex) . The approach has been aligned with that used in the REACH restriction dossier for DP (ECHA, 2021), where the main tool utilised is the European Union System for the Evaluation of Substances (EUSES 2.2.0 model) which assesses the risks posed by chemicals and estimates their environmental emission scenarios based on their pathway of direct releases into the environment (ECHA, 2019b). Only a summary of the approach is provided in this section, but the full REACH assessment and its methodology can be found in ECHA (2021).

For the emissions assessment, nine specific uses were analysed and the remaining releases were collated in the tenth use category: ‘other’. The release estimates were based on information on uses provided by stakeholders (see Section 1.2.2) and the ECHA Substance Infocard (accessed March 2021). The following uses have been assessed:

- Use 1: Formulation of sealants and adhesives;
- Use 2: Industrial use of sealants and adhesives;
- Use 3: Industrial use in polymers;
- Use 4: Formulation of greases;
- Use 5: Indoor use of articles containing DP over their service life;
- Use 6: Outdoor use of articles containing DP over their service life;
- Use 7: Dismantling and recycling of waste/articles containing DP;
- Use 8: Disposal of waste/articles containing DP by incineration;
- Use 9: Disposal of waste/articles containing DP by landfill; and,
- Use 10: Other sources.

It is important to note that there may be different uses of DP within some of these main areas of use, for example Use 3: Industrial Use in Polymers could cover uses such as use in plastic articles, electronic components and polymeric coatings used for cables and textiles. The available information does not allow the amounts used in these individual areas to be reliably quantified and so a generic approach has been taken, covering all of these applications. The manufacturing volumes used in this analysis is based on input data from stakeholders as presented above in Section 1.1.2.

Information on the potential releases of DP from polymer formulation and processing can be obtained from the OECD Emission Scenario Document (ESD) on plastics additives (OECD, 2009). The ESD provides a generic approach to estimate the releases of flame retardant additives such as DP from formulation (compounding) and processing (conversion) of polymers. A brief outline of the approach in the ESD and properties of DP that have been assumed in the exposure assessment are summarised Section 3.1 (Technical Annex).

The amount of flame retardant used at a typical polymer processing site can be estimated based on use volumes alongside the DP content of the polymer. The typical concentrations of DP found in various product types is presented in **Table 1.4**. The losses to the environment from the process(es) can then be estimated using the generic release factors from OECD (2009).

No new information has been identified on future trends. The amount released to the environment in the future is dependent upon the amount of the substance used in the future, along with any future risk management measures. It should also be noted that the use of DP is linked to the use of other alternatives including decaBDE. The global restriction on decaBDE, a substance which is used for many of the same applications for DP, entered into force for most parties to the Stockholm Convention in 2019, but several countries have registered for exemptions or have still not ratified the amendment[26] (POPRC-16, 2020). Furthermore, it is important to note that there is a historic "stock" of DP in articles and so there may be a delay before any changes in use can be observed as changes in the releases and environmental levels.

In terms of releases to the environment, the default release factors for the environmental release categories[27] (ERC) from ECHA Guidance R.16 (ECHA, 2016a) provides worst case estimates for the percentage of the substance used in each application that could be released from the process to air, water (before sewage treatment) and soil. These are summarised in **Table 1.10** for the relevant ERCs. These release factors give an indication of the relative release potential from the various processes but do not take into account the physico-chemical properties of the substance or any risk management measures that could be used in the process. In practice, the actual emissions from a process may be lower than these figures as a result of the actual operational conditions (OC) and risk management measures (RMM) used at a given site. This is particularly true for ERC 5, where the process leads to inclusion of the substance into an article.

Table 1.10: Default release factors for relevant ERCs from ECHA Guidance R.16 (ECHA, 2016a).

ERC	ERC description	Default release factor to air	Default release factor to water	Default release factor to soil
ERC 2	Formulation into mixture	2.5%	2%	0.01%
ERC 3	Formulation into solid matrix	30%	0.2%	0.1%
ERC 5	Use at industrial site leading to inclusion into/onto article	50%	50%	1%

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[26] National Implementation Plans transmissions:
http://www.pops.int/Implementation/NationalImplementationPlans/NIPTransmission/tabid/253/Default.aspx
Register for specific exemptions:
http://chm.pops.int/Implementation/Exemptions/SpecificExemptions/DecabromodiphenyletherRoSE/tabid/7593/Default.aspx

[27] Environmental release categories are important REACH use descriptors, used to define the release factors of a chemical substance in a specific use exposure scenario. These are used in modelling tools such as EUSES to derive environmental exposure estimates.

ERC 10a	Widespread use of articles with low release (outdoor)	0.05%	3.2%	3.2%
ERC 11a	Widespread use of articles with low release (indoor)	0.05%	0.05%	Not applicable
ERC 12c	Use of articles at industrial sites with low release	0.05%	0.05%	Not applicable

Release and exposure information related to the relevant ERC[28] or PROC[29], and any risk management measures necessary to control these releases/exposures, should be described further.

Other sources of generic exposure information are also available, including OECD Emission Scenario Documents and Specific Environmental Release Categories (SPERCs). The Association of the European Adhesive and Sealant Industry (FEICA) has developed SPERCs for the formulation and use of sealants or adhesives that can be used to determine the amounts of DP released to the environment, these are documented in **Table 3.3**. Where these SPERCs (specific release factors) are available and relevant to DP they have been used in preference to the default release factors from ECHA (2016a) in order to obtain more realistic estimates for the amounts of DP released to the environment.

The exposure assessment is given in two parts for each relevant lifecycle stage:

1) Firstly, the initial releases to air, wastewater and industrial soil[30] are estimated using generic exposure methods. This is carried out at the local (site), regional (highly industrialised area) and global scale.
2) The second part of the exposure assessment considers the distribution of the initial releases to wastewater in sewage treatment plants, estimated using the EUSES 2.2.0 model (ECHA, 2019b). The properties of DP mean that a large fraction of the substance entering into a sewage treatment plant (STP) will adsorb onto sewage sludge and this may subsequently be applied to agricultural land as a fertiliser and smaller fractions are distributed to air and water. Thus, this behaviour is taken into account in the estimated amounts released to air, water and agricultural soil following the STP (i.e. releases after wastewater treatment).

The predicted distribution of DP in a sewage treatment plant has been estimated using the EUSES 2.2.0 model (ECHA, 2019b) and is summarised in **Table 1.11**.

Table 1.11: Estimated distribution of DP in a sewage treatment plants

Distribution	Share of total DP in influent[31]
Percentage to air	0.1%
Percentage to water	7%
Percentage to sludge	93%
Percentage degraded	0%
Total	100%

The text below summarises the global exposure assessment, whilst the complete exposure assessment is in Section 3.1 (Technical Annex). DP enters the environment through releases to air, water, agricultural soil

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[28] *The Environmental Release Categories (ERCs) describe the processes from which releases to the environment could occur.*

[29] *The Process Categories (PROCs) describe the processes from which occupational exposure could occur.*

[30] *Direct releases to soil at an industrial site. ECHA Guidance R.16 indicates that such industrial soil is not itself a protection target, but the releases are taken into account at the regional scale.*

[31] *Influent refers to the wastewater flowing into a sewage treatment plant*

and industrial soil. **Table 1.12** and **Table 1.13** below shows the resulting releases to the environment after wastewater treatment, i.e. following the redistribution set out in **Table 1.11**.

As shown in **Table 1.12** manufacture of DP is by far the largest source of DP emissions with a share of around 54% of total emissions. The other main source of emissions is waste dismantling and recycling of products containing DP, which accounts for around 36% of total emissions of DP per year. The final two notable sources of DP emissions are landfill and polymer raw materials handling, compounding and conversation with shares of 4.3% and 3% respectively.

There is no information on DP emissions per sector, however it is assumed that the same pattern (of the automotive industry accounting for the majority of DP use) will repeat itself with respect to DP emissions. Thus, it is assumed that the automotive industry will be responsible for most of the DP emissions globally.

Table 1.12: Global emissions of DP after wastewater treatment, by primary emission source

Use	Total releases (kg/y)		Share of total
	Low	High	
Manufacture of substance	33,029	110,097	52.6%
Formulation of sealants / adhesives	4	292	0.1%
Industrial use of sealants / adhesives	255	1,000	0.5%
Polymer raw materials handling, compounding and conversion	1,825	6,156	2.9%
Formulation of greases	15	50	0.02%
Widespread use of articles over their service life - indoor use	265	882	0.4%
Widespread use of articles over their service life - outdoor use	955	3,185	1.5%
Waste dismantling and recycling	19,110	83,300	37.7%
Waste incineration	30	100	0.05%
Landfill	2,640	8,800	4.2%
TOTAL	**~58,000**	**~214,000**	**100%**

The estimated total global releases for DP are shown in **Table 1.13**. These include any direct releases to air and surface water and take account of the redistribution in the sewage treatment plants for emissions to wastewater. The releases were derived by adding up the contribution from each use scenario (Use 1 – Use 9), as detailed in Section 3.1 (Technical Annex). The table shows that agricultural soil and air are the largest transporters of DP. This is likely due to DP's affinity to bind to airborne particulate and organic compounds in soil. Industrial soil is often treated and then applied to agricultural land in order to boost levels of organic material – this is commonly referred to as sewage sludge.

Table 1.13: Estimated total global releases for DP after wastewater treatment

Releases to…	Lower estimate (kg/year)	Upper estimate (kg/year)	Share of total global releases
Air	34,600	135,000	62%
Water	6,020	20,200	10%
Agricultural soil	17,300	57,900	28%
Industrial soil	270	900	0.4%
Total	**58,100**	**214,000**	100%

A very recent study by Hansen et al. (2020) also estimated the global emissions of DP. The estimates were based on a global annual production of DP of 75-6,000 t/y (average assumed to be 1,980 t/y) and with two DP manufacturing plants (one in the United States and one in China). The emission estimates were carried out using emission factors for other flame retardants, pentabromodiphenyl ether and decabromodiphenyl ether, since no specific emission factors for DP are available. The exposure assessment by Hansen et al. (2020) considered releases to the environment from production of DP, production of plastics and electronics containing DP, indoor and outdoor consumer use of articles and waste management (recycling, incineration and landfill) of plastics and electronics. The study estimated the global releases of DP to air to be between 0.02 t/y and 3.2 t/y, 0.41 - 21.8 t/y to water, and 0 - 0.004 t/y direct to soil. Notably, the releases to air and soil estimated by Hansen et al. (2020) are significantly lower than the estimates calculated in this study (**Table 1.13**), more than 4,000 times lower and 19,000 lower respectively.

The very persistent nature of DP, suggests that past and current emissions will remain in the environment for a very long time, resulting in long-term exposures in sediment and soils. DP has a high adsorption potential, see ECHA (2021) for details. It is therefore expected to find DP in sewage sludge rather than in the water, either directly from industrial activities or indirectly via wastewater treatment systems, and eventually settle in depositional sediment areas (ECCC, 2019).

Manufacturing of DP have taken place in the U.S. and China, but no longer occurs in the U.S. and the only known manufacturing site for DP today is located in China. No information is available on the actual releases to the environment from the Chinese manufacturing site. A worst-case estimate of the releases from this manufacturing site can be obtained using the default release factors for ERC 1 – Manufacture of substances from ECHA (2016a). The assumptions and estimated releases are summarised in **Table 3.5**. It is important to note that the release estimate is based on worst-case default release factors and, as such, may significantly overestimate the potential for releases from the current manufacturing plant.

Temporal trends

Significant differences in information provided by stakeholders on supply and use of DP, i.e. reported range between 300 t/y – 1,000 t/y, may also indicate varying exposure to DP over time. There is no clear historic trend, but the estimated development in use and emissions are set out in Section 2.3.2.

The amount of DP released to the environment in the future is dependent upon the amount of the substance used in the future, along with any future risk management measures. It should also be noted that the use of DP is linked to the use of other alternatives including decaBDE. The global restriction on decaBDE, a substance which is used for many of the same applications for DP, entered into force for most Parties to the Stockholm Convention in 2019, but several countries have registered for exemptions or have still not ratified the amendment[32]. Furthermore, it is important to note that there is a historic "stock" of DP in articles and so there may be a delay before any changes in use can be observed within changes in the releases to the environment and concentrations in the environment.

1.4.3 Key uncertainties in the exposure assessment

Owing to a lack of site-specific exposure information, a generic approach closely aligned with ECHA Guidance R16 has been used for the exposure assessment. The approach involves a number of assumptions and, where appropriate, realistic worst-case assumptions have been used, in line with ECHA Guidance R16. Uncertainties in the use volumes, both at a given site (local scale) and globally, is another driving factor for the uncertainties in the results of the exposure assessment. The limited information on volumes used combined with the lack of information on fractions of DP released to air, water, and soil from the various processes using DP and lifecycle stages, creates significant uncertainties in the exposure assessment. The approach used is based on a combination of relevant release factors from OECD Emission Scenario Documents (ESD), industry Specific Environmental Release Categories (SPERCs) and default release factors from ECHA Guidance R16.

The situation within each use scenario will likely be different within the EU and globally. However, in the absence of any site-specific data in either region, using the described reasonable worst-case approach was deemed the most appropriate approach for both the EU REACH analysis as well as the global analysis for the Stockholm Convention. Using such an approach will typically lead to overestimated emissions, but in the absence of specific local or regional data, it is not possible to reach a robust conclusion on potential bias in the results.

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[32] National Implementation Plans transmissions:
http://www.pops.int/Implementation/NationalImplementationPlans/NIPTransmission/tabid/253/Default.aspx
Register for specific exemptions:
http://chm.pops.int/Implementation/Exemptions/SpecificExemptions/DecabromodiphenyletherRoSE/tabid/7593/Default.aspx

2. Socio-economic considerations

This section sets out:

- Approach taken for the socio-economic assessment (Section 2.3.1);
- Control measures available under the Stockholm convention (Section 2.1);
- Information on possible alternatives to the use of DP (Section 2.2); and
- Impacts on society from implementing possible control measures (Section 2.3).

Despite an extensive data collection exercise (literature review and stakeholder consultation in the EU and call for information from Parties and Observers under the Stockholm Convention) there is a lack of global data. The global assessment carried out here is based on a recent EU REACH restriction dossier (ECHA, 2021) that was prepared for a possible EU-wide restriction of DP.

2.1 Control measures for risk reduction

In the Stockholm Convention, an evaluation should be carried out regarding "*possible control measures for chemicals under consideration for inclusion in this Convention, encompassing the full range of options, including management and elimination. For this purpose, relevant information should be provided relating to socio-economic considerations associated with possible control measures to enable a decision to be taken by the Conference of the Parties*" (UNEP, 2017).

in May 2019, the Norway submitted a proposal to add DP to the Stockholm Convention on Persistent Organic Pollutants (POPs)[33]. To align risk management activities within the European Union and the Stockholm Convention, an Annex XV restriction dossier for DP in accordance with REACH Article 69(4) is being prepared by the Norwegian Environmental Agency (NEA). DP has also recently (October 2019) been recommended by the European Chemical Agency (ECHA) to be added to the REACH Authorisation List[34].

This section focuses only on indicating possible 'control measures' that could be undertaken under the Stockholm Convention. These would all apply at a global level, but it is recognised that additional regulatory action could also be carried out at national level (e.g. to enforce the requirements of any 'adopted control measure'). These further national level measures are not discussed in this section beyond this paragraph, with the focus being on what the global 'control measures' could be under the Stockholm Convention.

There is only one global producer of DP, but many users globally. According to **Table 1.12** around 54% of emissions come from the manufacture of DP. Listing DP in the Stockholm Convention with or without certain exemptions for production and use, will eventually reduce emissions of DP both from production and use due to voluntary measures in the industry and as a result of measures taken by parties to the Convention. The effectiveness of the Stockholm Convention in reducing these emissions will depend on how DP is listed in the Convention (in Annex A or B, see further explanation below), what exemptions are granted and the number of exemptions as well as their duration as well as the number. The effectiveness

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[33] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC15/Overview/tabid/8052/Default.aspx
[34] https://echa.europa.eu/-/echa-proposes-18-substances-for-authorisation/

of the Convention in reducing these emissions will also depend on the status of implementation i.e. for which countries the amendment that includes DP in the Convention has entered into force and at what time the amendment enters into force for these countries (i.e. some countries are so called "opt-in" countries that actively have to ratify each amendment to the convention while other countries are "opt-out" countries for which the amendments automatically enters into force unless they notify their intention not to ratify to the depositary of the Convention).

The next highest releases to the environment come from 'waste dismantling and recycling' (35.9%) and 'landfill' (4.3%). Listing DP in the Convention implies that also emissions of DP from these processes will also eventually decline. From Article 6 of the Convention it follows that wastes, including products and articles upon becoming wastes shall be handled, collected, transported and stored in an environmentally sound manner and disposed. Furthermore, wastes, including products and articles upon becoming wastes are not permitted to be subjected to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of persistent organic pollutants; and (iv) Not transported across international boundaries without taking into account relevant international rules, standards and guidelines; Additionally Parties shall endeavour to develop appropriate strategies for identifying sites contaminated by chemicals listed in the Convention and if remediation of those sites is undertaken it shall be performed in an environmentally sound manner. Again, the effectiveness of the Convention in reducing these emissions will depend on the status of ratification and entry into force for the Parties, but also on the low POP content value and technical guidelines on the environmentally sound management of wastes of wastes consisting of, containing or contaminated with persistent organic pollutant developed by the Basel Convention in close collaboration with the Stockholm Convention. Levels above the low POP value require the destruction/irreversible transformation of the POP content in wastes, including products and articles upon becoming wastes.

As set out in UNEP (2017) the possible control measures under the Stockholm Convention for a given chemical are as follows:

- (a) **Listing of the chemical in Annex A:** This would mean elimination of the production, use, export and import of the chemical. The Conference of the Parties might decide to provide for specific exemptions. It might also add provisions that would apply specifically to the chemical (as is currently done for PCBs in Part II of Annex A). These additional provisions can cover a wide range of control measures such as restriction of certain uses, labelling requirements, additional waste management requirements or provision of information to users along with a requirement to report on progress toward elimination at certain intervals;

- (b) **Listing of the chemical in Annex B:** This would mean restriction of the production, use, export and import of the chemical. If it decides to list the chemical in Annex B the Conference of the Parties will also specify acceptable purposes for continued use of DP. It might also add provisions that would apply specifically to the chemical (as is currently done for DDT in Part II of Annex B). These additional provisions can include the establishment of a register, a requirement to notify the Secretariat or other intergovernmental organizations regarding intent to use the substance, and a requirement for reporting on quantities used and conditions of use. Such provisions may also require the development and implementation of an action plan that includes the implementation of suitable alternatives and covers a wide range of control measures such as labelling or the provision of information to users;

- (c) **Listing of the chemical in Annex C:** This Annex is applicable only to unintentionally produced chemicals. Listing in Annex C would mean that the chemical would become subject to measures to prevent, reduce or eliminate the unintentional formation and releases of the chemical. The Conference of the Parties might also include any further amendments of Annex C that would be necessary to address the chemical (e.g., additional source categories, additional process control methods or additional pollution prevention options); and

- (d) Listing of the chemical in Annexes A, B and/or C also make the chemical subject to the control provisions of **Article 6 on stockpiles and waste**. These provisions in the Article include obligations to develop strategies for identifying products and articles in use that contain the chemical; to identify, to the extent practicable, stockpiles and waste; to manage such stockpiles safely; and to ensure that wastes are disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed.

Whilst in principle, DP can be listed in Annex A, B and C, **only listing on Annex A and B are deemed relevant (alongside provisions on stockpiles and waste under Article 6)**. Listing on **Annex C is not deemed relevant to consider as a control measure**, as DP is not known to be unintentionally produced.

In the remainder of this section, the option of listing DP on Annex A and B are introduced.

2.1.1 Annex A under the Stockholm Convention

DP is currently marketed as an alternative/replacement for decabromodiphenyl ether (decaBDE) and Mirex. Both decaBDE and Mirex are listed in Annex A to the Stockholm Convention (UNEP 2017) along with 15 other substances (UNEP, n.d.1). As indicated above, this control measure would eliminate the production, use, export and import of DP, and thereby prevent corresponding emissions from these activities. The Conference of the Parties (CoP) can decide for specific exemptions (e.g. on production and for specific uses) or to restrict the general exemptions laid down in paragraph 5[35] of Article 3 and notes (i)–(iii) of Annex A. Such exemptions will reduce the overall emission reduction capacity but will also reduce the costs to affected actors. In relation to exemptions, further consideration is given in the impact assessment (Section 1.4) on possible use-specific exceptions for DP and their impacts.

It is also possible to also add provisions that would apply specifically to DP (as is currently done for PCBs in Part II of Annex A). These additional provisions can cover a wide range of control measures such as restriction of certain uses, labelling requirements, waste management requirements or provision of information to users along with a requirement to report on progress toward elimination at certain intervals.

2.1.2 Annex B under the Stockholm Convention

As set out in UNEP (2017), there are currently two substances listed in Annex B (UNEP, n.d.2): (1) Perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride (PFOS) and (2) Dichloro-

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[35] *Article 3 Paragraph 3 states: "Except as otherwise provided in this Convention, paragraphs 1 and 2 shall not apply to quantities of a chemical to be used for laboratory-scale research or as a reference standard" (UNEP 2017).*

diphenyl-trichloroethane (DDT).

This control measure would restrict the production, use, export and import of DP, and reduce the emission from these sources. The CoP can specify acceptable purposes for DP, that will be listed in Annex B, for which manufacture, use and trade will still be permitted. As for Annex A, it might also decide to provide for specific exemptions or to restrict the general exemptions laid down in paragraph 5 of Article 3 and notes (i)–(iii) of Annex B. The emission reduction capacity of listing DP under Annex B would likely be lower than if listed under Annex A, but the costs to affected actors would also be reduced.

The CoP can also add provisions that would apply specifically to DP (as is currently done for DDT in Part II of Annex B). These additional provisions can include the establishment of a register, a requirement to notify the Secretariat or other intergovernmental organizations regarding intent to use the substance, and a requirement for reporting on quantities used and conditions of use. Such provisions may also require the development and implementation of an action plan that includes the implementation of suitable alternatives and covers a wide range of control measures such as labelling or the provision of information to users.

2.2 Alternatives

An assessment of alternatives was carried out in the preparation of the REACH restriction proposal for DP (ECHA, 2021), which is considered applicable also at a global level. The following section provides a summary of the assessment of alternatives, whilst the full assessment can be found in Section 3.2 (Technical Annex).

2.2.1 Introduction

A review of the literature and input from the stakeholder consultation indicates that there are two main functions that DP serves: (i) as an additive flame retardant; and (ii) as an extreme pressure (EP) additive in greases. These two separate and unique functions, and therefore two parallel assessments were carried out to identify feasible alternatives for both of these functions. Furthermore, the potential alternatives to DP would need to be technically and economically feasible but also have a favourable hazard profile to avoid regrettable substitution and subsequent regulatory action on the alternatives.

2.2.2 Approach and assessment of alternatives

As outlined in Section 3.2.2 (Technical Annex), the three general steps taken to screen the literature for potential alternative substances to DP were as follows:

- **Step 1**: An initial list of possible alternatives based on a review of existing literature was produced.
- **Step 2**: The suitability of these alternatives was assessed - again based on a review of existing literature.
- **Step 3**: Hazard criteria of the initial list of alternatives was used to screen out substances that are persistent, bioaccumulative and toxic (PBT) or carcinogenic, mutagenic or toxic for reproduction (CMR).
- Additionally, one last substance, chlorendic anhydride, was added to the shortlist, identified through Velsicol's website (Velsicol, 2020); Velsicol is the sole importer of DP in the EU.

Following this screening and shortlisting process, seven potential alternatives were chosen to undergo a more detailed assessment of availability, technical and economic feasibility as well as hazards to the environment and human health.

Four alternatives to DP as a flame retardant were shortlisted :

(i) aluminium hydroxide;
(ii) ammonium polyphosphate;
(iii) chlorendic anhydride; and
(iv) ethane-1,2-bis(pentabromophenyl) (EBP),

Three alternatives were identified for extreme pressure additive function:

(v) long chain chlorinated paraffins (LCCPs);
(vi) (vi) tricresyl phosphate (TCP); and
(vii) diallyl chlorendate.

2.2.3 Summary and conclusion from the assessment of alternatives

The assessment of alternatives indicates that there are three potentially suitable alternatives for DP when used as a flame retardant - ammonium polyphosphate, aluminium hydroxide and EBP. Two alternatives were found to be potentially suitable for DP when used as extreme pressure additive – LCCPs and TCP. The step-by-step approach and sources used to arrive at these alternatives is set out in the Technical Annex, Section 3.2.

There is some uncertainty as to whether these alternatives would be suitable for all applications within the uses set out. Generally, if alternatives that are equally effective and / or cheaper than DP are available, there is already an economic incentive for companies to switch to these alternatives regardless of whether a restriction is implemented or not. The fact that this has not been observed, may indicate that there are some further technical criteria not fulfilled that cannot be found by looking at the substance properties alone. Alternatively, or in addition, there could also be other costs (e.g. R&D and investments) not reflected in the cost of chemicals (price x loading) that might outweigh costs savings from purchase of chemical compounds. A third possibility is that some stakeholders have identified feasible alternatives but have not yet completed the substitution process.

The limited number of stakeholders that provided information on availability of alternatives, in the Call for Evidence (CfE) or the stakeholder consultation, indicated that there were no suitable alternatives presently available. However, none of the stakeholders provided the specific technical criteria that could not be fulfilled by other flame retardants or lubricants. In the absence of such information, it is not possible to reach a robust conclusion on the availability of suitable alternatives for all applications. Stakeholders may submit more detailed information in the public consultation on the REACH restriction proposal, which may allow for a more refined analysis of alternatives.

Table 2.1 summarises the conclusions from the assessment of alternatives carried out for the confirmed used of DP. Colour-coding has been used to indicate the level of suitability per category (i) Hazards, (ii) Technical feasibility, and (iii) Economic feasibility and availability, as well as for the overall suitability. The colours should be interpreted as follows:

🟩 **Clearly better**	🟢 **Potentially better**	🟨 **Potentially similar**	🔴 **Potentially worse**	🟥 **Clearly worse**

Table 2.1: Summary of assessment of alternatives

Substance	**Hazards**	**Technical feasibility**	**Economic feasibility and availability**	**Overall suitability**
Alternatives to DP as a flame retardant				
Aluminium hydroxide	🟩	🟨	🟩	🟩
Ammonium polyphosphate	🟩	🟨	🟢	🟩
EBP	🟨	🟨	🟩	🟩
Chlorendic anhydride	🟨	🟨	🔴	🔴
Alternatives to DP as an extreme pressure additive				
LCCPs	🟨	🟨	Unknown	🟨
TCP	🟨	🟨	Unknown	🟨
Diallyl chlorendate	🟨	🔴	Unknown	🔴

2.3 Impacts on society of implementing possible control measures

2.3.1 *Methodology*

A socio-economic analysis is a method used to identify, quantify and weigh pros and cons of an action (henceforth called benefits and costs) for society as whole. It is widely used in regulatory processes around the world. Several guidance documents for assessing benefits and costs of regulating chemicals under the EU regulation REACH are available. Due to the conceptual similarities between a restriction under REACH and a listing in Annex A or Annex B of the Stockholm Convention (effectively a restriction), the methodology set out in *Guidance on Socio-Economic Analysis – Restrictions* (ECHA, 2008) was deemed appropriate for the use in this assessment, albeit with the scope extended to the global level. 1 shows the general steps involved when developing a socio-economic assessment, which is mirrored in the ECHA (2008) guidance.

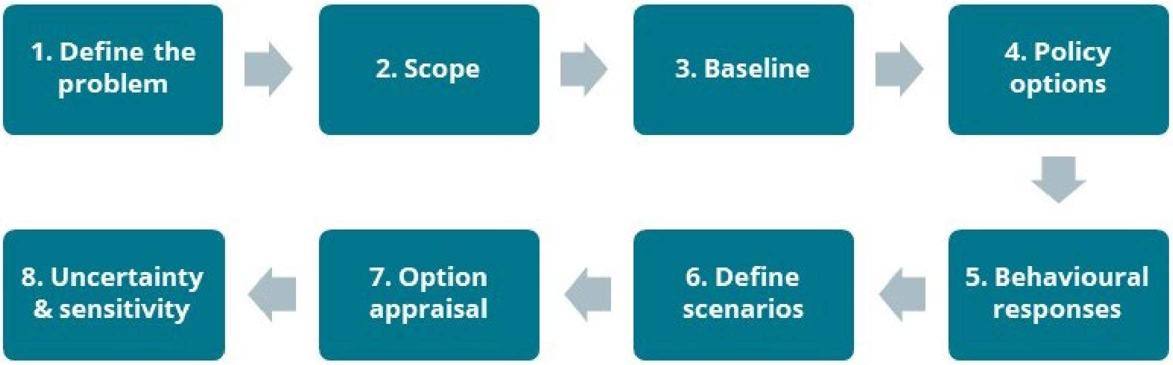

Figure 2.1: **Steps involved in a socio-economic assessment**

The data available at a global level is very limited, thus it has not been possible to carry out a full, standalone assessment of impacts associated with a listing of DP under the Stockholm Convention. Instead, this analysis closely follows the socio-economic analysis carried out as part of the preparations of the REACH restriction proposal for DP (ECHA, 2021). EU impacts have been extrapolated to the global level using the relationship (relative share) between the global and EU use volumes. For example, if a cost element for the EU was estimated at €1 million, the corresponding global estimate would be:

$$\text{global cost} = \text{€1 million} \times \frac{global\ use\ volume}{EU\ use\ volume}$$

This approach induces uncertainty in the global results, in addition to the uncertainties encompassed in the EU estimates, which means that the cost estimates presented in this report should be interpreted in terms of order of magnitude rather than an accurate global cost estimate. Despite these uncertainties it is believed that this approach is appropriate to use given the significant data limitations.

The complete step-by-step approach, including all input factors and assumptions used to derive costs in the REACH restriction proposal, is not detailed here, but can be found in Annex E and Annex F in the REACH restriction proposal (ECHA, 2021).

A complete socio-economic assessment would normally include a weighing of costs and benefits, also called an option appraisal or a proportionality assessment. A proportionality assessment was carried out in the REACH restriction proposal, but it has not been extended to the global level since proportionality of the costs of action is not directly considered under the Stockholm Convention.

2.3.2 Baseline

The “baseline” is the scenario in the absence of any global restriction or other control measures for risk reduction or interventions implemented to reduce the environmental risks from manufacture, import and use of DP. It is a projection for future DP volumes manufactured and used globally, and the corresponding projected releases of DP into the environment. The baseline scenario is the scenario all impacts are measured against and it is therefore fundamental for any socio-economic analysis.

The baseline was developed based on the data gathered on the manufacture and use of DP (summarised in Section 1.2.3) in conjunction with growth assumptions used in the socio-economic assessment carried out as part of the recent REACH restriction proposal (ECHA, 2021). The baseline covers the period 2023 – 2042 (hereafter: the analytical period), mirroring the baseline set out in the REACH restriction proposal.

Since manufacture and use are symmetrical, i.e. tonnes manufactured over time is equal to tonnes used over time, we will only focus on use in this section.

Baseline use volumes of Dechlorane Plus

The entry into force of the restrictions on decaBDE, both in the EU and the ongoing ratification process of the decaBDE listing under the Stockholm Convention, may result in increased demand and use of DP, as it is marketed as an alternative to decaBDE (ECHA, 2021). On the other hand, DP was not mentioned as an alternative to decaBDE at the time when the regulatory process was being decided. It is thus difficult to conclude what proportion of the market for decaBDE, that has not already switched to alternatives, could potentially be replaced by DP in the absence of further restrictions to DP. The analysis is therefore based on tonnage used as reported by stakeholders (reported in Section 1.2.2), and no major shift in demand, i.e. a sudden large increase in the use of DP, due to the phase-out of decaBDE has been included. In terms of market projections it was assumed that the split between volumes used in the EU and volumes used in other regions remains the same over the period analysed. Due to lack of information at a global level, it is not known whether this assumption will over- or underestimate the total volume used globally.

Based on the abovementioned assumptions, the average annual volumes used over the analytical period (2023 - 2042) were estimated to ~ 360 t/y in the low-use scenario and ~1,210 t/y in the high-use scenarios, with a central estimate[36] of 790 t/y. **Table 2.2** below shows the breakdown of use per sector for the central use scenario.

Table 2.2: Total (t) and average (t/y) global use of DP over the period 2023 - 2042

Sector/use	Total use (t), 2023-2042	Annual average use (t/y)	Share of total
Automotive	10,330	520	66%
Aviation	1,570	80	10%
Other	3,810	190	24%
All uses	**15,710**	**790**	**100%**

Note:

- Total volumes are rounded to nearest 10 t to avoid a false impression of precision. The sums may therefore not always add up.
- Annual averages were derived by dividing total use volumes by 20 (i.e. the analytical period).

Baseline emissions of Dechlorane Plus

The global emissions projections were developed considering the changes in use of DP over time, i.e. the baseline use volumes and the results from the exposure modelling set out in Section 3.1. It was assumed

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[36] *The central use volume scenario is here defined as a scenario that has a use equal to the average of the low-use scenario and the high-use scenario.*

that the market composition (shown in **Table 2.2**), in terms of uses and their market shares, remains constant over the analytical period. The corresponding projected emissions of DP over the analytical period (2023 to 2042) is shown in **Figure 2.2**. The central estimate is shown in green, whilst blue and orange represent the low and high estimates, respectively.

It should be noted that the emissions of DP were derived using a static exposure model (see ECHA, 2021), which implicitly assumes that emissions occur simultaneously with the use. This means that emissions from articles manufactured prior to 2023 are not included in the estimates, and future emissions (post 2042) resulting from service life, recycling and disposal of articles manufactured between 2023 – 2042 are allocated to the year of manufacture. The exclusion of emissions of historic use will lead to an underestimation of emissions over the analytical period, whilst the inclusion of future emissions from service life and disposal indicates overestimation. It is therefore not possible to conclude whether the baseline emissions are over - or underestimated.

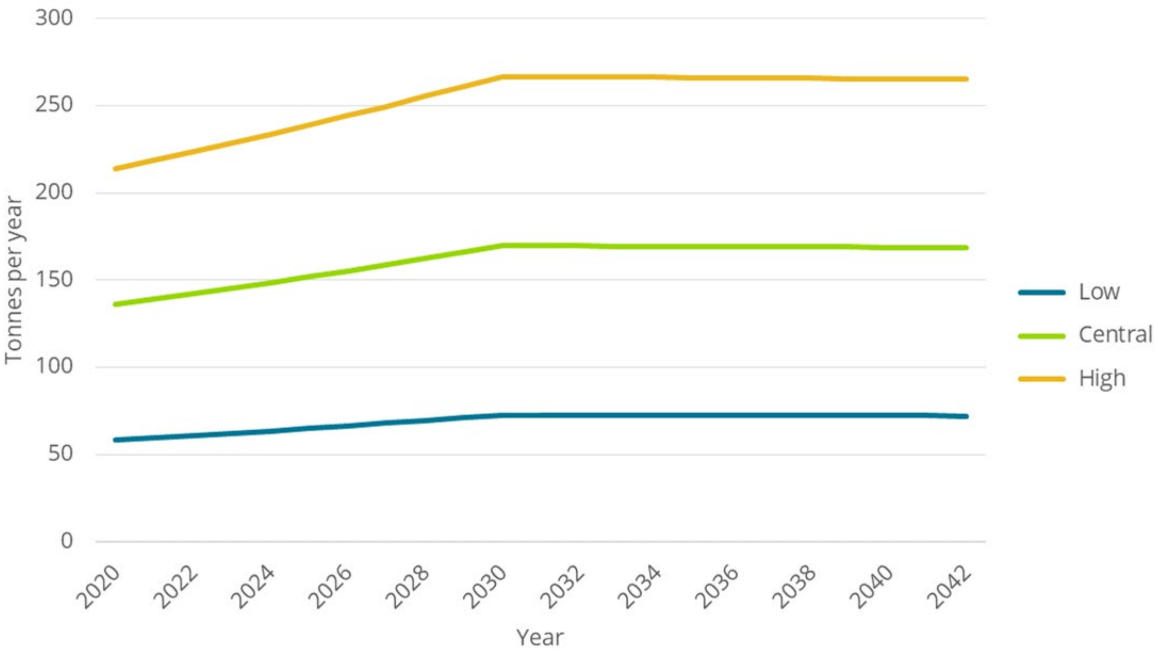

Figure 2.2: **Expected annual average emissions of DP over the period 2023 - 2042**

The total emissions of DP over the analytical period (2023-2042) and the average annual emissions were estimated based on the timeline presented in **Figure 2.2**. **The total global emissions of DP are estimated to be around 3,300 t** (central estimate) between 2023 - 2042 with average annual emissions of **160 t/y** for the central estimate. The *Low*, *Central* and *High* baseline emission estimates are shown in **Table 2.3**.

Table 2.3: **Total (t) and average annual (t/y) global emissions of DP over the period 2023 - 2042**

Baseline scenario	Total emissions (t), 2023-2042	Average annual emissions (t/y)
Low-volume scenario	1,400	70
Central volume scenario	3,290	160

High-volume scenario	5,170	260

Note:

- Volumes are rounded to the nearest 10 t to avoid a false impression of precision.
- Annual averages were derived by dividing total use volumes by 20 (i.e. the analytical period).

Table 2.4 shows the breakdown of emissions by sectors using DP, assuming that the volumes used by each sector remain the same over the whole analytical period (2032-2042).

Table 2.4: Total (t) and average annual (t/y) global emissions of DP (central estimate) for each use sector over the period 2023-2042

Sector/use	Total emissions (t), 2023-2042	Average annual emissions (t/y)	Share of total emissions
Automotive	2,160	110	66%
Aviation	330	20	10%
Other	800	40	24%
All uses	**3,290**	**160**	**100%**

Note: Volumes are rounded to the nearest 10 t to avoid a false impression of precision. Sums may therefore not always add up.

2.3.3 Impact assessment approach

An impact assessment is a tool which can help inform policy makers of the possible impacts associated with future regulatory action. It seeks to identify the most relevant costs and benefits of specific policy option(s), who benefits, and who bears the costs. It is rarely possible (or proportionate) to quantify and monetise all significant costs and benefits, so this impact assessment includes both an assessment of both quantified and unquantified costs and benefits. The absence of quantification of certain costs and benefits should therefore not diminish their relevance over those costs and benefits that have been quantified. The impact assessment conducted concludes with an overall assessment of the proportionality of different control measures, considering all relevant costs and benefits.

Control measures under the Stockholm Convention assessed

The impacts resulting from a global restriction on DP will depend on the stringency of the chosen restriction as well as the specific exemptions granted. The control measures available under the Stockholm Convention are described in Section 2.1.

As explained in Section 2.1, other control measures outside of the Stockholm Convention are not considered in this report, and within the Stockholm Convention listing DP in Annex C is not further considered, as there is no known unintentional production of DP.

Due to limited information that can be used to assess socio-economic impacts at a global level, it has not been possible to assess potential impacts related to a listing in Annex B. The socio-economic analysis thus focuses on listing in Annex A. A brief discussion on how the impacts may change if DP was listed under Annex B, is included in 2.3.5.

In the REACH restriction proposal (ECHA, 2021), three restriction options (RO1 – RO3) were investigated, shown in **Table 2.5**

Table 2.5: Restriction options assessed in the REACH restriction proposal (ECHA, 2021)

	RO1	RO2	RO3
A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF[37] + 18 months.			
(I) Derogation for aircrafts produced before:	None	EIF + 5 years	EIF + 10 years
(II) Derogation for motor vehicles produced before:	None	None	EIF + 5 years
(III) Derogation for spare parts for existing aircrafts/vehicles during their lifetime	None	Aircrafts: For aircrafts covered by the derogation in RO2 (I) Motor vehicles: For vehicles produced before EIF + 18 months	Aircrafts: For aircrafts covered by the derogation in RO3 (I) Motor vehicles: For vehicles covered by the derogation in RO3 (II)

Note:

- The provision in RO2 allows continued production of spare parts for the remaining lifetime of any motor vehicle manufactured before EiF + 18 months or aircraft manufactured before EiF + 5 years.
- The provision in RO3 allows continued production of spare parts for the remaining lifetime of any motor vehicle manufactured before EiF + 5 years and for any aircraft manufactured before EiF + 10 years.

The EU analysis (ECHA, 2021) was carried out for a 20-year analytical period (2023 – 2042) and it was assumed that the entry-into-force (EiF) date would be mid-2023 with an overall transition period of 18 months. This implies that manufacture and use of DP would have to cease by 2025, unless derogations are granted. Stakeholders from the automotive industry noted that 5 years were needed to successfully transition to alternatives. Information from the aviation sector was sparser, but some actors indicated that they had started the substitution process but would need at least 5 years before full transition would be achievable. No information indicating that an extended transition period was needed for any other industries were received. It was therefore assumed that users of DP outside the automotive and aviation industries have identified suitable alternatives (or are able to do so before the EiF + 18 months).

The impacts estimated for the EU restriction scenarios can serve as an indicator for the impacts of control measures of different stringency under the Stockholm Convention, when upscaled to the global market. Parallels can be drawn between the REACH restriction scenarios and the following example control options under the Stockholm Convention:

(i) Control Measure 1 (CM1): A listing under Annex A, without exemptions;
(ii) Control Measure 2 (CM2): A listing under Annex A, with specific exemptions as listed under RO2 in **Table 2.5** ; and
(iii) Control Measure 3 (CM3): A listing under Annex A, with specific exemptions as listed under RO3 in **Table 2.5** .

Due to limited information that can be used to assess socio-economic impacts at a global level, it has not

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[37] *EiF – Entry into Force - refers to the time when the legislation enters into force in the EU.*

been possible to assess potential impacts related to a listing in Annex B or Annex C. A brief discussion on how the impacts may change if DP was listed under Annex B is included in Section 2.3.5.

How affected companies might react to control measures

Affected companies (i.e. those using DP) who are faced with these global applied control measures have three main choices[38]:

- Switch to an alternative - This option is only available for the uses for which alternatives are available
- Temporarily cease parts of production until an alternative is found; or
- Permanently reduced production (full or partial closure).

A core difference between a global regulation and an EU regulation is that a global ban will not allow for relocation of companies between geographical regions in order to avoid regulation that is being imposed for a smaller geographical area, which means that either more substitution to alternatives to DP occurs globally or more production halts will occur under a global regulation (i.e. production is halted until companies are able to fully transition to an alternative to DP or permanently ceasing production). Furthermore, it is likely that there are larger differences between market actors operating globally than within in the EU market, where the largest differences are likely between developed and developing countries. The behavioural responses – the way affected actors will act - when faced with a global restriction on DP will therefore likely differ from that of an EU restriction, but the extent of these differences and how this will affect the overall impacts cannot be deduced due to lack of available global data. More information from stakeholders both within and outside the EU could reveal key differences that should be considered under the Stockholm Convention.

Impacts on the environment and human health

In 2018 DP was identified as a substance meeting the criteria of Article 57 (e) as a substance which is very persistent and very bioaccumulative (vPvB), both in accordance with the criteria and provisions set out in Annex XIII of Regulation (EC)1907/2006 (REACH) (ECHA, 2017b; 2021). DP is chemically stable in various environmental compartments with minimal or no abiotic degradation and is very bioaccumulative, which means that environmental stock may increase over time. The substance is also widely dispersed in both aquatic and terrestrial food chains including top predators (ECHA, 2021).

The ECHA Guidance for PBT/vPvB assessment (Chapter R.11) ECHA (2017d) states: "Experience with PBT/vPvB substances has shown that they can give rise to specific concerns that may arise due to their potential to accumulate in parts of the environment and
- that the effects of such accumulation are unpredictable in the long-term;
- such accumulation is in practice difficult to reverse as cessation of emission will not necessarily result in a reduction in substance concentration."

The toxicity of DP has not yet been thoroughly investigated, in particular with respect to effects upon long-term exposure (ECHA, 2017e). In their decision on the draft risk profile for DP the sixteenth meeting the

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[38] *The analysis does not consider non-compliance / illegal activities as a legitimate response, as this should be addressed through adequate enforcement*

Persistent Organic Pollutants Committee noted that the information on persistency, bioaccumulation and long-range environmental transport was conclusive, but the Committee was unable to reach agreement that the information on adverse effects was sufficient and agreed to defer its decision on the draft risk profile to its next meeting (UNEP/POPS/POPRC.16/9, Annex I, Decision POPRC-16/1). An intersessional process was set up to collect further information and to prepare a revised draft risk profile for consideration by the Committee at its seventeenth meeting.

DP has already been detected in human blood in studies from Europe, Canada and Asia. Furthermore, it has been shown that DP is transferred to the foetus during pregnancy via blood, and after delivery via breast feeding (POPRC, 2021). It is predicted that the environmental stock will increase if no risk reduction measures are introduced, due to the continued emissions under the baseline as shown in **Figure 2.2**. Since DP persists in the environment for a very long time and accumulates in humans and wildlife, effects of current emissions may be observed or only become apparent in future generations. Avoiding effects may then be difficult due to the irreversibility of exposure. The main benefits to society from a restriction of DP will thus be the avoidance of these potential transgenerational impacts on the environment and human health in the future, through reductions in emissions and exposure to these substances.

Emission reductions as a proxy for potential environmental benefits

Quantification of risks is not currently possible for substances that are persistent and bioaccumulative, which makes quantification of benefits challenging. However, the potential benefits will be linked to the environmental stock and therefore also reductions in emissions. SEAC is advising the use of emission reductions, in combination with factors of concern, including the level of persistence and bioaccumulation, long-range transport potential and uncertainty, as a proxy for potential future benefits (ECHA, 2008). The potential for to undergo long-range environmental transport potential combined with its persistent and bioaccumulative properties means that local control measures can be ineffective and that there is a risk of build-up of DP in remote and pristine areas.

For DP, factors which may indicate additional concern beyond its potential POPR properties include the wide dispersive use of the substance (ECHA, 2021). A wide dispersive use may result in exposure of DP to a considerable part of the population (workers, consumers, general public) and the environment.

As mentioned above, the concentrations of DP in environmental compartments will increase over time if emissions continue. The estimated half-lives of DP in soil have been predicted to be 10 years (Zhang et al., 2016), thus for practical purposes the increasing exposure due to continued emissions may be considered irreversible. It follows that it will take considerable time before cease of use of the substance, as a result of a listing under the Stockholm Convention, will lead to substantial reductions in the environmental stock. The resulting benefits associated with any reductions in environmental stock will therefore take place over a long time-period and may occur long after the end of the analytical period[39] for this socioeconomic assessment (see Section 2.3.2 Baseline). For the same reason, any reduction in environmental stock from historic use, which cannot be attributed to a listing under the Stockholm Convention, may occur within the analytical period. This real-life scenario is different to the modelled scenarios used as a basis this socio-economic assessment whereby all modelled emissions and modelled emission reductions resulting from

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[39] *Analytical period refers to the period over which the analysis is carried out, i.e. 2023-2041*

the use of DP and any regulations of this use fall within the analytical period. More specifically, as explained in Section 2.3.2, using a static exposure model means that the modelled emissions of DP occur in the same year as the modelled use of DP. Similarly, the modelled emission reductions will occur simultaneously with the cessation of use. This means that most of the modelled emission reductions will fall within the analytical period, and the total emission reductions are expected to be close to the actual, expected reductions in emission of DP under each control measure scenario.

2.3.4 Emission reduction capacity of the control measures

The dynamic aspects caused by the delayed response between emission reductions and reduction in environmental stock (described in Section 2.3.3) combined with emissions from service life (described in Section 2.3.2) makes modelling of changes in environmental stock particularly challenging. It is, however, no indication of bias in these uncertainties, and it is believed that the emission estimates are good indicators for the order of magnitude of the actual emissions and achievable emission reductions.

The drivers behind the emission reductions associated with each control measure (CM) is the entry into force (EiF) of the ban and the specific exemptions. Since the chosen CMs are aligned with the scope of the assessed restriction option in the REACH restriction dossier, the emission reduction capacities (% reduction compared to baseline emissions) of the EU measures are therefore deemed to be suitable indicators for achievable emission reductions under CM1 - CM3.

Figure 2.3 shows the modelled emissions (central estimate for each scenario) under the baseline (i.e. the scenario where no regulation of DP is implemented) and the three control measures. The results show that all of the control measures will result in substantial emission reductions, and by proxy, large expected benefits, with the strictest option (CM1) achieving a 91% reduction in emissions of DP.

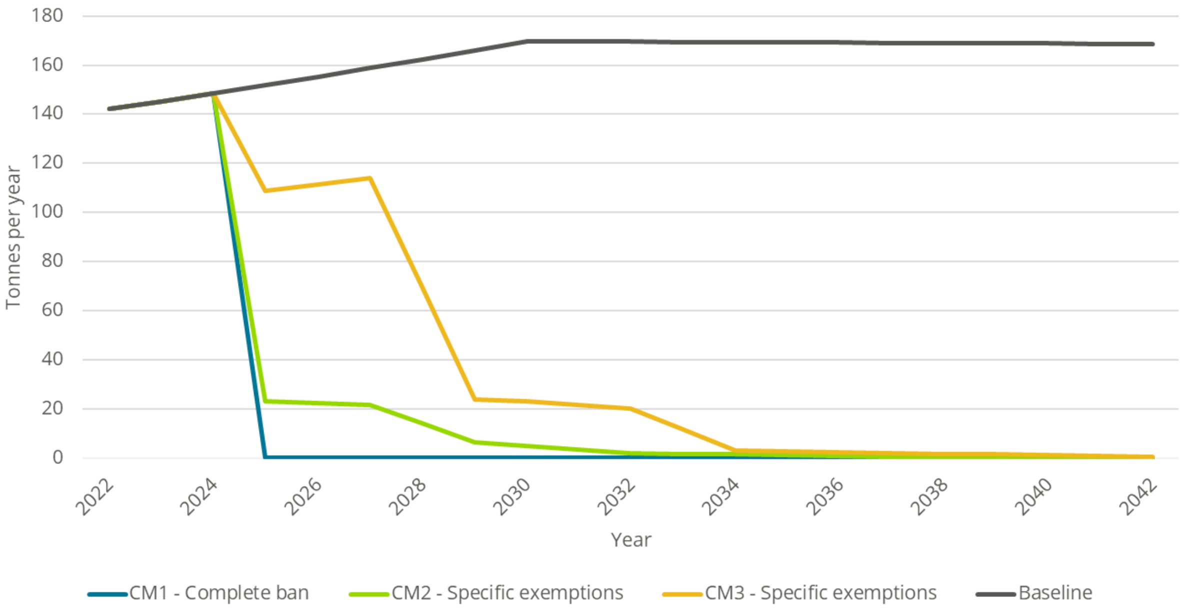

Figure 2.3: **Continued emissions (t/y) under the baseline (central estimate) and the three control measures over the period 2023 - 2042**

The estimated emission reduction capacities of CM1 - CM3 between 2023 – 2042 are presented in **Table 2.6**. The difference in emission reduction capacity between CM1 and CM2 is fairly small. The reason for this is that automotive industry, which is the by far largest user of DP, does not have an exemption for use in manufacture of new vehicles under CM1 or CM2. The only difference between CM1 and CM2 is that the latter includes an exemption for spare parts manufactured before the ban enters into force, which will only induce a small increase in total emissions.

Table 2.6: **Indicative emission reduction capacity for three control measures over the period 2023 - 2042**

No exemptions (CM1)	Specific exemptions (CM2)	Specific exemptions (CM3)
91%	88%	75%

By combining the emission reduction capacities of the CMs set out in **Table 2.6** with the baseline emissions derived in Section 2.3.2, the total achievable emissions reductions can be estimated. As explained above, the difference in reduction capacity between CM1 and CM2 is fairly small at <10 t/y. **Table 2.7** shows the estimated emission reductions per sector for each CM.

Table 2.7: **Annual emission reductions (t/y) of DP achievable under each control measure over the period 2023 - 2042**

Sector	No exemptions (CM1)	Specific exemptions (CM2)	Specific exemptions (CM3)
Automotive	100	97	83
Aviation	18	18	15
Other, including household electronics, construction	36	35	30

materials etc.			
Annual average reduction in emissions (t/y) – all uses	**154**	**150**	**128**

Using volume data to extrapolate from EU level impacts to global impacts (explained in Section 2.3.1) will induce uncertainty in the results. This is further detailed in Section 2.3.7.

2.3.5 Economic impacts

Limited information on the cost of substitution or other costs associated with restricting the manufacture and use of DP has been provided by stakeholders. Since the information is particularly sparse at a global level, the EU assessment of economic impacts carried out in the REACH restriction proposal was used a starting point.

As explained in Section 2.3.3, the restriction scenarios chosen for the EU analysis can be used as an indicator for certain control measures under the Stockholm Convention. The global market, however, is considerably larger than the EU market, and the economic impact are therefore likely to be larger as well. For the purpose of the quantitative assessment, it was assumed the economic impacts of a global regulation of DP will be closely linked to the volumes of DP used. The economic impacts estimated for the EU was then uplifted, using the relative share of use volumes globally and in the EU, to reflect the size of the global market (see formula set out in 2.3.1).

Considering the potentially large differences between markets in different regions, a simple upscaling of costs from EU estimates will induce significant uncertainties. It can be argued that many of the final products such as aircrafts and vehicles, but also parts of these, are part of a global market, and as such should have a similar overall value to society (global prices) for products of equal quality. However, production input factors, production processes, the quality of the end product, etc. may vary across regions, which means that the upscaled costs should be used as an indication of the order of magnitude of costs rather than absolute numbers. The estimates have also been rounded to highlight uncertainty in the analysis.

All costs are presented as an annual average over the 20-year analytical period, using a discount rate of 4%.

Substitution costs

Substitution costs is defined as including both any one-off or recurring costs directly associated with the substitution process, including R&D costs, investments, cost of raw materials (e.g. chemicals, water and other input materials) and energy costs.

In the analysis of alternatives it was concluded from a literature review that there could be several substances that are feasible alternatives to DP (see Section 2.2).The stakeholder did not provide information on any feasible alternatives, which either suggests that industry are not aware of such alternatives or simply did not volunteer the information in the consultation. This makes it difficult to reach a robust conclusion as to which substances (if any) are the most likely alternatives to be used if DP is listed under the Stockholm Convention. In the absence of information from stakeholders, the conclusions from the assessment of alternatives, including publicly available information on prices and loadings, was used to select and estimate costs associated with transitioning to alternatives. The resulting cost of substitution, upscaled to the global market, is shown in **Table 2.8**. The difference in cost of chemicals between the different control measures is so small that it is not visible when appropriate rounding is used publicly.

Table 2.8: Annual global cost of substitution(€ million per year) over the period 2023 - 2042

Sector	No exemptions (CM1)	Specific exemptions (CM2)	Specific exemptions (CM3)
Cost of chemicals, flame retardant	- 15 - 0	- 15 - 0	- 15 - 0
Cost of chemicals, greases	n/a	n/a	n/a
R&D and investment costs	> 0	> 0	> 0
Other operating costs	n/a	n/a	n/a
Total annual costs	**n/a**	**n/a**	**n/a**

Note:

- n/a indicates that neither value nor sign of the cost component can be established.
- Rounding reflects uncertainty in prices

Due to lack of information it has only been possible to quantify changes in cost of chemicals when used in flame retardants. However, the use of DP as a flame retardant in various applications is considered the main use accounting for 98% of the total use whereas uses in greases account for 2 % of the use. Interestingly, the estimated costs of using alternative flame retardants are overall lower than the costs of using DP (accounting for both price and loading, but not R&D, investments etc.), which means that cost savings are expected rather than increased costs. This means that either (i) the other cost elements outweigh these cost savings, (ii) the substances identified are not technically feasible for most uses, or (iii) the stakeholders are not aware that a feasible alternatives exists, e.g. because R&D has not been carried out to identify alternatives to DP.

Profits

If companies have to temporarily or permanently reduce the manufacture of products containing DP, this will be associated with profit losses. It is generally difficult to accurately estimate such losses as the reliance on DP and DP-containing products or parts may vary significantly throughout the supply chain. Again, no information was provided by stakeholders that could be used to derive potential lost profits following a global regulation of DP. The result from the REACH analysis was used in a similar manner - uplifting costs to the global market – as was done for the substitution costs.

The REACH analysis was based on publicly available information from Eurostat (PRODCOM and Structural Business Statistics). Profits linked to the sales of plastic parts and accessories for land vehicles, plastic parts for aircraft and space craft as well as insulation wiring (i.e. representing the main uses of DP) was considered at most risk of losing sales as a result of a restriction on DP (ECHA, 2021). No knock-on effects, e.g. profits lost for upstream users, was included.

The analysis is based on assumptions on the time necessary to substitute for each industry, and the share of the market that eventually will be able to move to an alternative (90% - 100% depending on the control measure) (ECHA, 2021). As a result, most of the profits lost are treated as temporary losses, occurring from the point at which the use of DP must cease until successful transition to alternatives.

Table 2.9 shows the potential profits lost in the global market, estimated by uplifting costs to the EU to the global market. The costs associated with a ban with no exemption **(CM1) are high at ~ €1.12 billion per year**, whilst **CM3 is more than 40 times lower at ~ € 30 million per year**.

The regional differences in profitability are expected to be much larger when looking at the global market, where on average, profitability is likely higher in the EU than in less developed countries. The upscaled estimates for potentially lost profits, shown in **Table 2.9**, may therefore be overestimated. On the other hand, knock-on effects, e.g. potentially lost profits in other parts of the supply chain has not been included, which could lead to an underestimation of the potentially lost profits. **Overall, it is not known whether the profits lost are over- or underestimated.**

Table 2.9: Potentially lost profits globally (€ million per year) over the period 2023 - 2042.

Sector	No exemptions (CM1)	Specific exemptions (CM2)	Specific exemptions (CM3)
Automotive	1,070	680	20
Aviation	170	30	10
Other, including consumer electronics, construction etc	0	0	0
Total profits at risk	**1,230**	**710**	**30**

Note: Numbers are rounded to the nearest €10 million to avoid a false impression of precision. Sums may therefore not always add up.

Employment

The impact on employment is closely linked to temporary and permanent reductions in production. The same approach as was used to estimate profits lost was also used to estimate effects on employment from a listing of DP under the Stockholm Convention, i.e. the EU results were uplifted to cover the global market.

Jobs lost will not be equally distributed across the analytical period but will be concentrated in the period before the majority of the market has transitioned to alternatives. It was therefore assumed that the total number of jobs lost was equally distributed between the entry-into-force date and successful substitution in the majority of the market. It was furthermore assumed that human resources will be redistributed over time, i.e. the job losses are considered temporary. Guidance provided by the Committee for Socio-Economic Analysis under REACH was used, which suggests that the total societal value of a job lost is "*around 2.7 times the annual pre-displacement wages*" (ECHA, 2008). Using PPP[40] adjusted values, the average world salary is close to that of the EU, ~€ 25,000 per year (Eurostat, n.d.)[41]. **It should, however, be highlighted that the distributional effects are significantly more 'severe' globally than in the EU**, e.g. due to larger variation in benefits received from the national government when losing a job. The upscaled societal value of potential jobs lost, shown in **Table 2.10** may therefore not be as representative for the global society as the cost of chemicals and potentially lost profits. The total number of jobs lost is presented

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[40] *Purchasing power parity*

[41] *Estimated by Patrick Belser, ILO economist in 2012, exchange rate for 2012 used before adjusting for inflation*

as an annual number by taking the total number of jobs lost and dividing it by 20 (the analytical period). In reality job losses are likely to occur between the entry-into-force date and when successful substitution to alternative to DP is possible by the majority of companies remaining in the market.

Table 2.10: Estimated annual jobs lost globally (average annual jobs lost) and their societal value (€ million per year) over the period 2023 - 2042

Sector	No exemptions (CM1)	Specific exemptions (CM2)	Specific exemptions (CM3)
Average annual number of jobs lost	1,810	1,020	40
Annual societal value of jobs lost (€ million/year)	90	50	2

Note: Numbers above €10 million are rounded to the nearest €10 million to avoid a false impression of precision

Total quantified economic impacts

Looking at the various cost elements analysed in above, it is clear that **the driver behind the costs of imposing a restriction on manufacture and use of DP are potential profit losses**. However, the most common approach to assessing *ex ante* costs of regulating chemicals is to use substitution costs, rather than profits lost. For example, in the decaBDE EU restriction proposal potential lost profits were not considered at all, neither qualitatively nor quantitatively. One of the reasons for omitting potential profit losses may be that it is difficult to accurately estimate these and/or that it is considered unlikely that a restriction will trigger such losses. **Generally, it is unlikely that significant profit losses will occur if technically and economically feasible alternatives exist and sufficient time to acquire the necessary authorisations (which may involve testing) is granted.**

Industry has at this stage in the regulatory process of DP under REACH, not provided any specific technical or economic reasons besides the lack of knowledge of any feasible alternatives. If feasible alternatives do exist (they are just not currently known to the companies in question or the companies have simply not provided this knowledge in the call for information), the time to substitute would be shorter than assumed in the analysis. As a result, a substantial part of the estimated loss in profit would be avoided under CM1 and CM2. If more information on substitution costs was available, in particular R&D and investment costs, such costs would have been the first-choice cost indicators, with lost profit used as supplementary information. In the absence of such cost information, lost profits were used as primary cost element. This creates a risk that the costs associated with CM1 and CM2 are overestimated. On the other hand, the omission of potential knock-on effects in the supply chain as well as the exclusion R&D and investment costs would lead to an underestimation of the costs. Stakeholders should therefore be further encouraged to provide information on available alternatives, the cost incurred to substitute, and the time necessary to transition to alternatives.

As shown in **Table 2.11**, the cost associated with the more stringent control measures are potentially high. However, the costs need to be considered in light of the abovementioned caveats of using potential profit lost as a core driver for costs.

Table 2.11: Estimated global costs (€ million per year) associated with the three control measures over the period 2023 - 2042

Type of costs	No exemptions (CM1)	Specific exemptions (CM2)	Specific exemptions (CM3)
Cost of chemicals, flame retardant	-15 - 0	-15 - 0	-15 - 0
Cost of chemicals, greases	n/a	n/a	n/a
R&D and investments	> 0	> 0	> 0
Potentially lost profits	1,230	710	30
Value of jobs at risk	90	50	<10
Total costs	**~ 1,310**	**~ 750**	**~ 20**

Note:

- All cost numbers are rounded in the same way as in previous tables. Sums may therefore not always add up.
- The mid-point for the interval presented for cost of chemical is used for the calculation of total costs.

Listing under Annex B

Another relevant control measure is to list DP in Annex B. The main difference between Annex A and Annex B as a control measures, is that a listing under Annex B allows for continued use for acceptable purposes. Specific exemptions, on the other hand, can be granted for listing in either Annex.

Stakeholders have indicated that there are uses for which DP is critical e.g. for the safety of a vehicle or aircraft. If it is not possible to find alternatives for these uses in the foreseeable future, it could be an option to define specific applications as acceptable purposes for continued use instead of granting a specific exemption. However, the information received on critical use was high-level, and it was not possible to deduce the exact applications referred to nor the specific functions or properties DP provides, and why alternative substances or techniques cannot be used instead.

Generally, a listing under Annex B would result in a less strict restriction on manufacture and use, and as such it can be expected that the costs would be lower. By similar argumentation it can be argued that the emission reduction capacity would also be lower. Without more detailed information on which applications could be considered an acceptable purpose for continued use of DP, no further analysis can be carried out.

2.3.6 Other, non-quantified socio-economic considerations

In any impact assessment there will always be impacts that cannot be quantified. This does not mean that these are more or less important than the quantified effects, but there might be lack of information or economic tools to allow for further assessment. These sections cover some aspects not covered in the quantitative assessment outlined above.

Avoided costs from measures potentially implemented in the absence of global regulation

Another aspect worth considering is that there are political goals in different regions for phasing out the use of POPs, PBTs, vPvB and other hazardous substances, and if DP is not listed under the Stockholm Convention, different countries could proceed with national/regional legislative measures. The economic burden on (some) industry actors may therefore be higher in the absence of global regulations. A listing of DP under the Stockholm Convention may thus induce indirect benefits in terms of avoided costs to industry from the adoption of differing national or regional risk management measures, by levelling the playing field in the global market.

If significant adverse impacts from exposure to DP occurs over time, in the absence of a global regulation, it is a possibility that some countries find it necessary to carry out remediation activities. Remediation, e.g. clean-up of contaminated soil, is typically associated with significantly higher cost than restrictions of manufacture and use, which is exemplified in Frans Oosterhuis and Roy Brouwer's report "*Benchmark development for the proportionality assessment of PBT and vPvB substances*" (IVM, 2015). Such remediation could potentially be avoided if DP is listed under the Stockholm Convention.

Enforceability

For articles placed on the market (i.e. except for derogated articles), enforcement authorities could check documentation from the supply chain confirming that the articles do not contain DP. In addition, it is envisaged they will verify if the articles contain DP by testing.

Analytical methods for qualitative and quantitative determination of halogenated flame retardants including DP, and its syn- and anti-isomers, have been described extensively in the literature in the past decade. Initial screening for chlorine in materials is reported using x-ray fluorescence (XRF) (Abbasi et al., 2016). However, XRF can only be used for crude identification because it does not distinguish chlorine (Cl) in polymers from Cl in DP. It is therefore typically used as first step for identifying materials for further assessment by more targeted approaches using mass-spectrometry or for crude sorting and separation of waste to separate out e.g. waste fractions heavily contaminated with halogenated compounds.

Precise determination and quantification of DP and its isomers have been reported in almost all environmental matrixes (Cheng et al., 2019b, Ganci et al., 2019b, Reche et al., 2019), including samples of human serum (Ren et al., 2011), and in consumer products, building materials and waste (Vojta et al., 2017) using quantitative target screening methods with reference standard solutions for identification and quantification. Typically, in such targeted approaches DP is extracted using solvent extraction and samples are cleaned up using standard column chromatography. Identification and quantification are usually determined using GC-MS or GC-MS/MS with negative chemical ionization. The level of quantification (LOQ) for these methods are typically in the range of 5 – 30 pg g^{-1} depending on matrix and sample preparation (Badea et al., 2020, Neugebauer et al., 2018). By applying high resolution mass spectrometry (HRMS) LOQs between 0.04 to 5 pg g^{-1} are reported depending on the sample preparation and matrices (Rjabova et al., 2018).

No international standard methods for determination of DP and its isomers exists today, but standards for determination of other halogenated flame retardants like bromophenyl ethers in different matrices like textiles, waste, electronic products and water are well established. These methods are based on the same analytical approach as used for determination and quantification of DPs. Reference standards for determination and quantification of DP are available online.

Costs associated with enforcement have not been estimated, but these are not expected to be significant in comparison to other cost elements that have been monetised.

Distributional effects

Distribution effects is the term used when negative impact on one actor or one country will be counterbalanced by an equal but positive impact on another actor or another region. For example, if one manufacturer loses profits but another manufacturer gains the same amount of profits the net effect to society would be zero, and the effect is simply a distribution of wealth from one actor to another. Even though distributional effects are not costs or benefits as such, they may still be important, in particular if the 'losing' actors or region are considered a vulnerable group or region.

Distribution between market actors

Information received in the stakeholder consultations indicates that the main sectors adversely affected by a restriction of the use of DP are the automotive and aviation industries. These are both large sectors with a strong foothold globally and are, as industries, therefore likely resilient too small to moderate changes in the market. The automotive industry reported that the original equipment manufacturers (OEMs) and their immediate suppliers are typically large corporations, whilst a large share of SMEs, which often manufacture 'simple' parts or materials, is found further down the supply chain. Although the industry as a whole is considered resilient, SMEs within the supply chain might be adversely affected, especially under CM1 and CM2. A risk is that smaller companies do not have the financial means for investments needed to transition to an alternative, nor withstand periods of production halts. Larger companies may therefore become more dominant in the market. It is not known whether the aviation sector has a similar structure as the automotive sector[42], but it is likely that similar impacts may be seen in this sector.

The most significant distributional effect associated with the control measure is the redistribution of market shares from late adopters (companies starting the substitution process late) to early movers. By implementing alternatives early, production halts may be avoided, creating a competitive advantage for early movers. These distributional effects are expected to occur under all control option but will be more significant with fewer derogations and shorter transition period(s).

It should be highlighted that distribution of profits to early movers is in general a positive aspect of regulations, as it creates incentives for the wider industry to be proactive in transitioning away from known, hazardous chemicals. These incentives may reduce costs of subsequent regulations, as lost profits and increased unemployment are less likely to occur if alternatives are known earlier in the regulatory process.

Regional differences

No information with respect to differences in the extent to which different regions are affected was received during the stakeholder consultation. In general, it can be expected that both economic impacts and impacts on the environment will vary between regions, but due to lack of data it has not been possible to robustly derive such differences.

2.3.7 Key uncertainties in the socio-economic assessment

The key uncertainties in the socio-economic assessment is related to the lack of robust data that could be

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[42] Given the similarities between DP and decaBDE in terms of uses, the risk management evaluation on decaBDE under the Stockholm Convention and the REACH restriction report were consulted in an attempt to identify information on the structure of the aviation sector. No relevant information could be identified.

used to develop the analysis. Since the global analysis is based on the analysis carried out in the REACH restriction proposal (ECHA, 2021), uncertainties in the socio-economic assessment prepared under REACH will also be carried over to the global estimates.

There were large differences in the total volume manufactured and used reported by stakeholders. These uncertainties are captured in the large tonnage band taken forward for both the exposure assessment and the socio-economic analysis. As noted in Section 1.1 and in Section 3.2), only a few uses of DP were verified in the stakeholder consultation. It may therefore be the case that additional uses of DP not reported in the stakeholder consultations exist, which means that the volume associated with the identified uses are also highly uncertain. Without further information from stakeholders on such uses, it is not possible to account for these uncertainties quantitatively. Other factors associated with use volumes, including short-term and long-term growth rates are less likely to induce significant uncertainties in comparison to the abovementioned uncertainties.

There are also uncertainties associated with assuming that the share of the total DP used in the EU and outside the EU will remain constant over time, however, these will have a marginal impact compared to the uncertainty in total volume induced by the differing information from stakeholders.

The estimated costs for the control measures are associated with a high degree of uncertainty mostly due to the lack of information on alternatives. It has not been possible to verify to what extent the identified alternatives are suitable for all uses, which makes it challenging to estimate the substitution costs of chemicals. For the same reason, it has not been possible to estimate R&D and investment costs which adds to the uncertainties in the total cost of substitution.

When there is stronger evidence for the existence of feasible alternatives, it is typical to only estimate the cost of substitution, i.e. it is assumed the no profit losses will occur. However, this is not the case for DP. If alternatives are not available, this may lead to significant costs, which is why it was chosen to include estimates for potentially lost profits. The profits at risk in the REACH restriction proposal were estimated based on Eurostat and PRODCOM data, but they also relied on a number of assumptions on behavioural responses, which are intrinsically uncertain. When extrapolating the costs to the global level, these uncertainties prevail, in addition to uncertainties arising from assuming that the profits associated with the use of DP is similar at a global level as in the EU.

Due to the lack of information on detailed alternatives, substitution costs and potential losses in sales, it is not possible to reduce these uncertainties any further. There is, however, no indication of a strong bias in the estimates (i.e. there is a balance in factors that could lead to overestimates and underestimates), so the results of this assessment are considered representative for the order of magnitude of potential impacts associated with a listing under the Stockholm Convention.

3. Technical Annex

This Annex presents the approach, input factors and assumptions used in the exposure assessment and the analysis of alternatives.

Section 1.4 set out the methodology and the aggregated results from the exposure assessment carried out for this study. Section 3.1 sets out further details on input factors and assumptions used, and presents resulting releases estimated for manufacture and all the nine uses.

Section 2.2 summarised the results from the analysis of alternative carried out as part of the REACH restriction proposal (ECHA, 2021). Section 3.2 below, presents the full analysis of alternatives, including approach, input factors and assumptions used.

3.1 Exposure assessment

Methodology for estimation of releases

Environmental releases for the nine different uses of DP have been estimated based on the ERCs given in the REACH registered substance factsheet and default release factors for these ERCs from ECHA Guidance or from other relevant sources (e.g. OECD Emission Scenario Documents). Exposure of DP occurs from releases to air and water from both points sources (e.g. industrial sites, dismantling plants) and via diffuse emissions. Subsequent distribution processes, such as adsorption to sludge, volatisation to air during wastewater treatment and atmospheric deposition of the airborne dust to soil from dismantling result in exposure of DP to air, water, sediment, soil and organisms. DP is also found in high concentrations in house dust, WWTP effluent and other (ECHA, 2017c, ComRef, 2019), indicating potential releases from the use of DP in articles.

Information on the potential releases of DP from polymer formulation and processing can be obtained from the OECD Emission Scenario Document (ESD) on plastics additives (OECD, 2009). The ESD provides a generic approach to estimate the releases of flame retardant additives such as DP from formulation (compounding) and processing (conversion) of polymers. A brief outline of the approach in the ESD and properties of DP that have been assumed in the exposure assessment are summarised below. **Table 3.1** outlines the physico-chemical properties of DP that were used in the exposure assessment.

Table 3.1: Properties of DP assumed in the exposure assessment (taken from ECHA, 2017e)

Property	Value
Molecular weight	653.73
Melting point	380°C
Boiling point	>380°C
Vapour pressure	4.6×10^{-4} Pa at 25°C
Water solubility	$\leq 1.67\times10^{-3}$ μ l^{-1} at 20°C
Henry's law constant	$\geq 1.39\times10^{5}$ Pa m^{3} mol^{-1} at 25°C
Log Kow	9
Log Koc	8
Biodegradation	Not biodegradable

Half-life in air (gas phase)	17 hours
Bioaccumulation parameters	ECHA (2017e) concludes that the substance is bioaccumulative but the actual bioaccumulation parameters are uncertain. For the exposure assessment the relevant bioaccumulation parameters have been estimated from the log K_{ow} using the default methods in the EUSES 2.2.0 programme.

The amount of flame retardant used at a typical polymer processing site can be estimated based on use volumes alongside the DP content of the polymer. The typical concentrations of DP found in various product types is presented in **Table 1.4**. The losses to the environment from the process(es) can then be estimated using the generic release factors from OECD (2009). The release factors relevant to DP are shown in **Table 3.2**.

Table 3.2: Generic release factors for DP in polymer processing from OECD (2009)

Process	Release factor to air	Release factor to water	Release factor to waste
Raw materials handling, powders of particle size <40 µm	0%	0.6% to solid waste/water	1% to solid waste as residue in bags
Raw materials handling, powders of particle size >40 µm	0%	0.2% to solid waste/water	0.01% to solid waste as residue in bags
Compounding, powders of particle size <40 µm.	0.001%	0.051%	Not applicable
Compounding, powders of particle size >40 µm.	0.001%	0.011%	Not applicable
Conversion, open processes, solid articles	0.005%	0.005%	Not applicable
Conversion, open process, foamed articles	0.01%	0.01%	Not applicable
Conversion, partially open processes	0.003%	0.003%	Not applicable
Conversion, closed processes	0.001%	0.001%	Not applicable
Article service life, indoor	0.05% over lifetime	0.05% over lifetime	Not applicable
Article service life, outdoor	0.05% over lifetime	$0.16\% \times T_{service}$	Not applicable
Disposal - landfill	0%	Not given	Not applicable
Disposal - incineration	0%	0%	Not applicable

Note: $T_{service}$ = service life of the article in years

The Association of the European Adhesive and Sealant Industry (FEICA) has developed SPERCs for the formulation and use of sealants or adhesives that can be used to determine the amounts of DP released to the environment. The SPERCs provide information on relevant operational conditions and risk management measures usually applied in the relevant industries, along with appropriate release factors associated with those conditions. The FEICA SPERCs are designed for use in exposure assessments carried out under the REACH Regulation and are available on the ECHA website[43]. The relevant release factors are summarised in **Table 3.3**.

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[43] *https://echa.europa.eu/csr-es-roadmap/use-maps/use-maps-library*

Table 3.3: Generic release factors from the FEICA SPERCs

SPERC	Process	Release factors			Comment
		Air	Water	Soil	
SPERC 2.1a.v3	Formulation of solvent-borne and solvent-less adhesives/sealants and construction chemical products – non-volatile substances	0.08%	0.02%	0%	Assumes equipment cleaned with organic solvent, washings are collected and disposed of as solvent waste
SPERC 2.2b.v3	Formulation of water-borne adhesives/sealants and construction chemical products – non-volatile substances	0.0097 %	0.505%	0%	Assumes equipment cleaned with water, washing disposed of with wastewater
SPERC 5.1a.v3	Industrial use of non-volatile substances in solvent-borne and solvent-less adhesives/sealants	1.7%	0%	0%	Assumes equipment cleaned with organic solvent, washings are collected and disposed of as external solvent waste. Mats used for scavenging overspray are disposed as external waste (no wet-scrubbing).
SPERC 5.1c.v3	Industrial use of non-volatile substances in water-borne adhesives/sealants	1.7%	0.3%	0%	Assumes equipment cleaned with water, washing disposed of with wastewater. Low amount of solid waste (mats used for scavenging overspray) is disposed as external waste (no wet-scrubbing).
SPERC 8c.3.v3	Widespread use of non-volatile substances in adhesives/sealants - indoor	0%	1.5%	0%	Assumes residues of products are cured in the container before discarded via household waste. Larger solvent washing volumes are collected and disposed of as solvent waste.
SPERC 8f.1a.v2	Widespread use of non-volatile substances in adhesives/sealants and construction chemical products - outdoor	0%	1.5%	0%	Assumes residues of products are cured in the container before discarded via household waste. Larger solvent washing volumes are collected and disposed of as solvent waste.

Note: In the SPERC, non-volatile substances are defined by a boiling point threshold of >250°C.

Manufacture

This section considers releases from manufacture of DP.

The only production site manufacturing DP is located in China. No information is available on the actual releases to the environment from this site. A worst-case estimate of the releases can be obtained using the default release factors for manufacture of substances (ERC1) from ECHA (2016a). Generic information on the release factors to the environment have been developed by the Association of the European Adhesive and Sealant Industry (FEICA) and are documented in FEICA SPERC 2.1a.v3 (for formulation of solvent-borne products) and FEICA SPERC 2.2b (for formulation of water-borne products) (FEICA, 2017a and 2017b). The input factors used to estimate releases from *Manufacture* are shown in **Table 3.4**.

Table 3.4: Input factors used to estimate releases to the environment from *Manufacture*

Input factor	Value	Comment
Total volume manufactured	300 – 1,000 t/y	See **Table 1.9**

Fraction released to air	0.05	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to wastewater	0.06	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to industrial soil[44]	0.0001	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction to solid waste	0.05	Default from ECHA (2012)

It is important to note that the release estimates are based on worst-case, default release factors, which may significantly overestimate the potential for releases from the current manufacturing plant. The estimated total releases before and after wastewater treatment are summarised in **Table 3.5**.

Table 3.5: Estimated global releases to the environment from *Manufacture*

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	15,000	50,000	kg/year
Wastewater	18,000	60,000	kg/year
Industrial soil	30	100	kg/year
Solid waste for disposal	15,000	50,000	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	15,000	50,000	kg/year
Water	4,650	15,500	kg/year
Agricultural soil	13,300	44,500	kg/year
Industrial soil	30	100	kg/year
Total	**33,000**	**110,000**	kg/year

Use 1: Formulation of sealants and adhesives

This section considers releases from industrial sites where DP is as a flame retardant in formulation of adhesives and sealants.

Environmental exposure is estimated in line with the ECHA (2016a) guidance. Generic information on the release factors to the environment have been developed by the Association of the European Adhesive and Sealant Industry (FEICA) and are documented in FEICA SPERC 2.1a.v3 (for formulation of solvent-borne products) and FEICA SPERC 2.2b (for formulation of water-borne products) (FEICA, 2017a and 2017b). The input factors used to estimate releases from *Formulation of sealants and adhesives* are shown in **Table 3.6**.

Table 3.6: Input factors used to estimate releases to the environment from *Formulation of sealants and adhesives*

Input factor	**Value**	**Comment**
Total volume	300 – 1,000 t/y	See **Table 1.9**
Share of total volume - sealants and adhesives	5%	See **Table 1.9**
Total volume in sealants and adhesives	15 - 50 t/y	
Fraction released to air - solvent borne	0.0008	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to air - water borne	0.000097	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to wastewater - solvent borne	0.0002	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3

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[44] *Direct releases to soil at an industrial site. ECHA Guidance R.16 indicates that such industrial soil is not itself a protection target, but the releases are taken into account at the regional scale.*

Fraction released to wastewater - water borne	0.00505	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to industrial soil	0	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction to solid waste	0.025	Default from ECHA (2012)

The total global releases before and after wastewater treatment, estimated using the assumptions set out in **Table 3.6**, are summarised in **Table 3.7**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.7: Estimated global releases to the environment from *Formulation of sealants and adhesives*

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	1	40	kg/year
Wastewater	3	253	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal	375	1,250	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	1	40	kg/year
Water	1	65	kg/year
Agricultural soil	2	187	kg/year
Industrial soil	0	0	kg/year
Total	**4**	**292**	kg/year

Use 2: Industrial use of sealants and adhesives

This section provides estimates of releases from industrial use of adhesives and sealants containing DP.

Environmental exposure is estimated in line with the ECHA (2016a) guidance. Generic information on the release factors to the environment have been developed by FEICA and are documented in FEICA SPERC 5.1a.v3 (for industrial use of solvent-borne products) and FEICA SPERC 5.1c (for industrial use of water-borne products) (FEICA, 2017c and 2017d). The input factors used to estimate releases from *Industrial use of sealants and adhesives* are shown in **Table 3.8**.

Table 3.8: Input factors used to estimate releases to the environment from *Industrial use of sealants and adhesives*

Input factor	Value	Comment
Total tonnage	300 - 1,000 t/y	See **Table 1.9**
Share of total volume - sealants and adhesives	5%	See **Table 1.9**
Total tonnage in sealants and adhesives	15 - 50 t/y	
Fraction released to air	0.017	Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction released to wastewater – solvent borne	0	Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction released to wastewater – water borne	0.003	Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction released to industrial soil	0	Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction to solid waste	0.05	Default from ECHA (2012)

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.9**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.9: Estimated global releases to the environment from *Industrial use of sealants and adhesives*

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	255	850	kg/year
Wastewater	0	150	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal	750	2,500	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	255	850	kg/year
Water	0	39	kg/year
Agricultural soil	0	111	kg/year
Industrial soil	0	0	kg/year
Total	**255**	**1,000**	kg/year

Use 3: Industrial use in polymers

This section provides release estimates for industrial use of DP during compounding and conversion of polymers containing DP.

Environmental exposure is estimated in line with the ECHA (2016a) and ECHA (2020) guidance. Generic information on the release factors to the environment have been developed and documented in the OECD Emission Scenario Document (ESD) for plastics additives (OECD, 2009)[45].

The emission factors in OECD (2009) depend, in part, on the substance particle size. Two ranges are considered, <40 μm and >40 μm and the release factor takes into account the potential for dust generation/emission for these two groups. There is a weight of evidence for the supply chain that the particle size of DP as a pure substance typically has a particle size <40 μm (e.g. the REACH Registration Dossier gives three measured values for average particle size below this value (ECHA, 2020c) and the OxyChem Manual reports three grades with average particle size below this value (OxyChem, 2007)). The input factors used to estimate releases from *Industrial use in polymers* are shown in **Table 3.10**

Table 3.10: Input factors used to estimate releases to the environment from *Industrial use in polymers*

Input factor	Value	Comment
Total volume	300 - 1,000 t/y	See **Table 1.9**
Share of volume used in polymers	93%	See **Table 1.9**
Total volume - indoor use of articles	279 - 930 t/y	
Fraction released to air – closed processes	0.00002	For powders <40 μm - OECD (2009)
Fraction released to air – partially open processes	0.00004	For powders <40 μm - OECD (2009)
Fraction released to air – open processes	0.00006	For powders <40 μm - OECD (2009)
Fraction released to wastewater – closed processes	0.00652	For powders <40 μm - OECD (2009)
Fraction released to wastewater – partially open processes	0.00654	For powders <40 μm - OECD (2009)

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[45] *Other methods are available for estimating the release of additives from plastics e.g. OECD (2019) and ECHA (2020). However, these a) are focused more on the release of additives over the service life of articles, b) require assumptions to be made over the plastics' properties (e.g. thickness and density) and c) require a substance-specific emission rate to be derived. Although these methods will provide more robust estimates of release rates from specific plastic types and thicknesses, they are less amenable for application in an overall generic exposure assessment that has been carried out here.*

Fraction released to wastewater – open processes	0.00656	For powders <40 µm - OECD (2009)
Fraction released to industrial soil	0	OECD (2009)
Fraction to solid waste	0.01	For powders <40 µm - OECD (2009)

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.11**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.11: Estimated global releases to the environment from *Industrial use in polymers*

Estimated releases of DP before wastewater treatment			
Estimated releases to…	**Lower estimate**	**Upper estimate**	**Unit**
Air	6	56	kg/year
Wastewater	1,820	6,100	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal	2,790	9,300	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to…	**Lower estimate**	**Upper estimate**	**Unit**
Air	7	60	kg/year
Water	470	1,580	kg/year
Agricultural soil	1,350	4,520	kg/year
Industrial soil	0	0	kg/year
Total	**1,820**	**6,160**	kg/year

Use 4: Formulation of greases

DP is used in greases for automotive uses. No specific information on the releases to the environment of DP from formulation of greases is available. OECD (2004) provides generic information on the formulation and use of greases and this has been used as the basis of the exposure estimation.

DP functions as an extreme pressure additive in greases. According to OECD (2004) greases containing extreme pressure additives are typically used in sealed-for-life systems in the automotive industry in applications such as wheel bearings, constant velocity joints, steering components etc. During use there is no leakage from such systems, and they do not need to be topped up. There is, however, potential for releases during formulation.

The potential for loss of additives from formulation of greases is discussed in OECD (2004). Losses to air from grease blending plants are very low. The worst-case loss of additives to drain is 0.25% assuming all of the additive loss partitions into water. The upper limit of the amount of waste grease generated is 1.5% as solid waste. This is disposed of (e.g. to landfill) but some may be re-used in low demand applications such as cheap anti-corrosion protection or for smearing onto paint-booths (OECD, 2004). It is not known if any waste grease containing DP is re-used in this type of application. Environmental exposure is estimated in line with the ECHA (2016a) guidance. As noted above, the formulated grease is used in sealed systems and so losses to the environment over the service life of such systems is minimal. The input factors used to estimate releases from *Formulation of greases* are shown in **Table 3.12**.

Table 3.12: Input factors used to estimate releases to the environment from *Formulation of greases*

Input factor	Value	Comment
Total volume	300 - 1,000 t/y	See **Table 1.9**
Share of total volume - greases	2%	See **Table 1.9**
Total volume used in greases	6 - 20 t/y	
Fraction released to air	0	Based on OECD (2004). Losses to air are very low.
Fraction released to wastewater	0.0025	Worst case estimate based on OECD (2004) assuming all of the additive partitions into water
Fraction released to industrial soil	0	Losses to soil expected to be low.
Fraction to solid waste	0.015	Based on OECD (2004)

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.13**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.13: Estimated global releases to the environment for DP from formulation of greases after wastewater treatment

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	0	0	kg/year
Wastewater	15	50	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal	90	300	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	0	0	kg/year
Water	4	13	kg/year
Agricultural soil	11	37	kg/year
Industrial soil	0	0	kg/year
Total	**15**	**50**	kg/year

Use 5: Indoor use of articles containing DP over their service life

As described in Section 1.2, DP is used in articles, e.g. within motorised vehicles, aircraft engines, computers and other electronics (ECHA, 2017b). DP is an additive flame retardant in such articles and there is the potential for releases to the environment over the articles' service lives. ECHA (2016a) provides a generic method of estimating the releases from such articles. This section considers releases of DP from indoor use of such articles.

Environmental exposure is estimated in line with the ECHA (2016a) guidance. The following assumptions have been made in the absence of other data.

- The industrial use of DP in polymers, greases, and sealants and adhesives will all lead to inclusion of DP in an article.
- Greases containing DP are generally used in sealed systems and so releases to the environment over the service life are minimal.
- The majority of the remaining articles containing DP will be used in indoor applications, or within

vehicles or aircraft that can be considered as similar to indoor applications). For the exposure estimation it is assumed that 90% of the amounts of DP in polymers and sealants/adhesives are in indoor applications (or used in conditions similar to indoor applications).

The input factors used to estimate releases from *Indoor use of articles over their service life* are shown in **Table 3.14**.

Table 3.14: Input factors used to estimate releases to the environment from *Indoor use of articles containing DP over their service life*

Input factor	Value	Comment
Total volume	300 – 1,000 t/y	See **Table 1.9**
Share of volume used in articles	98%	Total volume used in polymers and adhesives. See **Table 1.9**
Total volume used in articles	294 – 980 t/y	
Share of total volume used in articles that are used indoors	90%	Assumption
Total volume used in articles that are used indoors	265 - 882 t/y	
Fraction released to air	0.0005	Default for ERC 11a and ERC 12c (ECHA, 2016a) and OECD (2009)
Fraction released to wastewater	0.0005	Default for ERC 11a and ERC 12c (ECHA, 2016a) and OECD (2009)
Fraction released to industrial soil	0	Default for ERC 11a and ERC 12c (ECHA, 2016a) and OECD (2009)
Fraction to solid waste/recycling	1	Default from ECHA (2012).

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.15**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.15: Estimated global releases to the environment from *Indoor use of articles containing DP over their service life*

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	132	441	kg/year
Wastewater	132	441	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal	265,000	882,000	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	132	441	kg/year
Water	34	114	kg/year
Agricultural soil	98	327	kg/year
Industrial soil	0	0	kg/year
Total	**265**	**882**	kg/year

An estimate for the amount of DP from commercial and consumers products in Canada of 5 kg/year has been reported by ECCC (2019). This was based on a 2011 estimate for the upper limit of the import quantity in Canada of 10,000 kg of DP and assuming a release rate of 0.05% per year over the service life of the products. The estimate was considered by ECCC (2019) to be highly uncertain.

Use 6: Outdoor use of articles containing DP over their service life

As described in Section 1.2, DP is used in articles, e.g. within motorised vehicles, aircraft engines, computers and other electronics (ECHA, 2017b). DP is an additive flame retardant in such articles and there is the potential for releases to the environment over the articles' service lives. ECHA (2016a) provides a generic method for estimating the releases from such articles. This section considers releases of DP from outdoor use of such articles.

Environmental exposure is estimated in line with the ECHA (2016a) guidance. The following assumptions have been made in the absence of other data.

- The industrial use of DP in polymers, greases, and sealants and adhesives will all lead to inclusion of DP in an article.
- Greases containing DP are generally used in sealed systems and so releases to the environment over the service life are minimal.
- The majority of the remaining articles containing DP will be used in indoor applications, or within vehicles or aircraft. For the exposure estimation it is assumed that up to 10% of the amounts of DP in polymers and sealants/adhesives are in outdoor applications.

The input factors used to estimate releases from *Outdoor use of articles over their service life* are shown in **Table 3.16**.

Table 3.16: Input factors used to estimate releases to the environment from *Outdoor use of articles containing DP over their service life*

Input factor	Value	Comment
Total volume	300 - 1,000 t/y	See **Table 1.9**
Share of volume used in articles	98%	Total volume used in polymers and adhesives. See **Table 1.9**
Total volume used in articles	294 – 980 t/y	
Share of total volume used in articles that are used outdoors	10%	Assumption
Total volume used in articles that are used outdoors s	29 - 98 t/y	
Fraction released to air	0.0005	Default for ERC 10a (ECHA, 2016a) and OECD (2009)
Fraction released to wastewater	0.032	Default for ERC 10a (ECHA, 2016a) and OECD (2009)
Fraction released to industrial soil	0	Default for ERC 10a (ECHA, 2016a) and OECD (2009)
Fraction to solid waste/recycling	1	Default from ECHA (2012).

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.17**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.17: **Estimated global releases to the environment from *Outdoor use of articles containing DP over their service life***

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	15	49	kg/year
Wastewater	941	3,140	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal	29,400	98,000	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	15	51	kg/year
Water	243	810	kg/year
Agricultural soil	697	2,320	kg/year
Industrial soil	0	0	kg/year
Total	**955**	**3,180**	**kg/year**

Use 7: Dismantling and recycling of waste/articles containing DP

As described in Section 1.2, DP is used in articles, e.g. within motorised vehicles, aircraft engines, computers and other electronics (ECHA, 2017b). Many of these articles may be dismantled or shredded prior to, or as part of, recycling or waste disposal operations (see Section 1.3).

OECD (2004) gives generic information on the potential losses to the environment from vehicle dismantlers. Typically, vehicle dismantlers will drain off all fluids (e.g. engine oils, radiators, gearboxes, back axles) prior to dismantling or scrapping the vehicle. However, grease in sealed bearings is not removed during vehicle dismantling but is scrapped with the vehicle. Therefore, the potential for releases of DP from automotive greases during vehicle dismantling is low. The scrapped components are either re-melted (during which the DP will be essentially destroyed) or disposed of to landfill.

There are a number of publications available that show that releases to the environment can occur during recycling/dismantling or shredding processes (e.g. Wang et al., 2016; Yu et al., 2010; Gravel et al., 2019 and other references in the draft POPs risk profile for DP (UNEP/POPS/POPRC.16/2). For the assessment it is assumed that between 65% and 85% of the articles containing DP may undergo shredding/mechanical size reduction of some sort prior to recycling or ultimate disposal. This is based on the recycling figures for WEEE and ELV, and assuming that the recycling is carried out mainly be shredding (ECHA, 2021).

Following dismantling, polymers containing DP may be subjected to recycling. The potential for releases to the environment from polymer recycling is similar to that for the production of virgin polymeric materials and are covered under the exposure estimate for industrial use in polymers (ECHA, 2012). Dismantled articles may also be disposed of by landfill and incineration (see the specific exposure scenarios for these).

The input factors used to estimate releases from *Dismantling and shredding of waste articles containing DP* are shown in **Table 3.18**.

Table 3.18: Input factors used to estimate releases to the environment from *Dismantling and shredding of waste articles containing DP*

Input factors	Value	Comment
Total volume	300 - 1,000 t/y	See **Table 1.9**
Share of volume used in articles	98%	Total volume used in polymers and adhesives. See **Table 1.9**
Total volume used in articles	294 – 980 t/y	
Share of articles undergoing shredding	65% - 85%	Assumption
Total volume undergoing shredding	191 - 833 t/y	
Fraction released to air	0.1	Default from ECHA (2012)
Fraction released to wastewater	0	Default from ECHA (2012)
Fraction released to industrial soil	0	Default from ECHA (2012)
Fraction to solid waste/recycling	0	Default from ECHA (2012)

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.19**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.19: Estimated global releases to the environment from *Dismantling and shredding of waste articles containing DP*

Estimated releases of DP before wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	19,100	83,300	kg/year
Wastewater	0	0	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal / recycling	0	0	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to...	**Lower estimate**	**Upper estimate**	**Unit**
Air	19,100	83,300	kg/year
Water	0	0	kg/year
Agricultural soil	0	0	kg/year
Industrial soil	0	0	kg/year
Total	**19,100**	**83,300**	**kg/year**

Use 8: Disposal of waste/articles containing DP by incineration

The ultimate disposal of waste/articles containing DP will be by incineration or landfill. This section considers incineration.

Environmental exposure is estimated in line with the ECHA (2016a) and ECHA (2012) guidance. Ultimately articles (including recycled articles) and other waste will eventually be disposed of by either incineration or landfill. The split between these two disposal routes is not known for DP and for the exposure estimation it has been assumed that 50% are ultimately disposed of by incineration and 50% are ultimately disposed of to landfill.

The input factors used to estimate releases from *Disposal of waste/articles by incineration* are shown in **Table 3.20**.

Table 3.20: Input factors used to estimate releases to the environment from *Disposal of waste/articles containing DP by incineration*

Input factor	Value	Comment
Total volume	300 - 1,000 t/y	See **Table 1.9**
Share of volume used in articles	98%	Total volume used in polymers and adhesives. See **Table 1.9**
Total volume used in articles	294 – 980 t/y	
Share of total volume in articles ending up being incinerated	50%	Assumption
Total volume incinerated	147 - 490 t/y	
Fraction released to air	0.0001	Default from ECHA (2012)
Fraction released to wastewater	0.0001	Default from ECHA (2012)
Fraction released to industrial soil	0	Default from ECHA (2012)
Fraction to solid waste/recycling	0	Default from ECHA (2012)

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.21**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.21: Estimated global releases to the environment for DP from *Disposal of waste/articles containing DP by incineration*

Estimated releases of DP before wastewater treatment			
Estimated releases to…	**Lower estimate**	**Upper estimate**	**Unit**
Air	15	50	kg/year
Wastewater	15	50	kg/year
Industrial soil	0	0	kg/year
Solid waste for disposal / recycling	0	0	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to…	**Lower estimate**	**Upper estimate**	**Unit**
Air	15	50	kg/year
Water	4	13	kg/year
Agricultural soil	11	37	kg/year
Industrial soil	0	0	kg/year
Total	**30**	**100**	**kg/year**

Use 9: Disposal of waste/articles containing DP to landfill

The ultimate disposal of waste/articles containing DP will be by incineration or landfill. This section considers disposal to landfill.

Environmental exposure is estimated in line with the ECHA (2016a) and ECHA (2012) guidance. Ultimately articles (including recycled articles) and other waste will eventually be disposed of by either incineration or landfill. The split between these two disposal routes is not known for DP and for the exposure estimation it has been assumed that 50% are ultimately disposed of by incineration and 50% are ultimately disposed of to landfill.

The input factors used to estimate releases from *Disposal of waste/articles to landfill* are shown in **Table 3.22**.

Table 3.22: Input factors used to estimate releases to the environment from Disposal *of waste/articles containing DP to landfill*

Input factor	Value	Comment
Total volume	300 - 1,000 t/y	See **Table 1.9**
Share of volume used in articles	98%	Total volume used in polymers and adhesives. See **Table 1.9**
Total volume used in articles	294 – 980 t/y	
Share of total volume in articles ending up in landfill	50%	Assumption
Total volume landfilled	147 - 490 t/y	
Fraction released to air	0	Default from ECHA (2012)
Fraction released to wastewater	0.016	Default from ECHA (2012). Assumes a release fraction of 0.0016/year and a 20-year lifetime of the landfill – a removal fraction of 0.5 for on-site treatment is also assumed.
Fraction released to industrial soil	0.0016	Default from ECHA (2012)
Fraction to solid waste	0	Default from ECHA (2012)

The estimated total global releases before and after wastewater treatment are summarised in **Table 3.23**. These include any direct releases to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 3.23: Estimated global releases to the environment from *Disposal of waste/articles containing DP to landfill*

Estimated releases of DP before wastewater treatment			
Estimated releases to…	**Lower estimate**	**Upper estimate**	**Unit**
Air	0	0	kg/year
Wastewater	2,400	8,000	kg/year
Industrial soil	240	800	kg/year
Solid waste for disposal / recycling	0	0	kg/year
Estimated releases of DP after wastewater treatment			
Estimated releases to…	**Lower estimate**	**Upper estimate**	**Unit**
Air	2	6	kg/year
Water	620	2,070	kg/year
Agricultural soil	1,780	5,930	kg/year
Industrial soil	240	800	kg/year
Total	**2,640**	**8,800**	**kg/year**

Natural sources

There are no known natural sources of DP.

3.2 Analysis of Alternatives

This section sets out in full the analysis of alternatives carried out in the REACH restriction proposal. It is believed that the conclusions from this analysis holds also at a global level.

3.2.1 Description of the use and function of the restricted substance(s)

DP is part of a group of compounds arising from Diels-Alder reactions of hexachlorocyclo-pentadiene. They were first patented in the 1960s as replacements for the hazardous pesticide and flame retardant Mirex (Sverko et al., 2011). A review of the literature and input from the consultation indicates that there are two main functions that DP serves:

- (i) as an additive flame retardant; and
- (ii) as an extreme pressure additive in greases.

How DP is used in these functions and in that types of manufactured articles, is detailed below.

Functions and uses of Dechlorane Plus as a flame retardant

DP is a halogenated organic flame retardant, used as an additive flame retardant, i.e., it is not chemically bound to the material in which it is used (e.g., plastics and coatings) but is simply mixed in the polymer matrix it is made with, during manufacture. The overall function of DP is to slow the ignition and spread of fire in the materials to which it is applied. In plastics and other polymer-based materials, DP is used in both thermoplastic and thermosetting plastic types, and in a range of polymers and resins. As an additive flame retardant, DP is not covalently bound to the polymer-based materials but is rather 'immobilized' or 'entrapped' (words used by the manufacturer (OxyChem, 2013)) in the material in which it is used. This is understood to mean that because both DP and the polymers in which it is used are solid at normal temperature and pressure, that DP is not free to move in the polymer matrix. However, this would not mean that DP is completely immobilised in the polymer, but that releases would be limited[46] (see also Section 3.1).

Halogenated flame retardants like DP act by replacing the most reactive hydrogen (H·) and hydroxyl (OH·) free radicals in a flame with more stable chlorine (Cl·) or bromine (Br·) free radicals – sometimes called 'quenching' (Shaw et al., 2010). It is commonly applied in a synergist system by adding another substance that augments the flame retarding action of DP. Synergist systems involve the addition of other substances to flame retardants to lower the potential to propagate the radical oxidation reactions of combustion, thus improving the efficiency of the flame retardant (FR-online, 2021). Most halogenated flame retardants are used in conjunction with a synergist to enhance their efficiency. More specifically, halogenated flame retardants are often combined with antimony oxide, which is a strong synergist and works through the formation of flame-quenching antimony trichloride or tribromide (Weil and Levchik, 2009). According to a previous DP manufacturer (OxyChem, 2007) compounds of antimony, zinc or iron are used as synergists.

The uses confirmed by stakeholders of polymers containing DP are in automotive vehicles (57 – 75%), aircrafts (10%), electronics/electrical equipment and explosives. Due to limited information, uses outside

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[46] There would still be a concentration gradient set up in the polymer whereby as the substance at the surface is lost (by washing, volatilisation etc.), so diffusion from the inside of the polymer to the surface will occur slowly over time.

the automotive and the aviation sectors were grouped into “other uses” (15 – 33%), which also includes imported articles (Section 1.2.3). DP is predominantly used in polymers as a flame retardant additive, but DP is also used as an extreme pressure additive in greases.

The previous manufacturer, OxyChem, claims that benefits of DP used as a flame retardant in plastics, are insulation for maintaining electrical and physical properties, excellent UV stability, an increase in heat distortion temperature, and no blooming (OxyChem, 2007). It also states that DP is a more efficient flame retardant than brominated additive flame retardants in some polymers, and that it produces less smoke when used in polyolefin compositions (e.g. polyethylene, polypropylene) than decabromodiphenyl ether (OxyChem, 2007). The following information was presented in the OxyChem Dechlorane Plus® Manual (OxyChem, 2007):

> "*Dechlorane Plus® flame retardant additives are highly effective, chlorine-containing, crystalline organic compounds, which have been ground to free-flowing, white powders. They are the same chemical compound, differing only in particle size. The Dechlorane Plus® additives are used as non-plasticizing flame retardants in polymeric systems.*"

The product benefits in the OxyChem® Manual are stated as the following:

- **Colourability**: Unlike many other flame-retardant additives, Dechlorane Plus® is a fine white powder which easily allows colour coding and matching.
- **Excellent Flame Ratings**: Formulations may be tailored to meet the most demanding flammability specifications.
- **Thermal Stability**: Operating temperatures up to 285°C allow greater ease of processing in a wide variety of polymers.
- **Excellent Electrical Properties**: The absence of ionic impurities provides electrical performance that is unsurpassed by other flame-retardant additives.
- **Low Smoke**: Unlike other halogenated flame retardants, Dechlorane Plus® enhances the formation of an insulative char. This not only inhibits flaming drips and reduces flame propagation but has the additional benefit of lower smoke generation.
- **Synergist Options**: Due to the unique properties of Dechlorane Plus®, cost effective synergist alternatives to antimony trioxide are available.
- **Inert Filler**: Dechlorane Plus® has low solubility; it is non-reactive, non-plasticizing, and hydrophobic.
- **High CTI Performance**: Comparative tracking index values in excess of 400 volts may be achieved through the use of OxyChem technology.
- **Cost Effectiveness**: With a 1.8 specific gravity, Dechlorane Plus® has the cost advantage of comparable brominated flame retardants that range between 2.3 and 3.2.

Dechlorane Plus as a flame retardant in polymers

This section details information from polymer literature, including information on specific polymers where DP is known to be used or may be used. **Table 3.24** provides general information to support the understanding of uses of DP and may only mention polymer type or end-use application, and in some cases does not explicitly link the two. It may be that some of the listed polymers contain no DP as they do not require flame retarding and/or the polymers themselves are inherently flame retardant, or both. In the absence of an accurate breakdown of current uses, the polymer types have been assigned to the application types based on generic information on known relevance of polymer types in the various application areas and is informed by general literature from the polymers industry as summarised below.

The technical function and loading rate (listed in **Table 3.24**) are generic for that polymer type and there could be more specific values for various applications. It is important to consider the loading rates for alternatives substances; the loading rate indicates the amount of flame retardant that is needed to become functional as a flame retardant in the material. This is often expressed as a percentage, or weight for weight of manufactured product. Loading rate also influences the behaviour of the flame retardant additive in the manufactured product. Increasing the loading rates can potentially render alternatives unsuitable due to cost or changes in the properties of the manufactured product, decreasing loading rates may affect the functional efficiency or conflict with safety flameproofing certification requirements.

The information to complete **Table 3.24** was collected from prior literature (as referenced in the table) and the stakeholder consultation carried out for the REACH Restriction proposal (see Section 1.2.2) and builds directly on the narrative discussion of uses presented in Section 1.2.

There is significant potential for overlap between material types, parts being manufactured (particularly in the electronics context) and end use sector. For example, a specific polymer that is treated with DP to ensure it meets fire-safety needs could be made into a type of electronics part that can be used in appliances or components in different sectors. In the absence of more specific information, **Table 3.24** focuses on the polymer types that are understood to have relevance or possible relevance for DP.

Some of the uses referenced in the OxyChem literature (i.e. OxyChem, 2007 manual) may possibly represent product development or applications for which DP is no longer used rather than current commercial relevance in the EU. In the following sections, the term “confirmed use” relates to uses which have been confirmed through the stakeholder consultation or uses marketed on suppliers’ websites. There are relatively few uses that has been confirmed for DP, as shown in **Table 3.24**, and in the conclusions of Section 1.2.

Table 3.24: Use of DP in specific polymer types

Polymer (or other substrate)	Application type	Notes on technical function, loading rate and synergist systems	Comments
Thermoplastic polymers			
Acrylonitrile butadiene styrene (ABS)	Resin	FR at 16.9% with antimony trioxide synergist (OxyChem, 2007 manual) FR typical loading ~20% in ABS in appliances (ESD, OECD, 2004)	UV stability, high heat distortion temperature, and no blooming are particularly mentioned (OxyChem, 2007)
Natural rubber	Elastomers [Elastomer adhesives]	FR at 18.7% with antimony trioxide (OxyChem, 2007 manual)	No further information found
Nylon	Fibre reinforced polymer	FR at 10-25% in presence of inorganic synergist (zinc, antimony, iron compounds) (OxyChem, 2007)	
Nylon	Connectors, switches, cable straps, power tool housing and wall plates	FR at 11-22% in presence of inorganic synergist (zinc, antimony, iron compounds) (OxyChem, 2007)	"The synergist selected is a very important factor in determining the physical and electrical properties of the final formulation." (OxyChem, 2007) **Confirmed and significant commercial use of DP (see Section 1.2.2)**
Nylon coating	Wire and cable / cable coatings; cable jackets	FR at 11-22% in presence of inorganic synergist (zinc, antimony, iron compounds) (OxyChem, 2007) For 'high CTI' fibre-reinforced nylon, important for electrical insulation function: 11.2% in presence of synergist (zinc, antimony, melamine compounds) (OxyChem, 2007)	"The synergist selected is a very important factor in determining the physical and electrical properties of the final formulation." (OxyChem, 2007)
Polybutylene Terephthalate (PBT)	Connectors, switches, cable straps, power tool housing and wall plates	FR at 15.2-15.75% with antimony trioxide synergist ('high CTI') (OxyChem, 2007 manual)	
Polybutylene Terephthalate (PBT)	Fibre reinforced polymer	FR at 8-18% with synergists (antimony trioxide) (OxyChem, 2007 manual)	
Polyolefin Polyethylene	Wire and cable / cable coatings; cable jackets [Thermoplastic adhesives]	FR at ~25% in presence of inorganic synergist (antimony) (OxyChem, 2007)	**Confirmed and significant commercial use of DP (see Section 1.2.2)**

Kraton	Elastomers	FR at 30% with antimony trioxide (OxyChem, 2007 manual)	No further information found
TPU, Thermoplastic urethanes	Elastomers	FR at 16% with antimony trioxide (OxyChem, 2007 manual)	No further information found
TPU, Thermoplastic urethanes	Potting compounds		No further information found
Ethylene vinyl acetate (EVA)	Wire and cable / cable coatings; cable jackets [Thermoplastic adhesives]	FR at 25% in presence of inorganic synergist (antimony) (OxyChem, 2007)	Electrical properties, thermal stability and colourability; char formation and non-dripping, low smoke (OxyChem, 2007)
Expanded polystyrene	Foams / sound-absorbing panels		Relevance in EU is uncertain
Polyvinyl chloride (PVC)	PVC line pipes		Relevance in EU is uncertain
Thermoset polymers			
Cross-linked PE (XLPE)	Wire and cable / cable coatings; cable jackets	FR at ~25.5% in presence of inorganic synergist (antimony) (OxyChem, 2007)	Electrical properties, thermal stability, and colourability; char formation and non-dripping, extremely low smoke (OxyChem, 2007)
Epoxy	2-part Epoxy void filler / potting compound / syntactic foam [thermoset polymer adhesives]	FR at <15%	Exceptionally stringent qualification requirements apply in this sector (Rolls Royce PLC, comments received in 2019 to ECHA's Draft 9th Recommendation for DP [for inclusion of substances in Annex XIV of REACH]) **Confirmed commercial use of DP (Section 1.2.2)**
Epoxy resin	Resin	FR at 25.5% with synergists (antimony, zinc or iron compounds); Filler (OxyChem, 2007 manual)	Choice of synergist can affect amount of smoke production (OxyChem, 2007)
Ethylene/propylene diene monomer elastomers (EPDM)	Wire and cable / cable coatings; cable jackets	FR at 33% in presence of inorganic synergist (antimony) (OxyChem, 2007)	Electrical properties, thermal stability, and colourability; char formation and non-dripping (OxyChem, 2007)
Ethylene/propylene diene monomer elastomers (EPDM)	Nuclear power plant control cable (Wire and cable / cable coatings; cable jackets)	FR at 33% in presence of inorganic synergist (antimony) (OxyChem, 2007)	Electrical properties and colourability; char formation and non-dripping (OxyChem, 2007)
Hypalon	Elastomers	FR at 5-6% with antimony trioxide (OxyChem, 2007	No further information found

		manual)	
Neoprene	Elastomers [Elastomer adhesives]	FR at 10% with antimony trioxide (OxyChem, 2007 manual)	No further information found
Phenolic resin	Paper laminated resin [Structural adhesives]	FR at 12.9% with synergist (antimony oxide); Filler (OxyChem, 2007 manual)	
Polypropylene Talc-reinforced PP	Moulded parts / other plastics / circuit board / motherboard & components / chargers / appliance parts	FR at 20-35% in presence of synergist (antimony, zinc compounds) (OxyChem, 2007)	Colourability and non-drip useful (OxyChem, 2007)
Polypropylene	Moulded / extruded parts / other plastics / hard plastics	FR at 20-35% in presence of synergist (antimony, zinc compounds) (OxyChem, 2007)	Colourability and non-drip useful (OxyChem, 2007)
Silicon rubber	Elastomers [Elastomer adhesives]	FR at 18.8-40% with antimony trioxide (OxyChem, 2007 manual)	No further information found
Silicon rubber	Potting compounds		No further information found
Unsaturated polyester (UPE) resin	Resin [Thermoset polymer adhesives]	FR at 20% with synergists (antimony oxide); filler (OxyChem, 2007 manual)	
Urethane foam	Elastomers	FR at 17.5-35% with antimony trioxide (OxyChem, 2007 manual)	No further information found
Urethane rubber	Elastomers [elastomer adhesives]	FR at 20-30% with antimony trioxide (OxyChem, 2007 manual)	No further information found

Non-polymer uses of Dechlorane Plus

Although DP is predominantly used as a flame retardant additive in polymers, it can also be used as a flame retardant additive in non-polymer materials, an extreme pressure additive in greases and (in very small concentrations) as a colour intensifier in explosives (see Section 1.2.2). **Table 3.25** shows the uses of DP in non-polymers.

Table 3.25: Uses of DP in non-polymers

Material	Application type	Technical function, loading rate and synergist systems	Comments
Adhesives	Potting, encapsulating and bonding in electronics; cladding and flooring in building/construction; bonding composite panels, flooring and other fixtures and fittings; aircraft cabin interior		Many polymer types can be used as adhesives. Where polymers for which DP may be used also have polymer uses this is noted in the rows above in square brackets. **Confirmed commercial use of DP (see Section 1.2.2)**
Caulk	Building materials		Potential commercial use (see Section 1.2)
Greases		Dual function: FR and seizure resistance (from stakeholder consultation)	**Confirmed commercial use of DP (see Section 1.2.2)**
Cooling / coolant			No further information found. While some other polychlorinated FRs are reportedly used in coolants in electrical equipment, it is unknown whether this is a relevant use for DP in the EU.
Flame resistant paint	Emulsions and coatings		No further information found. Potential commercial use of DP, but relevance uncertain; the use is not confirmed in the registration dossier (see Section 1.2)
Foam	Foams / sound-absorbing panels		**Confirmed commercial use of DP (see Section 1.2.2)**
Foam or non-foam filling material	Mattresses		Textiles is a potential commercial use of DP but further information on the nature of the coating is not available (see Section 1.2)
Non-woven wallpaper	Wall papers		Relevance in EU is uncertain (see Section 1.2)
PVC/paper	Wall papers		Relevance in EU is uncertain (see Section 1.2)
Explosives	Fireworks	Colour intensifier additive in pyrotechnics (impag, 2018, US Army, 1967).	The use in explosives is recommended against by REACH registrants in the ECHA disseminated dossier. **Confirmed commercial use of DP in explosives (see Section 1.2.2) and commercially available for the use in fireworks (Impag, 2018)**

Textiles	Textile coating (i.e. finishing product) / clothing / curtains		Further information on the nature of the coating is not available (see Section 1.2). Coated and back-coated textiles are possible.
Textiles (toys)	Textile toys		Textiles is a potential commercial use of DP but further information on the nature of the coating is not available (see Section 1.2)
Textiles (military)	Military textiles		Textiles is a potential commercial use of DP but further information on the nature of the coating is not available (see Section 1.2)
Tile	Building materials (e.g. roofing materials, laminate flooring)		No further information found
Wood	Building materials (e.g. panels, roofing materials, insulation board, laminate flooring)		No further information found
Unknown (plastic toys)			No further information found
Unknown (food packaging and storage)			No further information found

1[1] https://echa.europa.eu/documents/10162/16908203/pt9_oecd_esd_no_7_textile_finishing_industry_en.pdf/2d6bb902-83cc-4ff1-94ef-6e8fb2aab978

DP as an extreme pressure agent

Chlorine containing extreme pressure (EP) additives such as DP are primarily used for industrial gear lubricants. These additives are temperature-activated and react with metal 'asperities' - tiny irregularities on the metal surface - to form a sacrificial film. The surface irregularities are subjected to repeated stress as the line of contact sweeps across (e.g. a tooth in a gear cog), to produce small surface cracks and clefts. In the 'dedendum' area (the bottom of the cog 'tooth') the oil under the high pressure of contact can enter these defects and extend them gradually, eventually reaching the surface again so that a pit is formed, and a small piece of metal is dislodged. In this function, DP decomposes at high temperature, producing very active chlorine, which reacts with the metallic surfaces, thought to produce iron chlorinate.

In the information gathered from the Call for Evidence (CfE), the automotive industry indicated an essential use for DP in greases (see Section 1.2.2). The function is described as when the "*chlorine bond substance is heated in contact with the metals, it reacts with the metals and forms metal chloride film. This film reduces the friction*". This is in line with the EP function described above. The specific seizure resistance standard referred in the CfE - *Evaluation method: DIN51350* – relates to the performance of greases and lubricants (EN ISO, 2003). The property of DP as an extreme pressure agent is associated with the reactive chlorine function, however, this property also works in combination with the other physicochemical properties of DP such as temperature stability, viscosity, vapour pressure and solubility. All the physicochemical properties contribute the overall performance and functionality of DP as an extreme pressure agent. Another critical aspect is the compatibility of DP with other components in the grease that DP is added to, the metal type of the gearing that the grease is applied to (different additives and greases for different alloy types).

An investigation into the function of DP as an extreme pressure additive is potentially a very broad one as there are a multitude of possible materials and use combinations. Unfortunately, stakeholder consultations did not reveal the specific properties of the substance (in addition to the chlorine reactivity) that make it most suitable for this use. Since this assessment is based on available literature and information from stakeholder consultees, both of which provided limited information, it was necessary to limit the investigation of alternatives to DP in materials other than polymers.

Summary of function and uses

Table 3.26 contains a summary of the confirmed and possible uses of DP in its flame-retardant and extreme pressure agent function. Most of the applications are found within the (i) automotive sector; (ii) aviation sector; and (iii) electronics and electrical equipment sector.

Table 3.26: **Summary of confirmed uses of DP in its flame-retardant function**

Use	Sector	Confirmed	Comment
Sealants & adhesives	• Electronics and Electrical Equipment • Transport	√	Insulation, sealants
Cables, wires and piping	• Electronics and Electrical Equipment • Transport	√	Insulation, component boxes
Automotive vehicles	• Transport	√	In seat fabrics, hoses, some electrical components, grease, lubricants, powertrain, cooling, chassis and bodywork parts
Aircraft	• Transport	√	In seat fabrics, hoses, grease, lubricants some electrical components

Note: Transport refers to both automotive and aerospace & defence sectors.

In summary, there are a wide range of polymer uses in manufacturing (both alone and in co-polymer systems) with different chemical additives for technical and functional attributes which offer a wide range of material characteristics. It is beyond the scope of this assessment to attempt to investigate all possible material and use combinations, since the assessment is based on available literature and information from stakeholders. It is possible that at least some of the identified applications are general-purpose which may indicate a degree of flexibility and acceptability of substitution.

There is limited information in literature on alternatives to DP in its function as an extreme pressure agent and no information on alternatives were provided by stakeholders.

3.2.2 Identification of potential alternative substances and techniques fulfilling the function

Introduction

This section describes the approach to identify, compare, and ultimately select potential alternatives to DP. The overall goal is to support informed decisions regarding the advantages and disadvantages of different alternatives to DP in various product applications. In the following sections, a stepwise qualitative methodology was developed to compare DP with potential alternative substances that fulfil the same function as DP.

In the initial stages of the identification of potential alternatives, it was noted that there are two primary technical functions that DP fulfils, namely as an additive flame retardant, and as an extreme pressure additive in grease/lubricant. These two functions are independent of one another and as such, have been considered separately in the alternatives analysis sections below. Additionally, the sub-section on 'Non-chemical alternatives' in this section details potential alternatives that do not require DP to be replaced by another substance or combination of substances that provide a similar function.

This section is structured as follows:

- The strategy of identifying DP alternatives is presented, detailing the stepwise approach to selecting substances based on their technical feasibility as flame retardants in the various manufactured article types.
- The strategy to identifying DP in its function as an extreme pressure additive in grease/lubricant is presented and the chemical groups that would serve the same chemical function as DP are identified.
- A short list of seven (7) substances; four (4) as substitutes for DP in its flame-retardant function, and three (3) in its function as an extreme pressure additive in grease/lubricant, is presented. As these functions are unrelated and have no overlap, their suitability was analysed separately.

Relevant information in the literature appears to be very limited, and as such a detailed analysis was not possible.

Approach for selecting alternative substances to Dechlorane Plus

There are several approaches that can be taken when considering alternatives for DP in its two primary functions: (i) use as a flame retardant in polymers; and (ii) extreme pressure additive in greases. Moreover, there are several arguments as to what the prime consideration for each use of DP would be in selecting a replacement substance. The alternative to DP would need to be available in sufficient quantities, be technically and economically feasible, and also have a favourable hazard profile to avoid regrettable substitution and subsequent regulatory action on the alternative.

The three general steps taken to screen literature for potential alternatives substances to DP were as follows:

- **Step 1:** An initial list of possible alternatives based on a review of existing literature was produced. It should be noted that since the literature review on alternatives to decaBDE compiled by RPA (2014) was conducted, few new sources of publicly available information have been published on either decaBDE or DP. As DP has been marketed as an alternative/replacement for decaBDE (POPRC, 2021), using this document as a starting point for the selection of alternative substances to DP was considered appropriate. Any new literature used in this report was obtained from various manufacturers manuals and/or publicly available databases and pertains to alternatives to DP as a high-pressure lubricant/grease.
- **Step 2:** The suitability of these alternatives was assessed - again based on a review of existing literature.
- **Step 3**: Hazard criteria of the initial list of alternatives was used to screen out substances that are persistent, bioaccumulative and toxic (PBT) or carcinogenic, mutagenic or toxic for reproduction (CMR) to avoid an instance of regrettable substitution in the selection of alternatives to DP as far as feasible. The identification of physical and chemical properties (including structure) that indicate they could persist, bioaccumulate or be toxic in the environment is part of the process for identification of PBT/vPvB substances, however for CMR it is not necessarily possible to

predict these properties on the basis of structure. Therefore, chemical structure is considered to avoid, as far as practicable, regrettable substitutions. However, the present assessment is based on how substances are designated or classified today and not on any prediction (e.g. based on structure) of hazardous properties that might lead to further designations in the future.

Additionally, one last substance was added to the shortlist, clorendic anhydride, identified through Velsicol's website (Velsicol, 2020); Velsicol is the sole importer of DP in the EU according to information from stakeholders.

First screening of DP alternatives from the literature

As specific information in the literature relating to alternatives for DP was lacking, the initial list of potential alternatives was taken from a literature review on alternatives to decaBDE (RPA, 2014; ECHA, 2015b). DecaBDE is a chemical with similar physico-chemical properties to DP and is also used as an additive in the flame-retardant matrix in a similar way to DP. DecaBDE had been widely used as a flame retardant in plastic articles as well as in adhesives, coatings, inks, and sealants. According to Regulation (EC) 2019/1021 (the POPs regulation), the manufacturing, placing on the market and use of decaBDE, whether on its own, in mixtures or in articles is prohibited in concentrations equal to or below 10 mg/kg (0.001 % by weight). The extensive list of alternatives to decaBDE were obtained from the report *'Support to an Annex XV Dossier on Bis-(pentabromophenyl) ether (DecaBDE)'* (RPA, 2014).

In the same report, publications were cited when an alternative for decaDBE was mentioned as having potential to replace decaBDE in plastics (P), textiles (T) or coatings (C) (RPA, 2014; ECHA, 2015b). DP is widely used in plastics and coatings while no stakeholders have indicated that they use DP in textiles. Textiles have thus been excluded from further assessment. The major product groups in which DP is incorporated into is polymers where it functions as a flame retardant, supporting the strategy mentioned above.

Initial screening criteria

For a substance to be considered in the initial screening as having a minimum level of technical feasibility, the following criteria based on the approach taken in the decaBDE restriction were applied (RPA, 2014; ECHA, 2015b):

- Substance appears to be suitable for both plastics (P) and coatings (C);
- Substance appears in at least five literature sources as a potential alternative for use in polymers;
- Substance appears as potentially suitable for use in coatings, and in the absence of detailed information this includes adhesives and sealants; and
- If the substance only appears in the literature for either plastics (P) or coatings (C) but appears in more than **several distinct literature** sources for uses in polymers, it was considered.

Alternatives to DP as an extreme pressure additive in greases were assessed separately. See the sub-section titled 'Discussion of alternatives to Dechlorane Plus as an extreme pressure additive in this section.

Initial list of potential alternatives to Dechlorane Plus

A list of almost 200 substances from the REACH restriction dossier on decaBDE (RPA, 2014; ECHA, 2015b) was used as a starting point for identifying potential alternatives to DP (Step 1). A shortlist of 20 substances (Step 2), presented in **Table 3.27** were retained after applying the screening criteria described in the preceding sub-section (RPA, 2014; ECHA, 2015b). These 20 alternatives to decaBDE have the highest occurrence in the literature (i.e. referred to as suitable alternatives) and as such, represent the most frequently cited of each manufactured article type and are available for use. It should be noted that for any one application, the most technically feasible option may not appear in the literature at a high occurrence rate and therefore, it is possible that a suitable alternative may not appear in this table. Conversely, an alternative appearing in this table may be incompatible with many DP applications, but this will only be resolved with input from stakeholders. Technical and economic feasibility is not assessed at this stage (see Section 3.2.3 for more details).

Table 3.27: List of potential alternatives to DP based on RPA (2014)

Cas No.	Alternative Substance	Plastics	Coatings	Literature source
115-27-5	Chlorendic anhydride	✓		*Velsicol (2020)*
1003300-73-9	Mixtures of esters of phosphoric acid	✓		*PINFA (2010b), PINFA (2010c), PINFA (2013)*
115-86-6	Triphenyl phosphate	✓		*Keml (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007),Illinois EPA (2007), Troitzsch (2011), UK HSE (2012), Lowell Center for Sustainable Production, (2005), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013)*
1309-42-8. 13760-51-5	Magnesium hydroxide	✓	✓	*Keml (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Illinois EPA (2007), UK HSE (2012), EFRA (2012a), EFRA (2012b), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013), Albemarle (2013), Chemtura (2011), ICL Industrial Products (2013); Stakeholder consultation*
13674-87-8	Tris(1,3-dichloro-2-propyl) phosphate	✓		*Keml (2004, 2005, 2009), Albemarle (2013) Chemtura (2011), ICL Industrial Products (2013)*
14728-39-9. 68333-79-9	Ammonium polyphosphate	✓	✓	*Keml (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Illinois EPA (2007), UK HSE (2012), EFRA (2012a), EFRA (2012b), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013)*
21645-51-2. 8064-00-4. 1318-23-7	Aluminum hydroxide	✓	✓	*Keml (2004, 2005, 2009), PAKALIN ET AL. (2007), US EPA (2012-2014), Illinois EPA (2007), UK HSE (2012), EFRA (2012a), EFRA (2012b), PINFA (2013, 2010a, 2010b, 2010c), ENFIRO (2014), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*
21850-44-2	Tetrabromobisphenol-A bis (2,3-dibromopropyl ether)	✓		*Keml (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Troitzsch (2011), UK HSE (2012), Albemarle (2013) Chemtura (2011), ICL Industrial Products (2013)*
218768-84-4	Melamine polyphosphate	✓	✓	*Keml (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), UK HSE (2012), EFRA (2012a), EFRA (2012b), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013)*
225789-38-8	Organic phosphinates (Diethylphosphinic acid, aluminum salt)	✓		*Keml (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Illinois EPA (2007), Troitzsch (2011), UK HSE (2012), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013)*
26444-49-5	Cresyl diphenyl phosphate	✓	✓	*Keml (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), Illinois EPA (2007), Troitzsch (2011), UK HSE (2012), Lowell Center for Sustainable Production, (2005), EFRA (2012a), EFRA (2012b), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*
32588-76-4	Ethylene bis(tetrabromophthalimide)	✓	✓	*Keml (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Troitzsch (2011), UK HSE (2012), EFRA (2012a), EFRA (2012b), Albemarle (2013) Chemtura (2011), ICL Industrial Products (2013)*
37853-59-1	Bis(tribromophenoxy)ethane	✓		*Keml (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007),*

Cas No.	Alternative Substance	Plastics	Coatings	Literature source
				UK HSE (2012), EFRA (2012a), EFRA (2012b)
57583-54-7. 125997-21-9	Resorcinol bis(diphenylphosphate) (RDP)	✓		*KemI (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), Illinois EPA (2007), Troitzsch (2011), UK HSE (2012), Lowell Center for Sustainable Production, (2005), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013), (ENFIRO, 2014), Albemarle (2013), Chemtura (2011), ICL Industrial Products (2013)*
5945-33-5. 181028-79-5	Bisphenol-A bis (diphenyl phosphate) (BDP/BAPP)	✓		*KemI (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), Illinois EPA (2007), Troitzsch (2011), UK HSE (2012), Lowell Center for Sustainable Production, (2005), EFRA (2012a), EFRA (2012b), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013), ENFIRO, Albemarle (2013), Chemtura (2011), ICL Industrial Products (2013)*
66034-17-1	Substituted amine phosphate mixture (P/N intumescent systems)	✓	✓	*US EPA (2012; 2014); Troitzsch (2011); UK HSE (2012); PINFA (2013, 2010a, 2010b, 2010c)*
7723-14-0	Red phosphorous (encapsulated)	✓	✓	*KemI (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012), US EPA (2014), Illinois EPA (2007), UK HSE (2012), EFRA (2012a), EFRA (2012b), PINFA (2013, 2010a, 2010b, 2010c), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*
79-94-7	Tetrabromobisphenol-A	✓		*KemI (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), Troitzsch (2011), UK HSE (2012), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*
84852-53-9	Ethane-1,2-bis(pentabromophenyl)	✓	✓	*KemI (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Troitzsch (2011), UK HSE (2012), EFRA (2012a), EFRA (2012b), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013); Stakeholder consultation*
88497-56-7. 57137-10-7	Brominated polystyrene	✓		*KemI (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Troitzsch (2011), UK HSE (2012), EFRA (2012a), EFRA (2012b), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*

Note: This list is generated from the RPA (2014) report on Support to an Annex XV Dossier on Bis-(pentabromophenyl) ether (DecaBDE) and represents alternatives to flame retardants presented in the literature.

Discussion of alternatives to DP as a flame retardant

The literature sources detailed in **Table 3.27** (initial screening – step 1) described above reveal that most of the alternatives to DP for flame retardant uses are proposed for plastics. Therefore, the analysis of the possible alternatives focused on the type of polymers that DP would be incorporated into as a flame retardant. The alternative substances which are principally used as flame retardant additives in the manufacturing of plastics were selected for the second screening (referred to as Step 2 in the sub-section titled 'Approach for selecting alternative substance to Dechlorane Plus' in this section). This reduced the initial list to 20 alternative substances. In Step 3, substances that possess hazard profiles that are likely to be the focus of future regulatory actions, such as those with persistent, bioaccumulative or toxic properties or those which are carcinogenic, mutagenic or toxic for reproduction, were eliminated from the second screening, to avoid potential regrettable substitutions. This reduced the shortlist of 20 substances which are reported as technically feasible alternatives as a flame retardant, to the three substances below, after which a fourth substance, chlorendic anhydride, was added based on information from Velsicol.

- aluminium hydroxide;
- ammonium polyphosphate;
- chlorendic anhydride; and
- ethane-1,2-bis(pentabromophenyl) (EBP),

Discussion of alternatives to Dechlorane Plus as a pressure resistant

Section 3.2.1 briefly explained the function of DP in greases as an extreme pressure additive. The efficiency of extreme pressure (EP) additives lies mainly in the prevention of loading and scouring of the abrasive layer. EP additives are organic compounds with phosphorus, chlorine, or sulfur, including chlorinated paraffins or aromatics, di- or polysulphurised organic compounds, sulphurised mineral oils, esters of aryl(alkyl)phosphoric acid, chlorinated and/or sulfurised fatty acids or olefins, esters of phosphoric acid, polyalkylene glycol. EP additives with various properties are used both for neat oils and for water-based fluids[47]:

- Sulphinated products, such as fatty esters with high sulphur concentration react at high temperature leading to the formation of a protecting layer of iron sulphur. The organic sulphurs seem to act in the following manner: the disulphides, initially adsorbed over the metallic surfaces are changing into organic monosulphides which present anti-wear properties. Then, organic sulphurs are destroyed or decomposed under the effect of pressure and temperature; the inorganic sulphides formed react with the metal and exhibit extreme pressure properties;
- The chlorinated products are primarily chlorinated fatty esters, chlorinated paraffin and chlorinated fatty acids. These products decompose themselves at high temperature, producing active chlorine, which reacts with the metallic surfaces to produce iron chlorinate. These products can be very corrosive in some cases and therefore are rather used for cutting oils.
- Phosphorus-sulphur derivatives are rather recently elaborated products and therefore their composition and acting mechanisms are less known. These compounds have excellent extreme pressure properties, are still stable up to temperatures of the order of 120°C and do not react readily with copper based alloys. Consequently, they are more frequently used in industrial oils.

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[47] Process fluids for abrasive machining (Marinescu et al., 2012).

The specific functional requirements of DP as an extreme pressure additive as described above is not precisely known and no further detail was provided from consultees in the automotive sector during the stakeholder consultation. The aerospace sector did not mention use of DP as an extreme pressure additive. However, as indicated above, there are substances based on different chemistries (sulphur, chlorine and phosphorus) that can potentially fulfil the function of DP in this use. Whether these are technically feasible and available for use in the automotive sector is not completely clear. If the formation of chlorides binding to specific metals is required, the use of chlorine chemistry is essential and narrows down the possibilities for alternatives. Product supplier lists have been consulted to identify possible alternative products and thus the substances they contain.

It is known that chlorine, potassium-borate and sulphur-phosphorus containing extreme pressure (EP) additives are primarily used for industrial gear lubricants. These additives are temperature-activated and react with metal asperities to form a sacrificial film.

Different types of EP additives have some limitations, these have been described by the lubricants experts in Noria (n.d.):

1) *They can be detrimental to slow-speed gear applications (less than 3 metres per minute), causing high rates of wear known as "polishing."*
2) *Extreme pressure additives like sulphur-phosphorus types can be "too chemically reactive," resulting in polishing wear. This type of wear is undesirable because it reduces gear accuracy by wearing away the tooth profiles. In these cases, potassium-borate additives can be used to deposit EP films without a chemical reaction with the metal.*
3) *The rate of reaction of EP additives is greatest where the gear tooth contact temperatures are highest; therefore, some difficulties are experienced in low-temperature applications when operating temperatures do not become high enough to fully activate the reactive EP agents. The viscosity of the base oil is of extreme importance. Anything that reduces the bulk oil temperature, or the flash temperature will reduce the total contact temperature and increase the risk of wear. If the total contact temperature is not at the necessary level, the extreme pressure additive may not react correctly or at the right rate.*
4) *Solid lubricants such as molybdenum disulphide, graphite or tungsten disulphide are sometimes used when the operating temperatures are too high or low for an oil in which the reaction rate may not be sufficient; however, these solid films have limited wear lives and may not carry the loads necessary for long gear and bearing life.*
5) *Sulphur-phosphorus EP additives have a high-temperature limit of approximately 95^{o}C. This restricts the temperature range in which these oils can be used.*
6) *Sulphur-phosphorus EP additives are somewhat corrosive to forms of brass ('yellow metals'), particularly at temperatures higher than 60^{o}C. Worm gearsets*[48] *frequently contain phosphor-bronze materials, and it is for this reason that gear oils using sulphur-phosphorus EP additives may not provide satisfactory service in worm gear drives.*
7) *Depending upon the amount used, sulphur-phosphorus EP additives may not be compatible with oils containing zinc anti-wear additives. Therefore, it is not recommended to mix anti-wear gear oils with EP gear oils.*

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[48] A worm gear is a gear consisting of a shaft with a spiral thread that engages with and drives a toothed wheel.

8) *Chlorine and borate EP additives may not be fully effective or may cause corrosive conditions where water is present.*

Substances have been identified on the basis of their use in greases and with flame retardant properties since the specific protective use in extreme pressure additives appears to rely on the breakdown at high temperature (as for flame retardants) to form compounds with metal components. Indications that the substances marketed for these specific uses is also a key consideration. Chlorine containing substances with flame retarding and extreme pressure additive properties include the chlorinated paraffins (short, medium and long chain), although today it seems that only medium and long chain chlorinated paraffins are on the market for this use, as the short chain chlorinated paraffins are listed in the Stockholm Convention. Aryl phosphates are generally used as flame retardant additives in polymer systems, but some are also used as fire-resistant hydraulic fluids, lubricants and lubricant additives (EA, 2009).

Phosphates

Johnson and Hils (2013) present a review of the function of phosphate esters, sulphur/phosphate-containing thiophosphate esters and metal thiophosphates as lubricant additives. It is mentioned that phosphate esters, thiophosphate esters and metal thiophosphates have been used as lubricant additives for over 50 years. It is noted that these substances have been used as fire retardants and insecticides and also applications as surfactants and as brighteners in detergents. The multiple industrial uses have led to the commercial availability of a wide range of phosphate esters with different properties and reactivities. The available esters include aromatic phosphate esters such as tricresyl phosphate, alkyl phosphate esters such as tributyl phosphate, thiophosphates and metal containing phosphate esters such as zinc dialkyldithio-phopsphates (ZDDP). However environmental limits on phosphorus and sulphur in lubricant formulations as well as the concern regarding heavy metal emissions, threatens the use of ZDDP in engine oil and has brought an increase in research to find replacements that do not contain phosphorus.

Aromatic and aliphatic phosphate esters have been used as antiwear additives for many decades. They were initially developed for aircraft engines and are used in automotive applications. Trialkyl phosphates, such as tri-butylphosphate are limited to use in mild lubrication conditions because of their higher reactivity limited.

Synthetic neopentyl polyol ester base stocks, triarylphosphates such as tricresyl phosphate are used because the film formed on the metal also reduces the reactivity of the base stock. Triaryl phosphate esters continue despite the need to reduce phosphorus in emissions and concerns about the toxicity of certain isomers of aromatic phosphate esters. When used with synthetic polyester base stocks, the film formed by phosphate esters passivated the metal surface, reducing base stock degradation. These concerns have led to the use of more highly substituted materials, such as butylated triphenyl phosphate (BTPP) as a replacement for tricresyl phosphate. Furthermore, tricresyl phosphate is currently under substance evaluation to clarify human health concerns.

Advances in the performance of modern aircraft engines have required more advanced bearing materials. In general, these materials have resulted in changes in the surface chemistry from primarily iron oxide to a mixture of carbides.

One of the major advantages of triaryl and trialkyl phosphates has been their perceived safety. They are non-flammable and have been shown to exhibit low order toxicity. There are, however, significant concerns about delayed neurotoxicity of some isomers of triaryl phosphates as well as the products that might be derived from high temperature decomposition of triaryl phosphates in the presence of other additive and the lubricant base stock (Johnson and Hils, 2013). In particular, the development of organophosphate-induced delayed neuropathy has been reported as a paralytic condition. A more recent concern has been the possibility of triaryl phosphate entering the cabin of jet turbine aircraft as a part of the bleed air. This has accelerated the search for safer phosphate ester additives. The Netherlands is currently performing a substance evaluation on Isopropylated Triaryl Phosphate based on the following concerns: Potential endocrine disruptor and Suspected PBT/vPvB (ECHA, 2020d).

Phosphate esters, possibly with sulphur and metals added, have found wide application because of their ability to form films on a wide range of materials. The films are all similar in composition with iron phosphate or iron polyphosphate being a major component. The films adhere strongly to the substrate, are durable and continue to form as long as there is additive remaining. Films can form by different mechanisms depending on the amount of oxygen present. An important aspect of the films formed is that their modulus increases in response to stress, allowing the films to maintain their integrity under extreme loads.

Chlorinated paraffins

Chlorinated paraffins are one of several extreme pressure additives used to boost the performance of metalworking fluids in specific applications. An article by Canter (2014) on chlorinated paraffins and possible alternatives is referred in the following text.

In the past, short chain chlorinated paraffins (SCCP), as well as medium (MCCP) and long chain chlorinated paraffins (LCCP) have been used as EP additives (which also have properties as flame retardants), the chlorine content being as critical feature in terms of functionality. Restrictions on SCCPs in the POPs regulation, SVHC-identification due to PBT/vPvB properties and other regulatory pressure has meant that SCCPS are effectively no longer used with products containing MCCPs, LCCPs and very long chain (vLCCPs) being marketed as substitutes for DP as EP additives. The article reports experts from several commercial lubricant manufacturers indicating possible alternatives for chlorinated paraffins. It is reported that modified natural esters provide extended boundary lubrication, but do not chemically react with the metal surface in the same manner as chlorinated paraffin. This extended performance can overlap with phosphate esters additives and in combination can replace chlorinated paraffin. Phosphorus and sulphur also can be used to provide actual extreme pressure functionality. Some phosphorus-containing anti-wear additives such as zinc dialkyldithiophosphate have been used as EP additives in neat oil applications (however see above on ZDPP). Oil soluble boron containing molecules also can be used in neat oils.

It is mentioned in the same article that development of intricately designed polymeric ‘lubricity’ additives that work synergistically with existing phosphorus and sulphur-containing EP additives may be necessary to replace chlorinated paraffins. DP is not mentioned, but this may also be the case for DP i.e. that replacing DP may require combinations of alternatives with synergists depending on the specific function required.

Other chlorinated alternatives

Information from patents literature indicates that diallyl chlorendate (CAS 3232-62-0) could be used as an extreme pressure additive in silicone greases (Iwaki Hirooka Terasu Yoshinari Google patent

US20170002285A1). The substance does not appear to be used in EU as it is not registered under REACH or notified in the CLH-inventory. However, according to the Synthetic Resins Technology Handbook (NIIR Board of Consultants & Engineers, 2005) it is known to have flame retarding properties. It does not appear that there are readily available commercial products on the EU market for diallyl chlorendate (CAS 3232-62-0).

Possible shortlist of alternatives for DP for Extreme Pressure Additives

It is clear that identification of specific alternatives for DP for the EP use is not possible without detailed technical knowledge from the industries within which the applications are required (in this case automotive) and also from technologists within the manufacturing companies that place substances on the market (EP lubricant manufacturers). It has not been possible to gain such information from the limited consultation responses received for this present work (see ECHA, 2021).

Possible alternatives to DP include chlorinated paraffins (SCCPs, MCCPs, LCCPs). However, SCCP has been restricted in the POPs regulation and has been included as a SVHC in the candidate list due to its PBT/vPvB properties. A substance evaluation confirms the PBT/vPvB concerns of MCCPs. Furthermore, LCCPs may contain significant amounts of medium-chained chloroparaffins (MCCPs) and can be regarded as a PBT/vPvB containing substance. Other alternatives are phosphate esters where two of them, (tris(isopropylphenyl) phosphate (CAS 68937-41-7) and tricresyl phosphate (CAS 1330-78-5), are currently subject to additional processes (SEv) in REACH to clarify their human health and environmental concern. There are also alternatives based on other chemistries as well as combinations of substances which act as synergists. As with many analyses of alternatives, there is not an apparent 'drop in' solution, but rather the possibilities very much depend on the specific application. The alternative for lubricant function in extreme pressure additives are summarised in Table 3.28 below. Given the uncertainty in specific alternatives, i.e. a certain chemical substance, the alternatives are grouped where relevant and possible example substances are indicated.

Table 3.28: Possible alternatives for DP functioning as a lubricant in Extreme Pressure Additives

Substance type	Example substances	Remarks
Chlorinated paraffins	Long chain chlorinated paraffins (LCCP), (paraffin waxes and hydrocarbon waxes, chloro) CAS 63449-39-8 Medium chain chlorinated paraffins (MCCP) (alkanes, C14-17, chloro) CAS 85535-85-9	LCCP product Cereclor 42 (Ineos) is used as an extreme pressure (EP) additive in metal working fluids, as a flame retardant additive and as a plasticiser in coatings, sealants, and adhesives. No specific indications of MCCPs (or SCCPs) as commercial products for this use were found.
Phosphate esters	cresyl diphenyl phosphate (CAS 26444-49-5); tricresyl phosphate (CAS 1330-78-5); tertbutylphenyl diphenyl phosphate (CAS 56803-37-3 and 68937-40-6); isopropylphenyl diphenyl phosphate (CAS 28108-99-8); tris(isopropylphenyl) phosphate (CAS 68937-41-7)	Information from Environment Agency in the UK in August 2009 indicates flame retardants with uses in lubricants. Information from other sources (see above) indicates that phosphate esters are used in EP additive uses, tricresyl phosphate taken forward as example of possible alternative for this group.

Other chlorinated flame retardants	diallyl chlorendate (CAS 3232-62-0)	Indicated for use as an extreme pressure additive in silicone greases - in patents literature (Iwaki HIROOKA Terasu Yoshinari Google patent US20170002285A1).

Non-chemical alternatives

Introduction

There are other options that may allow affected actors to move away from DP, without switching to a chemical alternative. Therefore, alternative techniques are defined as techniques that may be both technical solutions and or changes in product design or construction. For example, these can include the introduction of intumescent systems, nanocomposites and expandable graphite.

Alternative substances can be used in the substitution process at three different levels of the product: the flame retardant additive; the base material; or the end-product itself. Thus, alternatives can either replace (i) the flame retardant additive (without changing the base polymer), (ii) the base polymer with flame retardants and other additives (with another material, plastic or non-plastic, and other additives), or (iii) the product can be replaced by a different product, or the function can be fulfilled by the use of a totally different solution (Danish EPA, 1999; Defra, 2010).

No information was made available from the industry during the consultation process on the specific application of DP for the functions identified. The task of identification of potential alternative techniques fulfilling the function, of both flame retardant and as an extreme pressure additive in grease/lubricant, was therefore very difficult, because it was not possible to identify the precise technical function that the flame retarded materials were providing in specific sectors. For extreme pressure additives the function is identified, however whether there is a technical alternative (i.e. gear systems that do not require extreme pressure additives) would very much depend on precisely where the systems are deployed, and this would require detailed, industry-specific engineering knowledge. In addition, relevant information in the literature appears to be very limited, and as such a detailed analysis was not possible. The text below is based on available information and is necessarily broad since detail is missing from consultation and the literature consulted.

Alternative technique to DP in its function as a Flame Retardant

- **Intumescent systems:** Intumescent flame retardant additives undergo a thermal degradation process on heating, which produces a thermally stable, foamed, multicellular residue called ‘intumescent char’ (Camino, 1998). When these substances are added to a polymeric material which is later involved in a fire, they produce an intumescent char which accumulates on the surface, while the polymer is consumed, providing insulation to the underlying materials and partially protecting it from the action of the flame. In 2006 the Danish EPA suggested that intumescent system solutions for thermoplastics had been commercially available for many years (Lassen et al., 2006). Issues around the economic and technical viability have not been fully resolved and as substances utilised in intumescent systems often belong to nitrogen-containing or organophosphate flame retardants, they are not viewed as suitable alternative technologies for DP as a flame retardant additive.
- **Nanocomposites:** Nanocomposites have been reported to show improved thermal stability, optical and magnetic properties, chemical resistance and reduced permeability to water, gases and hydrocarbons (Chrissafis and Bikiaris, 2011). Nanoparticles have demonstrated improved flame

retardancy aspect through enhanced char formation, reduced heat release rate, increased time to ignition and reduced emission of combustible volatiles during a fire (Carretier et al., 2020).

Polymeric nanocomposites have demonstrated great potential as flame retardant materials and possess high thermal stability. Nanoparticles in polymer nanocomposites have demonstrated a simultaneous reduction in heat release rate (HRR) and an increase in thermal stability (Carretier et al., 2020). The combustion behaviour of polymer nanocomposites from the addition of nanofillers is because of a twofold mechanism; namely: physical barrier effect, and catalytic charring effect (Castrovinci and Camino, 2007). The physical barrier effect, also known as surface ceramisation process, occurs during the combustion when nanoparticles form a network of 'floccules' (a small clumps/aggregations of material). These floccules combine with an apparently small portion of carbonaceous char.

- **Expandable Graphite:** On exposure to fire, the graphite expands to over 100 times its original size producing a barrier effect. It has been used in thermoplastics and can be used in polyolefins in combination with another FR such as ammonium polyphosphate, magnesium hydroxide, chloroparaffins or red phosphorous (UK HSE, 2012). Without further information on the precise technical function of DP additives in flame retardants it is not possible to assess if expandable graphite would be a suitable alternative technique although it is considered a promising material for flame retardancy for cellulosic materials (Mazela et al., 2020).
- **Smoke suppressants**: In the event of fire these systems lead to the formation of glassy coatings or intumescent foams or dilution of the combustible material, which prevents further formation of pyrolysis products and hence smoke (KemI, 2005). Such systems are of particular relevance to transportation applications of DP Molybdic oxide is one such substance and common FRs used alongside it include aluminium hydroxide and magnesium hydroxide (KemI, 2005).
- **Polymer blends**: Readily flammable polymers (e.g. high impact polystyrene (HIPS) or acrylonitrile butadiene styrene (ABS)) may be blended with less flammable polymers such as polycarbonate, polyphenylene oxide (PPO) or polyphenylene sulphide (PPS). This enables lower flame-retardant loadings to be used with limited impact on other technical properties (UK HSE, 2012). Therefore, the more expensive polymers – in the presence of a synergist (such as a fluorinated polymer) – such as polycarbonate, PPO and PPS may also be used as a non-chemical alternative as the polymer blend can achieve an acceptable level of processability, will readily undergo recycling and exhibits a similar level of flame retardancy to that of the less expensive but more readily flammable polymer and a halogenated flame retardant (JRC, 2007).

  Another option is layering, where an article is produced using layers of polymers that are highly flame retardant between layers of polymer that are less flame retardant. This apparently gives a similar level of fire performance as would be achieved if the all the polymer layers had been treated with flame retardants, while helping to retain the mechanical properties of the polymer (UK HSE, 2012).
- **Use of inherently flame retardant materials**: Halogenated polymers such as PVC have flame retardant properties because they release halogen radicals, which have the same effect during combustion as halogen radicals released from halogenated flame retardants. This effect can be enhanced by the addition of synergists such as ATO to halogenated polymer blends. Polymers that char such as polyimides, polyaramides, liquid crystal polyesters, polyphenylene sulphide,

polyarylenes and many thermosets also tend to have a greater resistance to fire. Where the base polymer has flame retardant properties, depending on the end use, a sufficient level of fire performance may be achieved without the need for chemical flame retardants or much lower loadings may be required (UK HSE, 2012).

Some examples of new inherently flame-retardant materials are mentioned in literature or in commercial websites, and these are often promoted as replacements for decaBDE (UK HSE, 2012; Albemarle, 2015; Great Lakes Solutions, 2013). It may be necessary to change product designs to adopt these alternative materials and their implementation would require higher level of research and development activities than the substitution of DP with an alternative flame retardant.

- **Technological Developments:** Changes in technology and product redesign that avoids the use of flammable materials can reduce the need for flame retardants or allow for use of chemical alternatives. From the mid-1970s, television (TV) set enclosures included flame retardant chemicals to protect against internally initiated fires. However, modern TV technology contains high voltages (in the ballast of fluorescent lamps that backlight the LCD display or within the individual cells of a plasma display) meaning that the likelihood of internal fires is far lower.

  It is possible to make components of materials that do not require flame retardant additives, e.g. naturally flame-retardant materials like some metals, glass, or ceramics, instead of plastics, which can reduce flammability (Shaw et al., 2010). Thermally stable polymers can be designed but may exhibit performance limitations and are often too expensive and difficult to process (SpecialChem, n.d.). Inert substances (e.g. fillers such as talc or chalk) and additives which evolve as inert gases on decomposition can be added to dilute the fuel in the solid and gaseous phases, thus impeding the achievement of the lower ignition limit in the gas mixture (SpecialChem, n.d.).

- **Product Redesign:** In some instances, there may be an option to redesign products to exclude DP altogether. For example, in electric and electronic equipment (EEE), the replacement of some polymer materials with another in combination with shielding of power supplies has been successful to eliminate the use of decaBDE in some instances. However, this has not been possible in transportation equipment as the complexity of uses and the number of parts that rely on flame retardant chemistry requires long lead times for qualifying and certifying new materials (Lowell Centre for Sustainable Production, 2005). In another example, the power supply for certain electronic products has been removed altogether from the product, thus reducing the fire retardancy requirements of the electronic enclosure (i.e. printers, monitors). These separate power supplies are typically ‘black boxes’ connected to the power cord but not included in the unit itself and the separate power supply reduces the fire retardancy requirements of the electronic enclosure (Lowell Centre for Sustainable Production, 2005).

  In order to change the product design for polymers containing DP in the automotive industry, extensive research and development into the performance of alternatives as a flame retardant would be required to meet the strict safety criteria required. Currently, this level of research and development is not available and as such, product redesign would not be a suitable non-chemical solution to the use of DP in its flame-retardant function.

Alternative technique to DP in its function as an extreme pressure grease/lubricant

When lubricating oils are exposed to heavy loads, metal surface often begins to contract with friction. As a result, the oil film suffers damage and this creates high temperature (Wright, 2008). When the temperature is high, extreme-pressure additives begins to react, creating a solid layer between the friction surfaces to replace the original oil film which has been damaged. It is not possible to further analyse the putative alternative techniques to DP in its function as an extreme pressure grease/lubricant due to the lack of data available for review (Spurlock, 2005). The analysis of alternative techniques would require a high level of understanding of their composition, the required viscosity in relation to speed, specific additives, and lubricating regimes. This type of information is considered as confidential business information by many companies and is not available in the public domain. As the different components in the grease/lubricant provide unique properties, it is not possible to select an alternative technique as a substitute based on the available information on the application of DP for this use. More information regarding the circumstances and conditions concerning a specific application will enable further analysis of the suitability of alternative techniques.

Summary and Shortlist of Alternatives to DP

Given the wide range of polymer materials that require flame-retardant and grease/lubricant properties, it has been asserted that a universal alternative will likely not be available, and that any selection of an alternative will need to be considered for each polymeric compound individually.

Table 3.29 below presents the shortlist of alternatives for DP in its function as both a flame retardant and as an extreme pressure additive in grease/lubricant. These two functions are independent of one another and as such, alternatives may be suitable replacements for one function, but not the other. This is indicated in the following section (Section 3.2.3) that discusses the risk reduction, technical and economic feasibility, and availability of these DP alternatives.

Table 3.29: Shortlist of alternatives to DP

Cas No.	EC No.	Alternative Substance	Commercial products and notes	Literature source
Flame Retardant				
115-27-5	204-077-3	Chlorendic anhydride		*Velsicol (2020)*
14728-39-9. 68333-79-9	269-789-9	Ammonium polyphosphate	Flame retardant in many applications such as paints and coatings, and in a variety of polymers	*(KemI, 2004, KemI, 2005); Lassen et al. (2006); PAKALIN ET AL. (2007); US EPA (2012-2014); Illinois EPA (2007); UK HSE (2012); (EFRA, 2012a, EFRA, 2012b); PINFA (2013, 2010a, 2010b, 2010c); ENFIRO*
21645-51-2. 8064-00-4. 1318-23-7	244-492-7	Aluminium hydroxide	Aluminium Hydroxide has a wide range of applications, including a variety of polymers, paints and coatings.	*(KemI, 2004, KemI, 2005, KemI, 2009); PAKALIN ET AL. (2007); US EPA (2012-2014); Illinois EPA (2007); UK HSE (2012); (EFRA, 2012a, EFRA, 2012b); PINFA (2013, 2010a, 2010b, 2010c); ENFIRO; Albemarle (2013); Chemtura (2011); ICL Industrial Products (2013)*
84852-53-9	284-366-9	Ethane-1,2-bis (pentabromophenyl)		*(KemI, 2004, KemI, 2005, KemI, 2009); Lassen et al. (2006); Washington State (2006); PAKALIN ET AL. (2007); US EPA (2012-2014); Troitzsch (2011); UK HSE (2012); (EFRA, 2012a, EFRA, 2012b); Albemarle (2013); Chemtura (2011); ICL Industrial Products (2013); Stakeholder consultation*
Grease/Lubricant				
63449-39-8	264-150-0	Long chain chlorinated paraffins	Cereclor 42 (example)	
1330-78-5	215-548-8 809-930-9	Tricresyl phosphate	Celluflex TPP®, Disflamoll TP®, Phosflex TPP®, Phosphoric acid, triphenyl ester, Pilabrac 521®, Reofos TPP®, Reomol TPP® and TPP.	*As noted in Environment Agency (2009) Some of the tradenames and trademarks may refer to older products no longer supplied to the EU, or products produced outside the EU, but these are included in the report as they are sometimes referred to in the open literature.*
3232-62-0	221-775-3	Diallyl chlorendate	Only REACH pre-registered	*Indicated for use as an extreme pressure additive in silicone greases - in patents literature (Google patents).*

3.2.3 Hazard comparison, technical and economic feasibility, and availability of alternatives

In this section, the shortlist of most relevant potential alternative substances from Section 3.2.2 are assessed in more detail in terms of their hazard, technical and economic feasibility, and availability. Due to the limited available information in the literature and lack of information provided by stakeholders, technical feasibility can only be assessed in terms of proven or confirmed uses of DP. It may therefore be the case that some of the uses of DP are not covered in this analysis of alternatives.

The following sections detail the technical feasibility of alternatives that have been confirmed with each section comprising of the following sub-sections:

- Availability of alternative
- Human health risks related to alternative
- Environment risks related to alternative
- Technical and economic feasibility of alternative
- Other information on alternative

Since DP has been identified as a vPvB substance, quantitative risk characterisation is not appropriate nor meaningful. Therefore, it is not achievable to carry out a risk comparison between DP and its alternatives. Instead, a comparison of hazard properties has been used an indicator of potential regretful substitutions. Short-listed alternatives were assessed qualitatively based on a comparison of available information on hazard profile, including consideration of:

- Hazard classifications notified under CLP
- Ongoing regulatory assessments
- Relevant physico-chemical properties
- Relevant environmental fate properties (e.g. stability, degradation into hazardous products, etc., as well a PBT-related properties)
- Any significant differences in emission levels when using alternatives as opposed to DP.

It should be noted that the hazard profile is incomplete or uncertain for some alternatives, whilst others are currently undergoing regulatory scrutiny in relation to their hazard profile.

The assessment of economic feasibility is limited to changes in recurring costs based on changes in loading (% of substance required to deliver required effect) and price. Due to a lack of available information, it was not possible to factor any other cost parameters.

Assessment of chlorendic anhydride (CAS No. 115-27-5)

Availability of chlorendic anhydride

The REACH registration tonnage band for chlorendic anhydride is 1,000 – 10,000 t/y. This is a larger tonnage band than is registered for DP, so with this in mind, it is believed that chlorendic anhydride is or will be available in sufficient volumes by the time a restriction would enter into force.

Human health risks related to chlorendic anhydride

The substance 1-chlorendic anhydride (CAS 115-27-5, EC No. 204-077-3) was included in the Community Rolling Action Plan (CoRAP) in 2013 and is currently undergoing substance evaluation (SEv) as a result of concerns to PBT and CMR-properties. Further testing on environmental effects has been requested for (1-chlorendic anhydride, CAS 115-27-5) and for the hydrolysis product (chlorendic acid; CAS No. 115-28-6) testing is requested in order to clarify concerns for the mutagenicity of this substance.

1-chlorendic anhydride has the following harmonised classification for health effects:

- Skin Irrit. 2; H315 Specific concentration limit C ≥1%
- Eye Irrit. 2; H319 Specific concentration limit C ≥1%
- STOT SE 3; H315 Specific concentration limit C ≥1%

Based on the available data the main hazards to human health presented by chlorendic anhydride are related to skin, eye and respiratory irritation. Chlorendic anhydride hydrolyses rapidly to chlorendic acid (CAS 115-28-6) and exposure to the hydrolysis product may occur when hydrolysis during use is significant. Chlorendic acid has been self-classified as Carc. 1B by the majority of notifiers and, as noted above, the mutagenicity of this substance is currently under investigation.

Environmental risks related to chlorendic anhydride

There is no harmonised classification for environmental hazards. The following notified classifications are reported in the ECHA classification and labelling database (accessed March 2021).

- Aquatic Chronic 3; H412: 100 Notifiers
- Aquatic Chronic 4; H413: 1 Notifier
- Aquatic Chronic 1: H410: 1 Notifier
- Not classified: 50 Notifiers

The relevant property information taken from the publicly available REACH dissemination dossier (ECHA, 2020f) is summarised in **Table 3.30**.

Table 3.30: Predicted properties of 1-chlorendic anhydride (from REACH dissemination dossier)

Property	Value	Comment
Molecular formula	$C_9H_2Cl_6O_3$	
Molecular weight	370.83 g/mol	
Boiling Point	294.3°C	
Log Kow	-1.59	Refers to chlorendic acid
Vapour pressure	2.68×10^{-3} Pa at 25°C. 3.685×10^{-8} Pa at 25°C.	Chlorendic anhydride. Estimated for chlorendic acid.
Water solubility	<2.5 mg/l at 20°C 500 mg/l at 20°C	Chlorendic anhydride. Refers to chlorendic acid.
Henry's law constant	No available data	Data Gap
Hydrolysis half-life	Rapid	Chlorendic anhydride hydrolyses

Property	Value	Comment
		to chlorendic acid immediately on contact with water.
Biodegradation half-life	Not inherently biodegradable	
Bioconcentration factor	No available data	Data Gap
PNECs	$PNEC_{water}$ = 0.097 mg/l $PNEC_{marine\ water}$ = 0.01 mg/l $PNEC_{sediment}$ =0.097 mg/kg dw $PNEC_{marine\ sediment}$ = 0.01 mg/kg dw $PNEC_{soil}$ = 0.106 mg/kg dw $PNEC_{oral\ (secondary\ poisoning)}$ = 2.51 mg/kg food	

Chlorendic anhydride has a higher vapour pressure and water solubility than DP and so may have a higher potential than DP for loss to the environment from articles containing the substance by volatilisation and leaching during the service life of articles. However, the substance is used as a reactive flame retardant and, as such, will become chemically bound within the polymer matrix which then is unavailable for such losses. The substance reacts rapidly with water forming chlorendic acid. Chlorendic acid is not inherently biodegradable but, based on the log Kow value of -1.59, is not expected to bioaccumulate significantly in organisms in the environment.

The substance is currently undergoing SEv as a result of concerns over the exposure of the environment and the PBT/vPvB properties. It was concluded that the substance does not meet the criteria for a PBT or vPvB substance as it has a low bioaccumulation potential (ECHA, 2015a). However, ECHA has requested further information from the registrants on the environmental effects and to clarify the environmental exposure assessment for the whole lifecycle of this substance, including service-life and disposal as part of the on-going substance evaluation (ECHA, 2018). Chlorendic anhydride hydrolyses rapidly to chlorendic acid and exposure to the hydrolysis product may occur when hydrolysis during use is significant.

Technical feasibility of chlorendic anhydride

Chlorendic anhydride is used as an intermediate in synthesis of unsaturated flame-retardant polyester resins and plasticizers, and as a finishing flame-retardant treatment for wool. It is also used as a cross-linking agent in epoxy resins as a low-smoke component in polyols for rigid polyurethane foams and is also used in UV curable inks and coatings for its adhesion to metal. It is considered technically feasible based on proven existing use in the coating and epoxy resin applications (see Section 3.2.2 Identification of potential alternative substances and techniques fulfilling the function).

Economic feasibility of chlorendic anhydride

Loading

No information on loading was found for chlorendic anhydride.

Price

Chlorendic anhydride is significantly more expensive than DP. Price information found for this substance is summarised in **Table 3.31**.

Table 3.31: Prices for chlorendic anhydride

Price (€/kg)	Sources
22	Alibaba.com (2020a)
111	Alibaba.com (2020a)
63	Molbase.com (2020a)
106	P212121 (2020)
6	Zauba.com (2015)
6	Hangzhou Trigger Chemical (2020)
74	Alfa Aesar (2020)
Average 56	

Conclusions on chlorendic anhydride

Table 3.32 summarises the conclusions on feasibility and suitability of chlorendic anhydride as an alternative for DP.

Table 3.32: Conclusions on feasibility and suitability of chlorendic anhydride

Category	Conclusion
Hazard	There is no harmonised classification for environmental hazards, but around 100 notifications for *Aquatic Chronic* hazards (H410, H412, H413). Chlorendic anhydride is listed on the CoRAP for REACH Evaluation, and further testing has been requested for the mutagenicity of this substance. It currently has the following harmonised classification: • Skin Irrit. 2; H315 Specific concentration limit C ≥1% • Eye Irrit. 2; H319 Specific concentration limit C ≥1% • STOT SE 3; H315 Specific concentration limit C ≥1%
Technical feasibility	Chlorendic anhydride is technically feasible for the function flame retardancy, based on proven existing use in the coating and epoxy resin applications.
Economic feasibility	No loading information was found for chlorendic anhydride, but the price is considerably higher than DP, and chlorendic anhydride is thus unlikely to be an economically feasible alternative.
Overall conclusion	Chlorendic anhydride is technically feasible for some of the uses of DP (i.e. as coating and epoxy resin applications) but is not considered economically feasible. There is also a concern due to the identified hazards for human health and the environment. Overall, chlorendic anhydride is considered a poor alternative to DP.

Assessment of ammonium polyphosphate (CAS No. 14728-39-9; 68333-79-9)

Ammonium polyphosphate (APP) CAS numbers 14728-39-9 and 68333-79-9, EC No. 269-789-9 is a halogen-free flame retardant that is sold in the form of a white powder. APP is the main constituent of many intumescent flame-retardant systems (forming protective char foams upon combustion) in the form of coatings, paint, and engineering plastics. It meets the technical function of DP as described in Section 2.2.3.

Availability of ammonium polyphosphate

The REACH registration tonnage band for ammonium polyphosphate is 10,000 – 100,000 t/y. This is a larger tonnage band than is registered for DP, so with this in mind, it is believed that aluminium polyphosphate is or will be available in sufficient volumes by the time a restriction would enter into force.

Human health risks related to ammonium polyphosphate

There is no harmonised classification. The following human health classifications have been notified for ammonium polyphosphate (CAS No. 68333-79-9) (accessed March 2021):

- Acute Tox. 4; H302 and Eye Irrit. 2; H319: 15 Notifiers (Joint entry)
- Not classified: 472 Notifiers

On the basis of the majority of the notified classifications, ammonium polyphosphate is assumed to present a generally low hazard to human health. Some products may present hazards related to eye irritation and may be harmful if swallowed.

Environment risks related to ammonium polyphosphate

The substance is not classified for environmental hazards.

The relevant property information taken from the publicly available REACH dissemination dossier (ECHA, 2020g) is summarised in **Table 3.33**.

Table 3.33: Predicted properties of ammonium polyphosphate (from REACH dissemination dossier)

Property	**Value**	**Comment**
Molecular formula	$[NH_4PO_3]n$, where n <100	Substance appears to consist mainly of ammonium orthophosphates, ammonium diphosphate and ammonium triphosphates
Molecular weight	115.03 g/mol 132.06 g/mol 229.07 g/mol 270.95 g/mol	Ammonium dihydrogenorthophosphate Diammonium hydrogenorthophosphate Triammonium hydrogen diphosphate Pentaammonium triphosphate
Boiling Point	No available data	Thermal decomposition onset, °C 285 Min
Log Kow	Not relevant – inorganic substance	
Vapour pressure	0.076 Pa at 20°C	Read across from an analogous substance
Water solubility	>50% w/w of solution at 20°C	
Henry's law constant	No data	Data Gap
Hydrolysis half-life	Dissociates into ionic components and the phosphate anion has no potential for hydrolysis.	
Biodegradation half-life	Inorganic substance and therefore, biodegradation studies are not applicable	
Bioconcentration factor	No data	Data Gap
PNECs	$PNEC_{water}$ = no hazard identified $PNEC_{marine\ water}$ = no hazard identified $PNEC_{sediment}$ =no hazard identified $PNEC_{marine\ sediment}$ = no hazard identified $PNEC_{soil}$ = no hazard identified $PNEC_{oral\ (secondary\ poisoning)}$ = no potential for bioaccumulation	

Ammonium polyphosphate has a higher vapour pressure and water solubility than DP and so may have a higher potential than DP for loss to the environment from articles containing the substance by volatilisation and leaching during the service life of articles. It is not expected to bioaccumulate significantly in organisms in the environment and the available evidence suggests that the substance presents a low hazard to the environment.

Technical feasibility of ammonium polyphosphate

Ammonium polyphosphate is the main constituent of intumescent flame-retardant systems such as coating, paint, and engineering plastics. It is suitable for water and solvent based intumescent coatings and has low water solubility making it useful in applications where the product is exposed to high humidity conditions or water. It contains high concentrations of phosphorus and therefore is a very effective fire retardant. It is a technically feasible alternative to DP where DP functions as a fire retardant as described in Section 2.2.3.

Economic feasibility of ammonium polyphosphate

Loading

Ammonium polyphosphate is typically used in concentrations between 18% - 30%, whilst DP is used in 5% - 25% depending on use. It is therefore likely that a slightly higher loading will be needed if ammonium polyphosphate is used as a replacement for DP, although the difference is fairly small. **Table 3.34** presents information found on loading in available literature.

Table 3.34: Loading for ammonium polyphosphate

Loading (% w/w)	Material / Use	Sources
30%	PP	Wu, Wang and Liang (2008)
18%	PP / PE	Fr.polymerinsights.com (n.d.)
25%	PP / PE	Fr.polymerinsights.com (n.d.)
19%	PU	Yeo, Wang, Guan, Fu, Zhang, Dou (2017)
20%	PP / PVC / PE	Changsha Green Mountain Chemical Co (n.d.)
20%	PP / PVC / PE / PU	Connect Chemicals (2020)
80%	PP	Yang, Yu, Li, Zheng, Luo, Suo and Jiang (2019)
35%	PP	Shao, Deng, Tan, Yu, Chen, Chen and Wang (2014)

Notes: PP refers to polypropylene, PE refers to polyethylene, PU refers to polyurethane and PVC refers to polyvinyl chloride

Price

Ammonium polyphosphate is cheaper than DP, with average price (of the sources found) five times lower than DP. Price information found for ammonium polyphosphate is summarised in **Table 3.35**.

Table 3.35: Prices for ammonium polyphosphate

Price (€/kg)	Sources
1.7	Alibaba.com (2020b)
4.4	Alibaba.com (2020b)
2.3	Zauba.com (2016)
2.9	Zauba.com (2016)
1.1	Made-in-china.com (2020a)
5.5	Made-in-china.com (2020a)
1.8	Shandong Chenxu New Material(2020a)
2.1	Shandong Chenxu New Material (2020a)
1.3	dir.indiamart.com (2020a)
3.5	dir.indiamart.com (2020a)
Average 2.7	

Conclusions on ammonium polyphosphate

Table 3.36 summarises the conclusions on feasibility and suitability of ammonium polyphosphate as an alternative for DP.

Table 3.36: Conclusions on feasibility and suitability of ammonium polyphosphate

Category	Conclusion
Hazard	Ammonium polyphosphate does not have a harmonised classification, and based on notified classifications, it is concluded that the substance is of low concern to human health and the environment.
Technical feasibility	Ammonium polyphosphate is the main constituent of intumescent flame-retardant systems such as coating, paint, and engineering plastics. Due to its high concentration of phosphorus, it is a very effective flame retardant and is considered a technically feasible alternative to DP for the function flame retardancy.
Economic feasibility	The typical loading found for ammonium polyphosphate is on average higher than what has been reported for DP. However, since the price is considerably lower than the average price of DP, it is concluded that this substance is an economically feasible alternative to DP.
Overall conclusion	Ammonium polyphosphate is a both technically and economically feasible alternative to DP. Based on the available evidence, the substance is of low concern to the environment and for human health. Overall, it is concluded that ammonium polyphosphate is a suitable alternative to DP for flame retardant applications.

Assessment of aluminium hydroxide (CAS No. 21645-51-2; 8064-00-4; 1318-23-7)

Aluminium hydroxide is used as a fire-retardant filler for polymer applications. It is selected for these applications because it is colourless, inexpensive, and has good fire-retardant properties (Hudson et al., 2000). It decomposes at about 180 °C (356 °F), absorbing a considerable amount of heat in the process and giving off water vapour. In addition to behaving as a fire retardant, it is very effective as a smoke suppressant in a wide range of polymers, most especially in polyesters, acrylics, ethylene vinyl acetate, epoxies, PVC and rubber (Huber, 2017).

Availability of aluminium hydroxide

The REACH registration tonnage band for aluminium hydroxide is 1 million – 10 million t/y. This is a significantly larger tonnage band than is registered for DP. With this in mind, it is believed that aluminium hydroxide is or will be available in sufficient volumes by the time a restriction would enter into force.

Human health risks related to aluminium hydroxide

There is no harmonised classification of aluminium hydroxide. The following aggregated human health classifications have been notified for aluminium hydroxide (CAS No. 21645-51-2) (accessed March 2021):

- Not classified: 1624 Notifiers (joint entries)
- Not classified: 13 Notifiers
- Not applicable (no classification): 38 Notifiers
- Skin Irrit.2; H315, Eye Irrit. 2; H319, STOT SE 3; H335: 422 Notifiers
- H315, H319, H335: 4 Notifiers
- Aerosol 1: H222, H229; Eye Irrit. 2; H319, STOT SE 3; H336: 1 Notifier
- Eye Irrit. 2; H319, STOT SE 3; H335: 24 Notifiers
- Eye Irrit. 2; H319: 23 Notifiers
- H319: 3 Notifiers
- Skin Irrit. 2; H315: 20 Notifiers

Based on most of the notified classifications, aluminium hydroxide is assumed to present a generally low hazard to human health. Some products may present hazards related to skin and eye irritation and may cause respiratory irritation.

Environment risks related to aluminium hydroxide

The ECHA classification and labelling inventory contains over 2,000 Notified classifications for aluminium hydroxide. The vast majority of these indicate that the substance is not classified for environmental hazards. There are only six Notifications for Aquatic Acute 1; H400 and Aquatic Chronic 1; H410.

The relevant property information taken from the publicly available REACH dissemination dossier (ECHA, 2020h) are summarised in **Table 3.37**.

Table 3.37: Predicted properties of aluminium hydroxide (from REACH dissemination dossier)

Property	Value	Comment
Molecular formula	AlH_3O_3	
Molecular weight	78.00 g/mol	
Boiling Point	2980 °C	

Log Kow	Not relevant – inorganic substance	
Vapour pressure	No data	Expected to have negligible vapour pressure at 25°C
Water solubility	≤0.09 mg/L at 20°C.	
Henry's law constant	No data	Data Gap
Hydrolysis half-life	May form insoluble aluminium hydroxides.	
Biodegradation half-life	Not relevant – inorganic substance	
Bioconcentration factor	Does not bio magnify	BCF values range from ~100 l/kg to up to 11,000 l/kg depending upon the exposure conditions.
PNECs	$\text{PNEC}_{\text{water}}$ = no hazard identified $\text{PNEC}_{\text{marine water}}$ = no hazard identified $\text{PNEC}_{\text{sediment}}$ = insufficient data available $\text{PNEC}_{\text{marine sediment}}$ = insufficient data available $\text{PNEC}_{\text{soil}}$ = insufficient data available $\text{PNEC}_{\text{oral (secondary poisoning)}}$ = insufficient data available	

Aluminium hydroxide has a lower vapour pressure than DP and is sparingly soluble so may have a lower potential than DP for loss to the environment from articles containing the substance by volatilisation and leaching during the service life of articles. It is not expected to bioaccumulate significantly in organisms in the environment and the available evidence suggests that the substance presents a low hazard to the environment.

Technical feasibility of aluminium hydroxide

In plasticised polyvinyl chloride (PVC) fine precipitated aluminium hydroxide trihydrate (ATH) is used as a flame retardant and smoke suppressant. The major use is in so called Low Smoke Flame Retardant (LSFR) cables. It is a technically feasible alternative to DP where DP functions as a fire retardant in cables as described in Section 2.2.3.

Economic feasibility of aluminium hydroxide

Loading

Information found in publicly available sources indicate that aluminium hydroxide is used as a flame retardant in concentrations around 60%. This is considerably higher than loading for DP. **Table 3.38** presents information found on loading in available literature.

Table 3.38: Loading for aluminium hydroxide

Loading (% w/w)	Material / Use	Sources
65%	SEBS	Xiao and Kibble (2008)

Notes: SEBS refers to styrene-ethylene/butylene-styrene block copolymer

Price

Aluminium hydroxide is cheaper than DP, with an average price substantially lower than DP (€/kg). **Table 3.39: Prices for aluminium hydroxide** shows the price information found for aluminium hydroxide.

Table 3.39: Prices for aluminium hydroxide

Price (€/kg)	Sources
0.3	alibaba.com (2020c)
0.9	alibaba.com (2020c)
0.9	Molbase.com (2020b)
2.2	Molbase.com (2020b)
0.5	Shandong Chenxu New Material (2020b)
2.2	Shandong Chenxu New Material (2020b)
0.4	Made-in-china.com (2020b)
Average 1.1	

Conclusions on aluminium hydroxide

Table 3.40 summarises the conclusions on feasibility and suitability of aluminium hydroxide as an alternative for DP.

Table 3.40: Conclusions on feasibility and suitability of aluminium hydroxide

Category	Conclusion
Hazard	Aluminium hydroxide does not have a harmonised classification, and based on notified classifications, it is concluded that the substance is of low concern to human health and the environment is of low concern.
Technical feasibility	The most common use of aluminium hydroxide is in 'Low Smoke Flame Retardant (LSFR)' cables. It is considered a technically feasible alternative to DP for the function flame retardancy where DP functions as a fire retardant in cables.
Economic feasibility	Aluminium hydroxide is cheaper than DP per kg. Although, the typical loading found is considerably (>3x) higher than what has been reported for DP, it is considered an economically feasible alternative to DP.
Overall conclusion	Aluminium hydroxide is an economically and technically feasible alternative to DP. Based on the available evidence, the substance is of low concern to the environment and for human health. Overall, it is concluded that aluminium hydroxide is a suitable alternative to DP for flame retardant applications.

Assessment of ethane-1,2-bis (pentabromophenyl) (EBP) (CAS No. 84852-53-9)

Availability of ethane-1,2-bis (pentabromophenyl)

ECHA (2015b) reported that EBP is being marketed as a direct "drop-in" replacement of decaBDE, and that several industry actors saw EBP as the obvious replacement for decaBDE. It is therefore reasonable to assume that production capacity for this substance has increased, in anticipation of the decaBDE restriction. A similar process occurs if a restriction for DP is recommended by the SEAC and RAC. With this in mind, it is believed that EBP will be available in sufficient volumes by the time a restriction would enter into force.

Human health risks related to ethane-1,2-bis (pentabromophenyl)

There is no harmonised classification for EBP. The notified classifications in the ECHA classification and labelling inventory indicates that the substance is not classified for hazards to human health. Therefore, available data suggests that the substance presents a low hazard to human health.

Environment risks related to ethane-1,2-bis (pentabromophenyl)

There is no harmonised classification for EBP. The ECHA classification and labelling inventory contains 611 Notified classifications for EBP. The vast majority of these indicate that the substance is not classified for environmental hazards. There is only one notification for Aquatic Chronic 4; H413.

A comprehensive environmental risk assessment of EBP is available (Dungey and Akintoye, 2007). The relevant property information from Dungey and Akintoye, (2007) are summarised in **Table 3.41**. Where different data are reported in the disseminated registration dossier ECHA website (ECHA, 2020i) this is noted in the comment column.

Table 3.41: Predicted properties of ethane-1,2-bis(pentabromophenyl) (from Dungey and Akintoye, 2007)

Property	Value	Comment
Molecular formula	$C_{14}H_4Br_{10}$	
Molecular weight	971.23 g/mole	
Boiling Point	Probably degrades before boiling occurs	
Log Kow	~7 to 10	The ECHA disseminated dossier gives the log Kow as 3.55.
Vapour pressure	~1×10^{-6} Pa at 25ºC	The ECHA disseminated dossier gives the vapour pressure as $<1\times10^{-4}$ Pa at 20°C
Water solubility	~0.72 µg/l at 25ºC	
Henry's law constant	1.35 Pa.m^3/mol at 25°	The ECHA disseminated dossier gives the estimated Henry's law constant as 6.5×10^{-3} Pa.m^3/mole (Bond method) and 3.0×10^{-3} Pa.m^3/mole (Group method)
Hydrolysis half-life	Insignificant removal process in the environment	
Biodegradation half-life	Not readily biodegradable	
Bioconcentration factor	Uncertain	Dungey and Akintove (2007) assumed BCF values of 25 l/kg and 1,600 l/kg but both values have limitations. The ECHA disseminated dossier concludes that the substance does not bioconcentrate in fish.
PNECs	$PNEC_{water}$ = no hazard identified $PNEC_{marine\ water}$ = no hazard identified $PNEC_{sediment}$ ≥60 mg/kg wet weight $PNEC_{marine\ sediment}$ ≥6 mg/kg wet weight $PNEC_{soil}$ = 26 mg/kg wet weight PNECoral $_{(secondary\ poisoning)}$ ≥220 mg/kg food	The ECHA dissementated dossier gives the following PNECs: $PNEC_{water}$ = no hazard identified $PNEC_{marine\ water}$ = no data; aquatic toxicity unlikely $PNEC_{sediment}$ 100 mg/kg dw $PNEC_{marine\ sediment}$ 10 mg/kg dw $PNEC_{soil}$ = 156 mg/kg dw PNECoral $_{(secondary\ poisoning)}$ = no potential for bioaccumulation

EBP has lower vapour pressure than DP, suggesting that it may have a slightly lower potential than DP for loss to the environment by volatilisation from articles during their service life. The water solubility of EBP is higher than that for DP, suggesting that it may have a slightly higher potential for loss to the environment by leaching from articles than for DP over their service life. The available evidence suggests that EBP presents a generally low hazard to organism in the environment, but there are uncertainties over the bioaccumulation potential of the substance.

In relation to the PBT-properties of the substance, Dungey and Akintove (2007) concluded that the substance was potentially very persistent but did not meet the REACH Annex XIII toxicity criterion. However, the lack of reliable data meant that no firm conclusions on the bioaccumulation potential could be drawn. The substance is undergoing Substance Evaluation within the EU (ECHA, 2015b; 2016b) due to suspected PBT/VPvB concern, high aggregated tonnage and wide dispersive use. Further testing has been requested to address concerns over the PBT/vPvB properties of this substance.

Technical feasibility of ethane-1,2-bis (pentabromophenyl)

EBP is a flame retardant containing a high level of aromatic bromine which can be used in a wide range of high-performance applications. It is widely used in styrenic polymers, engineering resins, wire and cables. It has strong thermal stability which makes it suitable for high temperature applications. It also exhibits good UV resistance and is therefore suitable for use in applications requiring colour stability. Due to its thermal stability and low blooming characteristics, this DP alternative is suitable for use in systems where recycling is anticipated. It is a technically feasible alternative to DP in its functions as a flame retardant as detailed in Section 2.2.3.

Economic feasibility of ethane-1,2-bis (pentabromophenyl)

Loading

In the REACH restriction proposal for decaBDE (ECHA, 2015b) it was presented information on loading for various materials for which EBP is used as a flame retardant, shown in **Table 3.42**. The loading reported by ECHA indicates that EBP is used in similar concentrations as DP.

Table 3.42: Loading for EBP

Loading (% w/w)	Material	Sources
12%	HIPS	ECHA (2015b)
13%	HIPS	ECHA (2015b)
10%	PBT	ECHA (2015b)
16%	PA	ECHA (2015b)
18%	PA	ECHA (2015b)
20%	Polyolefins	ECHA (2015b)
30%	Polyolefins	ECHA (2015b)

Notes: HIPS refers to high impact polystyrene, PBT refers to polybutylene terephthalate and PA refers to polyamide.

Price

Available price information for EBP indicates that it is generally cheaper than DP. Price information is found for this substance in **Table 3.43**.

Table 3.43: Prices for EBP

Price (€/kg)	Sources
5.5	alibaba.com (2020d)
11.1	alibaba.com (2020d)
6.8	Guanzhou Realise Green Chemical Technology (2008)
6.9	Guanzhou Realise Green Chemical Technology (2008)
3.3	Chongqing Caifchem (2020)
3.9	Chongqing Caifchem (2020)
5.0	Qingdao Richkem (2020)
4.4	ECHA (2015b)
5.0	ECHA (2015b)
Average 5.8	

Conclusions on ethane-1,2-bis (pentabromophenyl)

Table 3.44 summarises the conclusions on feasibility and suitability of EBP as an alternative for DP.

Table 3.44: Conclusions on feasibility and suitability of EBP

Category	Conclusion
Hazard	EBP does not have a harmonised classification for human health or environmental hazards. However, there are uncertainties over the bioaccumulation potential of the substance. In relation to the PBT-properties of the substance, Dungey and Akintove (2007) concluded that the substance was potentially very persistent but did not meet the REACH Annex XIII toxicity criterion. The substance is undergoing Substance Evaluation within the EU due to PBT/vPvB concern (ECHA, 2015b; 2016b). Further testing has been requested to address concerns over the PBT/vPvB properties of this substance.
Technical feasibility	EBP contains a high level of aromatic bromine, which can be used in a wide range of high-performance applications. It is widely used in styrenic polymers, engineering resins, wire and cables. Due to its thermal stability and low blooming characteristics, this DP alternative is suitable for use in systems where recycling is anticipated. It is a technically feasible alternative to DP in its functions as a flame retardant.
Economic feasibility	The necessary loadings found for EBP are similar to loadings reported for DP in the stakeholder consultation. The price is considerably lower (50%), which combined implies that the alternative is economically feasible.
Overall conclusion	EBP is considered a technically feasible alternative, requiring similar loading as DP and with a considerably lower price. It therefore seems to be the most obvious replacement for DP. However, its hazard profile is unclear and still under investigation due to suspected PBT/vPvB concern, high aggregated tonnage and wide dispersive use, hence, it may be a regrettable substitute.

Assessment of long chain chlorinated paraffins (CAS No. 63449-39-8) – LCCP

Availability of long chain chlorinated paraffins

The REACH registration tonnage band for long chain chlorinated paraffins is 10,000 – 100,000 t/y. This is a larger tonnage band than is registered for DP, so with this in mind, it is believed that long chain chlorinated paraffins is or will be available in sufficient volumes by the time a restriction would enter into force.

Human health risks related to long chain chlorinated paraffins

There is no harmonised classification for long chain chlorinated paraffins. The vast majority of the Notified classifications in the ECHA classification and labelling inventory indicate that the substance is not classified for hazards to human health (648 Notifications) (accessed March 2021). The Notifications are summarised below.

- Not classified: 649 Notifications
- Eye Irrit. 2; H319: 20 Notifications
- Lact.; H362: 12 Notifications
- Acute Tox. 4; H332: 2 Notifications
- Carc, 2; H351: 2 Notifications
- STOT RE 2; H373: 2 Notifications
- Skin Irrit. 2; H315, Eye Irrit. 2; H319: 1 Notification
- Flam. Liq. 2; H225, Eye Irrit. 2; H319, STOT SE 3, Carc. 2; H351, STOT RE 1, H372: 1 Notification

Based on the majority of the notified classifications, long chain chlorinated paraffins seems to present a relatively low hazard to human health.

Environment risks related to long chain chlorinated paraffins

The ECHA classification and labelling inventory contains 681 Notified classifications for long chain chlorinated paraffins. The vast majority of these indicate that the substance is not classified for environmental hazards. There are only two Notifications for Aquatic Acute 1; H400 and three Notifications for Aquatic Acute 1; H400; Aquatic Chronic 1; H410.

A comprehensive environmental risk assessment of long chain chlorinated paraffins is available (Brooke et al, 2009a). The relevant property information from Brooke et al. (2009a) is summarised in **Table 3.45**.

Table 3.45: Predicted properties of long chain chlorinated paraffins (from Brooke et al., 2009a unless otherwise stated)

Property	**Value**	**Comment**
Molecular formula	$C_nH_{2n+2-y}Cl_y$, where n=18–32 and y=4–30	Long chain chlorinated paraffins are UVCB substances with a range of carbon chain lengths and chlorine contents. Long chain chlorinated paraffins fall into two main categories; $C_{18–20}$ products and $C_{>20}$ products.
Molecular weight	$\sim$323 to >1,000 g/mole	
Boiling Point	>200°C	The ECHA disseminated registration dossier indicates that the substance decomposes at >210°C
Log Kow	9.7 10.3 17	$C_{18–20}$ liquids (typically 40–52% wt Cl) $C_{>20}$ liquids (typically 40–54% wt. Cl) $C_{>20}$ solids (typically 70% wt. Cl)
Vapour pressure	2.5×10^{-4} Pa at 25°C 2.5×10^{-5} Pa at 25°C 1.5×10^{-14} Pa at 25°C	$C_{18–20}$ liquids (typically 40–52% wt Cl) $C_{>20}$ liquids (typically 40–54% wt. Cl) $C_{>20}$ solids (typically 70% wt. Cl)

		The ECHA disseminated registration dossier gives similar estimates of representative chloroalkane chemicals range from around 5×10^{-4}Pa to 6.3×10^{-15} Pa at 25°C for liquid products and 1.4×10^{-15} to 6.1×10^{-19} at 25ºC for solid products.
Water solubility	0.003 mg/l at 16–20°C 0.0066 mg/l at 25°C 0.0059 mg/l at 25°C	C_{25}, 42% wt. Cl C_{25}, 43% wt. Cl C_{25}, 70% wt. Cl The ECHA disseminated registration dossier indicates that the water solubility is 0.005 mg/l or lower at 25°C.
Henry's law constant	16 Pa m^3/mole at 25°C 15 Pa m^3/mole at 25°C 1×10^{-6} Pa m3/mole at 25°C	$C_{18–20}$ liquids (typically 40–52% wt Cl) $C_{>20}$ liquids (typically 40–54% wt. Cl) $C_{>20}$ solids (typically 70% wt. Cl)
Hydrolysis half-life	Stable	
Biodegradation half-life	Not readily biodegradable	The ECHA disseminated registration dossier concludes that although long-chain chlorinated paraffins are not readily biodegradable there is evidence that they will biodegrade in the environment.
Bioconcentration factor	1,069 l/kg 192 l/kg <1 l/kg	$C_{18–20}$ liquids (typically 40–52% wt Cl) $C_{>20}$ liquids (typically 40–54% wt. Cl) $C_{>20}$ solids (typically 70% wt. Cl)
PNECs	$PNEC_{water}$ = 0.0029 – 0.005 mg/l $PNEC_{sediment}$ 5,710 to >1,200,000 mg/kg wet weight $PNEC_{marine\ sediment}$ 1,140 to >239,000 mg/kg wet weight $PNEC_{soil}$ = 4,640 to >971,000 mg/kg wet weight PNECoral $_{(secondary\ poisoning)}$ 5 to 22 mg/kg food	Range reflects the different chain lengths and chlorine contents considered.

Long chain chlorinated paraffins are UVCB substances (substances of unknown or variable composition, complex reaction products or biological materials) and the properties of long chain chlorinate paraffins depend upon the carbon chain lengths and chlorine contents contained within the products. In general terms, long chain chlorinated paraffins with shorter carbon chains and lower chlorine contents have vapour pressures of a similar order of magnitude as DP, suggesting that these long chain chlorinated paraffins may have a similar potential for loss to the environment by volatilisation from articles over their service life as DP. The vapour pressure (and hence potential for volatilisation loss from articles) of long chain chlorinated paraffins tends to decrease as both the carbon chain length and chlorine content increases. The water solubility of long chain chlorinated paraffins is generally slightly higher than that for DP which suggests that long chain chlorinated paraffins may have a slightly higher potential for leaching loss to the environment from articles than DP.

Long-chain chlorinated paraffins are persistent in the environment but have a generally low potential for bioaccumulation. The substance has undergone a PBT assessment and it was concluded that the substance is not a PBT substance (ECB, 2007).

Certain long-chain chlorinated paraffins may contain significant amounts of shorter-chain chlorinated paraffin constituents. This is a relevant consideration as medium-chain chlorinated paraffins (C_{14-17} chlorinated paraffins) have been identified as PBT/vPvB substances during substance evaluation (UK EA, 2019). The situation, however, is complex and requires and understanding of the constituents that may be common to both medium-chain chlorinated paraffins and long-chain chlorinated paraffins, and the possible PBT-properties of those common constituents.

Brooke et al. (2009a) identifies two main groups of long-chain chlorinated paraffins:C_{18-20} long-chain chlorinated paraffins which are based on a C_{18-20} feedstock; and $C_{>20}$ long-chain chlorinated paraffins which are based on a $C_{>20}$ feedstock. The feedstocks used for the $C_{>20}$ long-chain chlorinated paraffins have no constituents in common with medium-chain chlorinated paraffins (they contain <0.2% C_{20} and 0% C_{19} or below; Brooke et al. (2009a)). However, feedstocks used for the C_{18-20} chlorinated paraffins contain around 17% C_{17} constituents (typical value; range 10-20%) but <1% C_{16} constituents and so could potentially have C_{17} chlorinated constituents (and small amounts of C_{16} chlorinated constituents) that may also be present in medium-chain chlorinated paraffins. The medium-chain chlorinated paraffins have been identified as PBT/vPvB substances based on their content of persistent, bioaccumulative and toxic constituents in the <C_{14} to C_{15} range. For C_{16} and C_{17} carbon chain lengths the conclusions were less clear, with evidence of degradation occurring for products with chlorine contents ≤45% weight (UK EA, 2019). Overall, it can be concluded that long-chain chlorinated paraffins with carbon chain lengths >C_{20} do not have significant amounts of constituents in common with medium-chain chlorinated paraffins. The C_{18-20} chlorinated paraffins may have constituents in common with medium-chain chlorinated paraffins but the consequence of this, in terms of the PBT-properties, is not clear.

Technical feasibility of long chain chlorinated paraffins

Long chain chlorinated paraffins as extreme pressure (EP) additives are a specific class of boundary lubricity additives that either react with the metal surface to form a metal salt layer under extreme boundary lubrication conditions or form a carbonated film between two metal surfaces under severe lubrication conditions. Chlorinated Paraffins (CPs) are found in plastics, rubber, paints, adhesives, and miscellaneous other substances. When used as an additive in cutting oils and machining fluids they function effectively as an extreme pressure agent and based on the established existing use it is a technically feasible alternative for DP in the same applications as detailed in Section 2.2.3.

Economic feasibility of long chain chlorinated paraffins

Loading

No information has been found on loading of LCCPs used as a lubricity additive.

Price

The available price information for LCCPs indicates that the price of these substances is generally lower than that of DP. Price information found for this is presented in substance **Table 3.46**.

Table 3.46: Prices for LCCPs

Price (€/kg)	Sources
1.7	Alibaba.com (2020e)
1.3	Alibaba.com (2020e)
1.2	Shandong Chenxu New Material (2020)
Average 1.4	

Conclusions on long chain chlorinated paraffins

Table 3.47 summarises the conclusions on feasibility and suitability of LCCPs as an alternative for DP.

Table 3.47: Conclusion on feasibility and suitability of LCCPs

Category	Conclusion
Hazard	LCCPs do not have a harmonised classification. LCCPs are persistent in the environment but have a generally low potential for bioaccumulation. The substance group has undergone a PBT assessment and it was concluded that it is not a PBT. However, certain long-chain chlorinated paraffins may contain significant amounts of shorter-chain chlorinated paraffin constituents, which is relevant as medium-chain chlorinated paraffins (C14-17 chlorinated paraffins) have been identified as PBT/vPvB substances.
Technical feasibility	Chlorinated paraffins (CPs) are found in plastics, rubber, paints, adhesives, and miscellaneous other substances. When used as an additive in cutting oils and machining fluids, they function effectively as an extreme pressure agent and based on the established existing use, it is a considered a technically feasible alternative to DP.
Economic feasibility	The prices found are low compared to the price of DP, but without information on loading a firm conclusion on economic feasibility cannot be drawn. However, considering the low price compared to DP, it is likely that this substance group may be an economically feasible alternative.
Overall conclusion	LCCPs are technically feasible alternatives for DP in the function as extreme pressure additives for lubricants and greases. The substance group is also likely economically feasible and available, and thus is a potential alternative for DP for the function as an extreme pressure additive for lubricants and greases. The substance is not a PBT, but it is persistent in the environment. An additional concern is that, in some cases, LCCPs may contain significant amounts of medium-chain chlorinated paraffins which are identified as PBT/vPvBs. In such cases, LCCPs would be a regrettable substitute to DP.

Assessment of tricresyl phosphate (CAS No. 1330-78-5; EC 809-930-9) – TCP

Availability of tricresyl phosphate

The REACH registration tonnage band for tricresyl phosphate is 1,000 – 10,000 t/y. This is a larger tonnage band than is registered for DP, so with this in mind, it is believed that tricresyl phosphate is or will be available in sufficient volumes by the time a restriction would enter into force.

Human health risks related to tricresyl phosphate

There is no harmonised classification for tricresyl phosphate (CAS No. 1330-78-5; EC 809-930-9). The Notified classifications in the ECHA classification and labelling inventory are summarised below (accessed March 2021).

- Repr. 2; H361: 7 Notifications

The substance therefore presents a hazard to fertility or the unborn child.

The substance is currently undergoing substance evaluation (ECHA, 2016b). Further information has been requested on the worker exposure and further testing has been requested in order to clarify concerns over the neurotoxicity of the substance.

Environment risks related to tricresyl phosphate

The notified classifications in the ECHA classification and labelling inventory indicate are summarised below (accessed March 2021).

- Aquatic Acute 1; H400, Aquatic Chronic 1; H410 7 Notifications

A comprehensive environmental risk assessment of tricresyl phosphate is available (Brooke et al., 2009b). The relevant property information from Brooke et al. (2009b) is summarised in **Table 3.48**.

Table 3.48: Predicted properties of tricresyl phosphate (from Brooke et al., 2009b unless otherwise indicated)

Property	Value	Comment
Molecular formula	$C_{21}H_{21}O_4P$	
Molecular weight	368.37 g/mol	
Boiling Point	>300°C	The ECHA disseminated registration dossier gives the boiling point as 400°C.
Log Kow	5.11	The ECHA disseminated registration dossier gives the log Kow as 5.93.
Vapour pressure	6.6×10^{-5} Pa at 25°C	The ECHA disseminated registration dossier gives the vapour pressure as 0 Pa at 20°C.
Water solubility	0.36 mg/l at room temperature	The ECHA disseminated registration dossier gives the water solubility as 0.27 mg/l at 20°C.
Henry's law constant	0.068 Pa m^3/mol at 25°C	
Hydrolysis half-life	1,100-2,200 days at pH 7 and 25°C 30-40 days at pH 8 and 25°C	The ECHA disseminated registration dossier gives the half-life as 44.4 days at pH 7 25°C.
Biodegradation half-life	Estimated to be 15 days in surface water, 30 days in soil and 300 days in sediment	
Bioconcentration factor	310 to 800 l/kg	
PNECs	$PNEC_{water}$ = 0.032 µg/l $PNEC_{marine\ water}$ = 0.0032 µg/l $PNEC_{sediment}$ = 0.0033 mg/kg wet weight $PNEC_{marine\ sediment}$ 0.00033 mg/kg wet weight $PNEC_{soil}$ = 0.0027 mg/kg wet weight $PNECoral_{(secondary\ poisoning)}$ 1.7 mg/kg food	The ECHA disseminated registration dossier gives the following: $PNEC_{water}$ = 0.001 mg/l $PNEC_{marine\ water}$ = 0.0001 mg/l $PNEC_{sediment}$ = 2.05 mg/kg dry weight $PNEC_{marine\ sediment}$ 0.205 mg/kg dry weight $PNEC_{soil}$ = 1.01 mg/kg dry weight $PNECoral_{(secondary\ poisoning)}$ 0.65 mg/kg food

Brooke et al. (2009b) concluded that tricresyl phosphate does not meet the criteria for a PBT or vPvB substances. However, the PBT properties are one of the areas currently under consideration in the on-going Substance Evaluation (ECHA, 2016b).

The vapour pressure is of a similar order to, but slightly lower than, that of DP suggesting that the substance may have a similar potential to DP for loss to the environment by volatilisation from articles over their service life. Tricresyl phosphate has a higher water solubility than DP and therefore may have a higher potential for loss to the environment by leaching from articles over their service life than DP. However, once in the environment the tricresyl phenol is expected to biodegrade and would not be expected to bioaccumulate appreciably. However, the classification of the substance indicates that the substance is very toxic to aquatic life with long-lasting effects.

Technical feasibility of tricresyl phosphate

As described in Section 2.2.3, tricresyl phosphate forms a multilayer film on steel surfaces which acts as a lubricious polymer. Tricresyl phosphate have been known to reduce friction and wear under boundary lubrication conditions since the 1940s. It is widely available and performs the same function as DP when employed as an extreme pressure lubricant and based on the established existing use it is a technically feasible alternative for DP in the same applications as detailed in Section 2.2.3.

Economic feasibility of tricresyl phosphate

Loading

No information has been found on loading of TCP used as a lubricity additive.

Price

The prices found for TCP are similar to that of DP (€ 5 – € 10/kg). Price information found for this substance is listed in **Table 3.49**.

Table 3.49: Prices for TCP

Price (€/kg)	Sources
4	Alibaba.com (2020f)
6	Alibaba.com (2020f)
7	Molbase.com (2020c)
8	Molbase.com (2020c)
9	dir.indiamart.com (2020b)
10	dir.indiamart.com (2020b)
11	N SHASHIKANT & CO. (n.d.)
Average 8	

Conclusions on tricresyl phosphate

Table 3.50 summarises the conclusions on feasibility and suitability of tricresyl phosphate as an alternative for DP.

Table 3.50: Conclusions on feasibility and suitability of TCP

Category	Conclusion
Hazard	There is no harmonised classification for TCP. However, the notified classifications in the ECHA classification and labelling inventory contain Repr. 2 classifications, which indicates a hazard to fertility or an unborn child.
Technical feasibility	TCP forms a multilayer film on steel surfaces which acts as a lubricious polymer. It has been known to reduce friction and wear under boundary lubrication conditions since the 1940s and performs the same function as DP when employed as an extreme pressure lubricant.

Economic feasibility	The prices found are similar compared to the price of DP, but without information on loading a firm conclusion on economic feasibility cannot be drawn.
Overall conclusion	TCP is a technically feasible alternative for DP in the function as a lubricant, but its economic feasibility is unknown. Availability is seemingly not a problem. It does, however, have notified classifications as Repr. 2, which could mean that it is a regrettable substitute.

Assessment of diallyl chlorendate (CAS No. 3232-62-0)

Availability of diallyl chlorendate

This substance has no tonnage (per annum) data for manufacture and/or import into the European Economic Area on the ECHA website. Thus, it is unlikely that diallyl chlorendate is or will be available in sufficient volumes by the time a restriction would enter force.

Human health risks related to diallyl chlorendate

Diallyl chlorendate has not been registered under the EU REACH Regulation and there are no entries for the substance in the ECHA classification and labelling inventory below (accessed March 2021).

No information has been located on the human health hazards or risks associated with this substance. Even though there is no experimental data available, diallyl chlorendate is predicted as 'likely' to meet criteria for category 1A or 1B carcinogenicity, mutagenicity, or reproductive toxicity (ECHA, 2020e).

Environment risks related to diallyl chlorendate

Very limited information on the environmental risks from diallyl chlorendate is available. The properties in **Table 3.51** have been predicted for the substance by the US EPA (2021).

Table 3.51: Predicted properties of diallyl chlorendate (from US EPA, 2021)

Property	Predicted average	Predicted range
Molecular formula	$C_{15}H_{12}Cl_6O_4$	
Molecular weight	468.96 g/mol	
Boiling Point	441°C	387 to 495°
Log Kow	5.98	4.67 to 7.31
Vapour pressure	2.0×10^{-5} Pa (temperature not stated)	8.1×10^{-8} to 3.9×10^{-5} Pa (temperature not stated)
Water solubility	3.50 mol/l (temperature not stated).	5.36×10^{-5} to 7.00 mol/l (temperature not stated)
Henry's law constant	3.46 Pa m^3/mol (temperature not stated)	
Hydrolysis half-life	No data	Data Gap
Biodegradation half-life	12.9 days (temperature not stated)	
Bioconcentration factor	356 l/kg	
PNECs	No data available	Data Gap

Based on the predicted data available the substance is not likely to be a PBT or vPvB substance. The predicted vapour pressure is of a similar order to, but slightly lower than, that of DP suggesting that the substance may have a similar potential to DP for loss by volatilisation from articles. There is a large uncertainty over the water solubility with predictions in the range 5.36×10^{-5} to 7.00 mol/l (this is equivalent to 0.025 to 3,280 g/l), therefore the potential for leaching from articles is uncertain, but may be higher than that for DP. However, once in the environment the substance is expected to biodegrade rapidly and would not be expected to bioaccumulate appreciably.

No information is available on the environmental toxicity of this substance.

Technical feasibility of diallyl chlorendate

Diallyl chlorendate is a sulfur-chlorinated ester of chlorendic acid and used in mineral oils to provide extreme pressure lubricants and metal working oils. Under extreme pressure it significantly improves the load carrying ability thus satisfying the requirements demanded in the lubrication of bearing, gears, which are subjected to heavy loads per unit area of surface.

Economic feasibility of diallyl chlorendate

No information was found on the loading and prices for diallyl chlorendate.

Conclusions on diallyl chlorendate

Table 3.52 summarises the conclusions on feasibility and suitability of diallyl chlorendate as an alternative for DP.

Table 3.52: Conclusions on feasibility and suitability of diallyl chlorendate

Category	Conclusion
Hazard	Diallyl chlorendate is not registered under REACH and no information has been located on the human health hazards or risks associated with this substance. It is, however, predicted as 'likely' to meet criteria for category 1A or 1B carcinogenicity, mutagenicity, or reproductive toxicity.
Technical feasibility	Under extreme pressure, diallyl chlorendate, significantly improves the load carrying ability thus satisfying the requirements demanded in the lubrication of bearing gears. Based on the available information, this substance may be a technically feasible alternative.
Economic feasibility	No loading or price information was found for diallyl chlorendate. Economic feasibility can therefore not be assessed.
Overall conclusion	Diallyl chlorendate is potentially a technically feasible alternative to DP in lubricants/greases. However, due to the lack of information on economic factors and availability, it is not considered a suitable alternative in the short term.

References

ABBASI, G., SAINI, A., GOOSEY, E. & DIAMOND, M. L. (2016). Product screening for sources of halogenated flame retardants in Canadian house and office dust. Science of the Total Environment, 545, 299-307.

ACEA (2015). European Automobile Manufacturers Association (2015) POPs and Vehicle Recycling – Proposal for a time limited solution, POP-RC 11 Meeting, Rome, 20 October 2015.

ADAMA (2019). ADAMA Reports on Progress Towards Anpon Acquisition. Available at: https://www.adama.com/en/449/adama-reports-on-progress-towards-anpon-acquisition

AECOM (2018). Promising New PFAS Treatment Technology DE-FLUOROTM Shows Complete Destruction of PFAS. Available at: https://www.aecom.com/wp-content/uploads/2018/10/PFAS-Info-Sheet.pdf

Albemarle (2013). Chemical Safety Report, 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] (EBP), EC No. 284-366-9, CAS No. 84852-53-9.

Alfa Aesar (2020). Alfa Aesar – Products: Chlorendic Anhydride, 95%, may cont. up to 3% chlorendic acid. Available at: https://www.alfa.com/en/catalog/L07349/

Alibaba.com (2020a). Alibaba – Products: Chlorendic Anhydride. Available at: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=chlorendic+anhydride

Alibaba.com (2020b). Alibaba – Products: Ammonium Polyphospate. Available at: https://www.alibaba.com/trade/search?IndexArea=product_en&CatId=&fsb=y&viewtype=&tab=&SearchScene=&SearchText=Ammonium+polyphosphate

Alibaba.com (2020c). Alibaba – Products: Aluminium Hydroxide. Available at: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=Aluminium+hydroxide&viewtype=&tab=

Alibaba.com (2020d). Alibaba – Products: Ethan-1,2-bis(pentabromophenyl). Available at: https://www.alibaba.com/trade/search?IndexArea=product_en&CatId=&fsb=y&viewtype=&tab=&SearchScene=&SearchText=Ethan-1%2C2-bis+%28pentabromophenyl%29

Alibaba.com (2020e). Alibaba – Products: Long chain chlorinated paraffins. Available at: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=Long+chain+chlorinated+paraffins&viewtype=&tab=

Alibaba.com (2020f). Alibaba – Products: Tricresyl phosphate. Available at: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=Tricresyl+phosphate

BADEA, S. L., GEANA, E. I., NICULESCU, V. C. & IONETE, R. E. (2020). Recent progresses in analytical GC and LC mass spectrometric based-methods for the detection of emerging chlorinated and brominated contaminants and their transformation products in aquatic environment. Science of the Total Environment, 722.

Baldé et al., (2017). The Global E-waste Monitor 2017 – Quantities, Flows and Resources. Available at: https://www.itu.int/en/ITU-D/Climate-Change/Documents/GEM%202017/Global-E-waste%20Monitor%202017%20.pdf

Basel Convention (2020). Updating and or Development of Technical Guidelines for the Environmentally Sound Management of Wastes Consisting of, Containing or Contaminated with Persistent Organic Pollutants. Available at: http://www.basel.int/Implementation/POPsWastes/TechnicalGuidelines/tabid/5052/Default.aspx

Brooke DN, Crookes MJ and Merckel D (2009a). Environmental risk evaluation report: Long-chain chlorinated paraffins. Environment Agency Science Report SCHO0109BPGR-E-E. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290855/scho0109bpgr-e-e.pdf

Brooke DN, Crookes MJ, Quarterman P and Burns J (2009b). Environmental risk evaluation report: Tricresyl phosphate (CAS no. 1330-78-5). Environment Agency Science Report SCHO0809BQUJ-E-E. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290861/scho0809bquj-e-e.pdf

Camino, (1998). Camino, G., 1998. Flame retardants: intumescent systems. In Plastics Additives (pp. 297-306).

Springer, Dordrecht. Available at: https://link.springer.com/chapter/10.1007/978-94-011-5862-6_33

CANTER, N. (2014). EP additives: Regulatory updates of chlorinated paraffins and options on alternatives. Tribology & Lubrication Technology, 70, 10.

CARRETIER, V., DELCROIX, J., PUCCI, M. F., RUBLON, P. & LOPEZ-CUESTA, J.-M. (2020). Influence of Sepiolite and Lignin as Potential Synergists on Flame Retardant Systems in Polylactide (PLA) and Polyurethane Elastomer (PUE). Materials, 13, 2450.

Castrovinci and Camino, (2007). Fire-Retardant Mechanisms in Polymer Nano-Composite Materials. In: Duquesne S., Magniez C., Camino G. (eds) Multifunctional Barriers for Flexible Structure. Materials Science, vol 97. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-71920-5_5

Changsha Green Mountain Chemical Co (n.d.). Products – Ammonium Polyphosphate. Available at: http://www.greenmountchem.com/product_detail_en1/id/46.html

Chaqmaqchee et al. (2017). Comparison of Various Plastics Wastes Using X-ray Fluorescence. Available at: https://www.oeko.de/fileadmin/oekodoc/ACEA-DecaBDE-final-report.pdf

Chemtura. (2011). Chemtura launches Great Lakes Solutions brand with three new flame retardants. Additives for Polymers. Volume 2011, Issue 1, 2011, Pages 2-3, ISSN 0306-3747. https://doi.org/10.1016/S0306-3747(11)70002-1

CHENG, Y., DING, J., XIE, X. C., JI, X. W. & ZHANG, Y. K. (2019). Validation and Application of a 3-Step Sequential Extraction Method to Investigate the Fraction Transformation of Organic Pollutants in Aging Soils: A Case Study of Dechlorane Plus. Environmental Science & Technology, 53, 1325-1333.

Chongqing Caifchem (2020). ECVV – Chongqing Caifchem Co. Ltd.: 1,2-bis(pentabromophenyl) ethane. Available at: https://www.ecvv.com/product/4684792.html

Chrissafis and Bikiaris, (2011). Can nanoparticles really enhance thermal stability of polymers? Part I: An overview on thermal decomposition of addition polymers. Thermochimica Acta. 523. 1-24. 10.1016/j.tca.2011.06.010.

ComRef (2019). "Comments and references to responses" document. Document compiling comments and references to respective answers from commenting period 05/09/2018 – 05/12/2018 on ECHA's proposal to include Dechlorane Plus in its 9th recommendation of priority substances for inclusion in the list of substances subject to authorisation (Annex XIV).

Connect Chemicals (2020). Products – Ammonium Polyphosphate. Available at: https://connectchemicals.com/en/product-finder/ammonium-polyphosphate

Danish EPA (1999). Danish Environmental Protection Agency. Brominated Flame Retardants – Substance Flow Analysis and Assessment of Alternatives. Available at: https://www2.mst.dk/udgiv/Publications/1999/87-7909-416-3/html/kap07_eng.htm

Danish EPA (2006). Environmental Project No. 1141 2006 Deca-BDE and Alternatives in Electrical and Electronic Equipment. https://www2.mst.dk/Udgiv/publications/2007/978-87-7052-349-3/pdf/978-87-7052-350-9.pdf

Defra (2010). Department for Environment, Food and Rural Affairs. Annex 3: Review of Alternative Fire Retardant Technologies. Available at: https://www2.mst.dk/udgiv/Publications/1999/87-7909-416-3/html/kap07_eng.htm

Defra (2020). Department for Environment, Food & Rural Affairs. Methods for the pre-treatment and destruction of persistent organic pollutants. Available at: https://www.google.com/search?q=Methods+for+the+pre-treatment+and+destruction+of+persistent+organic+pollutants&rlz=1C1GCEA_enGB871GB871&oq=Methods+for+the+pre-treatment+and+destruction+of+persistent+organic+pollutants&aqs=chrome..69i57j69i60.1702j0j7&sourceid=chrome&ie=UTF-8#

dir.indiamart.com (2020a). Indiamart – Products: Ammonium Polyphosphate. Available at: https://dir.indiamart.com/impcat/ammonium-polyphosphate.html

dir.indiamart.com (2020b). Indiamart – Products: Tricresyl Phosphate. Available at: https://dir.indiamart.com/impcat/tricresyl-phosphate.html

Dungey S and Akintoye L (2007). Environmental risk evaluation report: 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]. Environment Agency Science Report SCHO0507BMOR-E-P. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290840/scho0507bmor-e-e.pdf

EA (2009). Environment Agency August 2009, An overview of the environmental risk evaluation reports for aryl phosphate esters, Authors: Brooke D N, Crookes M J, Quarterman P and Burns J,. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290484/scho0809bqtz-e-e.pdf

EA (2018). UK Environment Agency. Risk Management Option Analysis Conclusion Document "Dechlorane Plus" TM (Public version). 02 July 2018. In: AGENCY, E. (ed.). https://echa.europa.eu/documents/10162/789c216f-575f-74ab-8090-960cdc763156

EC (2018). European Commission. COMMISSION STAFF WORKING DOCUMENT - A European Strategy for Plastics in a Circular Economy. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018SC0016&from=EN

EC (2019). 32st Meeting of Competent Authorities for REACH and CLP (CARACAL). Open session, Doc. CA/66/2019, AP 7.1 (REACH) - Summary of inputs to the call for information on socio-economic elements related to the ECHA's 9th draft recommendation for prioritisation of substances for authorisation.

EC (2020a). European Commission. Cosmetic ingredient database. Available at: https://ec.europa.eu/growth/sectors/cosmetics/cosing_en

EC (2020b). European Commission. EU Circular Economy Action Plan. https://ec.europa.eu/environment/circular-economy/

ECB (2007). Summary Fact Sheet, Paraffin waxes and hydrocarbon waxes, chloro. TC NES Subgroup on Identification of PBT and vPVB substances. PBT Working Group – PBT List No 110. European Chemicals Bureau, November 2007. https://www.echa.europa.eu/documents/10162/53d22bf8-517b-41fb-9808-84a9535b4574

ECCC (2019). Environment and Climate Change Canada. *Screening Assessment; Certain Organic Flame Retardants Substance Grouping; Dechlorane Plus*. *May 2019*. Available at: https://www.canada.ca/content/dam/eccc/documents/pdf/pded/ofr-dp/Screening-assessment-certain-organic-flame-retardants-substance-grouping-dimethanodibenzo-cyclooctene-dodecachloro-dodecahydro-dechlorane-plus-dp.pdf

ECHA (2008). Guidance on Socio-economic Analysis – Restrictions. Available at: https://echa.europa.eu/documents/10162/23036412/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

ECHA (2012). European Chemicals Agency. Guidance on information requirements and chemical safety assessment. Chapter R.18: Exposure scenario building and environmental release estimation for the waste life stage. Version 2.1, October 2012.

ECHA (2015a). DECISION ON SUBSTANCE EVALUATION PURSUANT TO ARTICLE 46(1) OF REGULATION (EC) NO 1907/2006 For l,4,5,6,7,7-hexachloro-8,9,l0-trinorborn-5-ene-2,3-dicarboxylic anhydride, CAS No 115-27-5 (EC No 204-077-3), ECHA 19 March 2015. https://echa.europa.eu/documents/10162/09664e38-5357-ebb2-a9e0-f05495acf590

ECHA (2015b). European Chemicals Agency. *Bis(pentabromophenyl)ether Background Document*. *2015*. Available at: https://echa.europa.eu/documents/10162/2c27ddcc-dd0c-49e3-85ba-fa64b0813775

ECHA (2016a). European Chemicals Agency. *Guidance on information requirements and Chemical Safety Assessment. Chapter R.16: Environmental exposure assessment. European Chemicals Agency, Version 3.0. February 2016.*

ECHA (2016b). Decision on Substance Evaluation for tris(methylphenyl) phosphate. European Chemicals Agency, July 2016. https://www.echa.europa.eu/documents/10162/7ece29a7-3859-2fd7-742e-f278f443dd24

ECHA (2017a). European Chemicals Agency. *Annex XV report: Proposal for identification of a substance of very high concern on the basis of the criteria set out in REACH Article 57*. *2017*. Available at: https://echa.europa.eu/documents/10162/2b729df8-a54f-1485-f77b-185457d96fbd

ECHA (2017b). European Chemicals Agency. *MEMBER STATE COMMITTEE SUPPORT DOCUMENT FOR IDENTIFICATION OF 1,6,7,8,9,14,15,16,17,17,18,18-DODECACHLOROPENTACYCLO[12.2.1.16,9.02,13.05,10] OCTADECA-7,15-DIENE ("DECHLORANE PLUS"TM) [COVERING ANY OF ITS INDIVIDUAL ANTI- AND SYN-ISOMERS OR ANY COMBINATION THEREOF] AS A SUBSTANCE OF VERY HIGH CONCERN BECAUSE OF ITS vPvB PROPERTIES (ARTICLE 57(E)). 2017.* Available at: https://echa.europa.eu/documents/10162/97b3c3bf-f38a-f3e2-6b53-45654bcc02dc

ECHA (2017d). Guidance on Information Requirements and Chemical Safety Assessment, Chapter R.11: PBT/vPvB assessment, Version 3.0, June 2017

ECHA (2017e). Annex XV Appendix - Identification of Dechlorane Plus as SVHC. Detailed summaries of the data cited in the main report. Available at: https://echa.europa.eu/documents/10162/86c6520a-cdc8-86bf-cc86-57beef04bc6f

ECHA (2018). DECISION ON SUBSTANCE EVALUATION. Substance name: 1,4,5,6,7,7-hexachloro-8,9,1O-trinorborn-5-ene-2,3-dicarboxylic anhydride, hereinafter referred as chlorendic anhydride. EC number: 204-077-3. CAS number: 115-27-5. Date of latest submission(s) consideredL: 22 September 2016. Helsinki, 20 December 2018. . In: AGENCY, E. C. (ed.). https://echa.europa.eu/documents/10162/695a4b48-187b-bef4-85df-9c786fc3bf3b

ECHA (2019a). European Chemicals Agency. *Background document for 1,6,7,8,9,14,15,16,17,17,18,18-dodecachloropentacyclo[12.2.1.16,9.02,13.05,10]octadeca-7,15-diene1 ("Dechlorane Plus"™)*. *2019*. Available at: https://echa.europa.eu/documents/10162/13640/9th_recom_final_backgdoc_dechlorane_plus_en.pdf

ECHA (2019b). EUSES - European Union System for the Evaluation of Substances. Available at: https://echa.europa.eu/support/dossier-submission-tools/euses

ECHA (2019c). European Chemicals Agency. *Comments on ECHA's Draft 9th Recommendation for Dechlorane Plus*. *2019*. Available at: https://echa.europa.eu/documents/10162/13640/9th_recom_respdoc_dechlorane_plus_en.pdf

ECHA (2020a). European Chemicals Agency. *Substance Information 1,6,7,8,9,14,15,16,17,17,18,18-dodecachloropentacyclo[12.2.1.16,9.02,13.05,10]octadeca-7,15-diene*. *2020*. Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.033.575

ECHA (2020b). European Chemicals Agency. Brief Profile 1,6,7,8,9,14,15,16,17,17,18,18-dodecachloropentacyclo[12.2.1.16,9.02,13.05,10]octadeca-7,15-diene. *2020*. Available at: https://echa.europa.eu/brief-profile/-/briefprofile/100.033.575

ECHA (2020c). European Chemicals Agency. *1,6,7,8,9,14,15,16,17,17,18,18-dodecachloropentacyclo[12.2.1.16,9.02,13.05,10]octadeca-7,15-diene - uses at industrial sites*. *2020*. Available at: https://echa.europa.eu/registration-dossier/-/registered-dossier/11906/3/1/4

ECHA (2020d). European Chemicals Agency. *Dechlorane Plus_draft supporting document (INF)*. *2020*. Available at: https://www.echa.europa.eu/documents/10162/bd568772-caf2-9848-b3a1-0ba640821fe9

ECHA (2020e). European Chemicals Agency. Annex III inventory. Available at: https://echa.europa.eu/information-on-chemicals/annex-iii-inventory/-/dislist/details/AIII-100.019.796

ECHA (2020f). European Chemicals Agency. 1,4,5,6,7,7-hexachloro-8,9,10-trinorborn-5-ene-2,3-dicarboxylic anhydride – General information. Available at: https://www.echa.europa.eu/web/guest/registration-dossier/-/registered-dossier/2215

ECHA (2020g). European Chemicals Agency. Polyphosphoric acids, ammonium salts – General information. Available at: https://www.echa.europa.eu/web/guest/registration-dossier/-/registered-dossier/11698

ECHA (2020h). European Chemicals Agency. Aluminium hydroxide – General information. Available at: https://www.echa.europa.eu/web/guest/registration-dossier/-/registered-dossier/15529

ECHA (2020i). European Chemicals Agency. 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] – Physical & Chemical properties. Available at: https://echa.europa.eu/registration-dossier/-/registered-dossier/15001/4/8

ECHA (2021). Registry of restriction intentions until outcome – 1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.16,9.02,13.05,10]octadeca-7,15-diene ("Dechlorane Plus"™). Available at: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e184a168c4

EEA (2021). Fogh Mortensen, L., Tange, I., Stenmarck, Å., Fråne, A., Nielsen, T., Boberg, N. and Bauer, F., 2021. Plastics, the circular economy and Europe' s environment-A priority for action. EEA Report, (18/2020). Available at: https://www.eea.europa.eu/publications/plastics-the-circular-economy-and

EFRA (2012a). Fireaway! The EFRA Quarterly Newsletter. European Flame Retardants Association. Summer 2012. https://polymerandfire.files.wordpress.com/2012/07/efra-newsletter-n3_summer-2012.pdf

EFRA (2012b). The Voluntary Emissions Control Action Programme. MAINTAINING MOMENT. European Annual Progress Report 2012. https://www.vecap.info/uploads/graphs_March_XP8_08-04_light.pdf.

ENFIRO (2014). ENFIRO [Online]. http://www.compoundingworld.com/enfiro

EN ISO (2003). EN ISO 20623, 2003. Petroleum and related products-Determination of the extreme pressure and anti-wear properties of fluids-Four ball method (European conditions). . https://www.iso.org/obp/ui/#iso:std:iso:20623:ed-2:v1:en

EuRIC (2020). EuRIC call for recycled plastic content in cars – Position paper, 24 February 2020. . https://www.euric-aisbl.eu/position-papers/download/616/351/32

Eurostat (n.d.). Median gross hourly earnings, all employees (excluding apprentices), 2014. Available at: https://ec.europa.eu/eurostat/statistics-explained/images/e/ec/Median_gross_hourly_earnings%2C_all_employees_%28excluding_apprentices%29%2C_2014.png

FEICA (2017a). FEICA/EFCC SPERC 2.1a.v3 - Formulation of Solvent-borne and Solvent-less Adhesives / Sealants and Construction Chemical Products - non-volatile Substances. Available at: https://echa.europa.eu/documents/10162/22872657/feica_efcc_sperc_2.1a.v3_en.pdf/43c2d358-7c5d-cd35-0df6-646c7a02acca

FEICA (2017b). FEICA / EFCC SPERC 2.2b.v3 - Formulation of Water-borne Adhesives / Sealants and Construction Chemical Products – non-volatile Substances. Available at: https://echa.europa.eu/documents/10162/22872657/feica_efcc_sperc_2.2b.v3_en.pdf/fa26637d-610d-e4ff-59ea-eb424960ac7b

FEICA (2017c). FEICA SPERC 5.1a.v3. Industrial Use of non-volatile Substances in Solvent-borne and Solvent-less Adhesives / Sealants. Available at: https://echa.europa.eu/documents/10162/22751800/feica_sperc_5.1a_v3_en.pdf/a5dcd77d-6d64-80dc-5ac4-fe1a19e8a7b0

FEICA (2017d). FEICA SPERC 5.1c. v3. Industrial Use of non-volatile Substances in Water-borne Adhesives / Sealants. Available at: https://echa.europa.eu/documents/10162/22751800/feica_sperc_5.1c_v3_en.pdf/02a8fefc-6596-a0b8-51ec-0c1415d3b574

FR-ONLINE (2021). Flame Retardants Online. Flame Retardants – Synergism. [Online]. https://www.flameretardants-online.com/flame-retardants/synergism [Accessed].

Fr.polymerinsights.com (n.d.). Flame Retardants – Ammonium Polyphosphate. Available at: http://fr.polymerinsights.com/fr-types/phosphorous/app

GANCI, A. P., VANE, C. H., ABDALLAH, M. A. E., MOEHRING, T. & HARRAD, S. (2019). Legacy PBDEs and NBFRs in sediments of the tidal River Thames using liquid chromatography coupled to a high resolution accurate mass Orbitrap mass spectrometer. Science of the Total Environment, 658, 1355-1366.

GRAVEL, S., LAVOUÉ, J., BAKHIYI, B., DIAMOND, M. L., JANTUNEN, L. M., LAVOIE, J., ROBERGE, B., VERNER, M.-A., ZAYED, J. & LABRÈCHE, F. (2019). Halogenated flame retardants and organophosphate esters in the air of electronic waste recycling facilities: Evidence of high concentrations and multiple exposures. Environment international, 128, 244-253.

GREAT LAKES SOLUTIONS 2013. Recent developments in flame retardants for sustainable fire safety solutions. May 2013. [Online presentation] [Online]. http://greatlakes.com/deployedfiles/ChemturaV8/GreatLakes/Flame%20Retardants/FR%20Brochures/GLS%20-%202013%20Chinaplas.pdf . [Accessed].

Guanzhou Realise Green Chemical Technology (2008). LookChem – Products: 1,2,-bis(pentapbromophenyl) ethane DBDPE Flame Retardant. Available at: https://www.lookchem.com/product_1-2-bis-pentabromophenyl-Ethane-Dbdpe-Flame-Retardant/13473954.html

Hangzhou Trigger Chemical (2020). Made in China – Hangzhou Trigger Chemical: Chlorendic Anhydride. Available at: https://www.made-in-china.com/showroom/duguanghua/product-detailyfgxbUpMOnXD/China-Chlorendic-Anhydride.html

Hansen, K. M., Fauser, P., Vorkamp, K. and Christensen, J. H., (2020). Global emissions of Dechlorane Plus. Science of the Total Environment, 742, 140677.

Hou et al. (2018). Hou, M., Wang, Y., Zhao, H., Zhang, Q., Xie, Q., Zhang, X., Chen, R. and Chen, J., 2018. Halogenated flame retardants in building and decoration materials in China: Implications for human exposure via inhalation and dust ingestion. Chemosphere, 203, pp.291-299. Available at: https://www.sciencedirect.com/science/article/pii/S0045653518306106?via%3Dihub

HUBER (2017). Huber Engineered Materials. Non-Halogen Fire Retardant Additives. [Online]. https://www.hubermaterials.com/userfiles/files/PFDocs/Huber%20Non-

Halogen%20Fire%20Retardant%20Additives.pdf

HUDSON, L. K., MISRA, C., PERROTTA, A. J., WEFERS, K. & WILLIAMS, F. (2000). Aluminum oxide. Ullmann's Encyclopedia of industrial chemistry.

ICL Industrial Products (2013). Flame retardants http://iclip.com/wpcontent/uploads/2013/08/FR-Brochure-2013-web.pdf

Illinois EPA (2007). Report on Alternatives to the Flame Retardant DecaBDE: Valuation of Toxicity, Availability, Affordability and Fire Safety Issues. http://www.epa.state.il.us/reports/decabde-study/decabde-alternatives.pdf

ILO, (2012). International Labour Office. The global impact of e-waste: Addressing the challenge. Author Karin Lundgren. Program on Safety and Health at Work and the Environment (SafeWork), Sectorial activities Department (SECTOR), Geneva, pp 1-71.

Impag (2018). ChemWorld 2018. Available at: https://www.impag.ch/fileadmin/user_upload/CH/Files/Performance_Chemicals/Publikationen/Chemworld_2018_Web.pdf

IVL (2010). Swedish Environmental Research Institute. *Results from the Swedish National Screening Programme 2009*. *2010*. Available at: https://www.ivl.se/download/18.343dc99d14e8bb0f58b75d8/1445517465108/B1950.pdf

IVM (2015). Benchmark development for the proportionality assessment of PBT and vPvB substances. Report by IVM Institute for Environmental Studies (Frans Oosterhuis and Roy Brouwer). Available at: https://echa.europa.eu/documents/10162/13647/R15_11_pbt_benchmark_report_en.pdf

Johnson and Hills (2013). Lubricants 2013, 1, 132-148; doi:10.3390/lubricants1040132: Phosphate Esters, Thiophosphate Esters and Metal Thiophosphates as Lubricant Additives; Link: https://www.mdpi.com/2075-4442/1/4/132

JRC, European Commission Joint Research Centre (2007). Review on production processes of decabromodiphenyl ether (decabde) used in polymeric applications in electrical and electronic equipment, and assessment of the availability of potential alternatives to DecaBDE https://publications.jrc.ec.europa.eu/repository/bitstream/JRC36323/EUR%2022693.pdf

KemI (2004). Survey and technical assessment of alternatives to Decabromodiphenyl ether (DecaBDE) in textile applications, Sundyberg, Sweden: Swedish Chemicals Inspectorate. https://www.kemi.se/global/pm/2004/pm-5-04.pdf

KemI (2005). Survey and technical assessment of alternatives to Decabromodiphenyl ether (decaBDE) in plastics, Stockholm: Swedish Chemicals Inspectorate (KEMI). https://www.kemi.se/global/rapporter/2005/rapport-1-05.pdf

KemI (2007). Swedish Chemicals Agency Commodity Guide [database]. 2007. CAS no 13560-89-9 Dechlorane Plus. Cited in ECCC, 2019a.

KemI (2009). Swedish Chemicals Agency. DecaBDE - Report from a government assignment. ISSN: 0284 - 1185. https://www.kemi.se/download/18.6df1d3df171c243fb23a9912/1591454113711/rapport-1-09-dekabde.pdf

Kumar et al. (2017). Kumar, A., Holuszko, M. and Espinosa, D.C.R., 2017. E-waste: an overview on generation, collection, legislation and recycling practices. Resources, Conservation and Recycling, 122, pp.32-42.

LASSEN, C., HAVELUND, S., LEISEWITZ, A. & MAXSON, P. (2006). Deca-BDE and alternatives in electrical and electronic equipment. Danish EPA. https://www2.mst.dk/Udgiv/publications/2007/978-87-7052-349-3/pdf/978-87-7052-350-9.pdf

Lowell Centre for Sustainable Production (2005). Decabromodiphenylether: An Investigation of Non- Halogen Substitutes in Electronic Enclosure and Textile Applications. https://noharm-uscanada.org/sites/default/files/documentsfiles/29/DecaBDE_Non_Halogen_Substitutes.pdf

Made-in-china.com (2020a). Made in China – Products: Ammonium Polyphosphate. Available at: https://www.made-in-china.com/products-search/hot-china-products/Ammonium_Polyphosphate_Price.html

Made-in-china.com (2020b). Made in China – Products: Aluminium Hydroxide. Available at: https://www.made-in-china.com/products-search/hot-china-products/Aluminium_Hydroxide_Price.html

MAISEL, F., CHANCEREL, P., DIMITROVA, G., EMMERICH, J., NISSEN, N. F. & SCHNEIDER-RAMELOW, M. (2020). Preparing

WEEE plastics for recycling–How optimal particle sizes in pre-processing can improve the separation efficiency of high quality plastics. Resources, Conservation and Recycling, 154, 104619.

MARINESCU, I. D., ROWE, W. B., DIMITROV, B. & OHMORI, H. (2012). Tribology of abrasive machining processes, William Andrew.

Mazela, B, Batista, A and Grzeskowiak, W. (2020). Expandable Graphite as a Fire Retardant for Cellulosic Materials - A Review. Forests,11, 755. doi:10.3390/f11070755.

MERKISZ-GURANOWSKA, A. Waste recovery of end-of-life vehicles. IOP Conference Series: Materials Science and Engineering, 2018. IOP Publishing, 032019.

Molbase.com (2020a). Molbase – Products: Chlorendic Anhydride. Available at: https://www.molbase.com/cas/115-27-5.html

Molbase.com (2020b). Molebase – Products: Aluminium Hydroxide. Available at: http://www.molbase.com/cas/21645-51-2-p-2.html

Molbase.com (2020c). Molbase – Products: Phosphoric Acid Tricresyl Ester. Available at: http://www.molbase.com/cas/1330-78-5.html

N SHASHIKANT & CO. (n.d.). Fire Retardant Liquid TCP Tricrysl Phosphate. Available at: https://www.nescoglobal.com/fire-retardant.html

NEA (2019). Norwegian Environment Agency. *Survey of hazardous substances in articles.* Report M-1259. (2019). Available at: https://www.miljodirektoratet.no/publikasjoner/2019/februar-2019/survey-of-hazardous-substances-in-articles/

NEUGEBAUER, F., DREYER, A., LOHMANN, N. & KOSCHORRECK, J. (2018). Determination of halogenated flame retardants by GC-API-MS/MS and GC-EI-MS: a multi-compound multi-matrix method. Analytical and Bioanalytical Chemistry, 410, 1375-1387.

NIIR BOARD OF CONSULTANTS & ENGINEERS (2005). Chapter 13 Allyl Ester resins,. Synthetic Resins Technology Handbook. https://www.niir.org/books/book/synthetic-resins-technology-handbook-niir-board-consultants-engineers/isbn-8178330261/zb,,cf,a,0,0,a/index.html : Asia Pacific Business Press Inc.

Noria, n.d. Machinery Lubrication – Limitations of Extreme Pressure Additives. Available at: https://www.machinerylubrication.com/Read/29031/extreme-pressure-additives

OECD (2004). OECD Series On Emission Scenario Documents Number 3 Emission Scenario Document On Plastic Additives
ENV/JM/MONO(2004)8/REV1 http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)8/rev1&doclanguage=en

OECD (2009). Organisation for Economic Co-operation and Development. *OECD Series on Emission Scenario Documents. Number 3. Emission Scenario Document on Plastic Additives.* ENV/JM/MONO(2004)8/REV1., *2009*. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)8/rev1&doclanguage=en

OxyChem (2007). Occidental Chemical Corporation. Dechlorane Plus Manual. 2007. Available at: https://www.oxy.com/OurBusinesses/Chemicals/Products/Documents/dechloraneplus/dechlorane_plus.pdf

OxyChem (2013). Occidental Chemical Corporation. *Product Stewardship summary – Dechlorane Plus*. *2013*. Available at: https://www.oxy.com/OurBusinesses/Chemicals/ResponsibleCare/Documents/Dechlorane%20Plus.pdf

P212121 (2020). P212121 – Chemicals: Chlorendic Anhydride 100g. Available at: https://store.p212121.com/chlorendic-anhydride/

PINFA (2010a). Innovative Flame Retardants in E&E Applications - Non-halogenated phosphorus, inorganic and nitrogen flame retardants. Available at: https://www.pinfa.eu/wpcontent/uploads/2018/05/PINFA_Transportation_Brochure_2010_Final_Version.pdf

PINFA (2010b). Innovative and Sustainable Flame Retardants in Transportation - Non-halogenated phosphorus, inorganic and nitrogen flame retardants. Available at: https://www.pinfa.eu/wp-content/uploads/2018/05/PINFA_Transportation_Brochure_2010_Final_Version.pdf

PINFA (2010c). Innovative and Sustainable Flame Retardants in Transportation. Non-halogenated phosphorus, inorganic and nitrogen flame retardants. Phosphorus, Inorganic and Nitrogen Flame Retardants Association. September 2010. [Online] https://www.pinfa.eu/wp-content/uploads/2018/05/PINFA_Transportation_Brochure_2010_Final_Version.pdf

PINFA (2013). Innovative and Sustainable Flame Retardants in Building and Construction - Non-halogenated phosphorus, inorganic and nitrogen flame retardants. [Online] https://www.pinfa.eu/wp-content/uploads/2018/05/pinfa_BC_edit-2017-web.pdf

Plastics Market Watch (2016). Automotive Recycling. Devalued is now Revalued. SPI: The Plastics Industry Trade Association, 2016. Available at: https://www.plasticsindustry.org/sites/default/files/2016-03256-SPI-PMW-Auto-Recycle-web.pdf

POPRC (2021). Persistent Organic Pollutants Review Committee (POPRC). *Revised Draft Risk Profile: Dechlorane Plus*. *February 2021*. Available at: http://www.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Meetingdocuments/tabid/8500/Default.aspx

POPRC-16 (2020). Sixteenth meeting of the Persistent Organic Pollutants Review Committee (POPRC.16). Available at: http://www.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx

Qingdao Richkem (2020). Made in China – Products: 1,2-bis(pentabromophenyl) ethane. Available at: https://www.made-in-china.com/showroom/renben0707/product-detailOyYnlqSGbahu/China-1-2-Bis-pentabromophenyl-Ethane.html

Qiu et al. (2007). Xinghua Qiu, Chris H. Marvin, Ronald A. Hites. Dechlorane plus and other flame retardants in a sediment core from Lake Ontario. Environmental Science and Technology 41: 6014–6019. 2007. Available at: https://pubs.acs.org/doi/10.1021/es070810b

Ramboll (2021) (in prep)). Environmental Pollutants in Post-Consumer Plastics (in preparation). Ramboll Deutshland GmBH on behalf of the Norwegian Environment Agency.

Reche et al. (2019). C. Reche M. Viana, X. Querol, C. Corcellas, D. Barceló, E. Eljarrat. *Particle-phase concentrations and sources of legacy and novel flame retardants in outdoor and indoor environments across Spain*. Science of the Total Environment 649:1541-1552. *2019.* Available at: https://www.sciencedirect.com/science/article/pii/S0048969718333849

Ren et al. (2009). Guofa Ren, Zhiqiang Yu, Shengtao Ma, Huiru Li, Pingan Peng, Guoying Sheng, Jiamo Fu. Determination of Dechlorane Plus in Serum from Electronics Dismantling Workers in South China. Environ. Sci. Technol. 43, 24, 9453-9457. 2009. Available at: https://pubs.acs.org/doi/abs/10.1021/es901672m

REN, G. F., LUO, X. F., MA, S. T., SUN, Y. F., YU, Z. Q., SHENG, G. Y. & FU, J. M. (2011). Quantification of Dechlorane Plus in Human Serum by Gas Chromatography Coupled with Negative Chemical Iionization Mass Spectrometry. Chinese Journal of Analytical Chemistry, 39, 235-238.

RJABOVA, J., VIKSNA, A. & ZACS, D. (2018). Development and optimization of gas chromatography coupled to high resolution mass spectrometry based method for the sensitive determination of Dechlorane plus and related norbornene-based flame retardants in food of animal origin. Chemosphere, 191, 597-606.

RPA (2014). Risk and Policy Analysts (2014). Multiple Framework Contract with Re-opening of competition for Scientific Services for ECHA, Reference: ECHA/2011/01 - Support to an Annex XV Dossier on Bis-(pentabromophenyl) ether (DecaBDE), Final Report Prepared for ECHA. https://echa.europa.eu/documents/10162/13641/annex_xvi_consultant_report_decabde_en.pdf/337cc41c-0964-41a3-8d97-40b785f22fad

Sakai, S., Yoshida, H., Hiratsuka, J., Vandecasteele, C., Kohlmeyer, R., Rotter, V.S., Passarini, F., Santini, A., Peeler, M., Li, J., Oh, G.-J., Chi, N.K., Bastian, L., Moore, S., Kajiwara, N., Takigami, H., Itai, T., Takahashi, S., Tanabe, S., Tomoda K., Hirakawa, T., Hirai, Y., Asari, M. and Yano, J. (2014) An international comparative study of end-of-life vehicle (ELV) recycling systems. Journal of Material Cycles and Waste Management. 16, 1–20. https://doi.org/10.1007/s10163-013-0173-2

Shandong Chenxu New Material (2020b). Made in China – Shandong Chenxu New Material: Aluminium Hydroxide. Available at: https://chenxuchem2001.en.made-in-china.com/product/keywordSearch?word=Aluminium+hydroxide&subaction=hunt&style=b&mode=and&code=0&comProvince=nolimit&order=0&isOpenCorrection=1

Shandong Chenxu New Material(2020a). Made in China – Shandong Chenxu New Material: Ammonium

Polyphosphate. Available at: https://chenxuchem2001.en.made-in-china.com/product/keywordSearch?searchKeyword=Ammonium+polyphosphate&viewType=1

Shao, Deng, Tan, Yu, Chen, Chen and Wang (2014). Shao, Z.B., Deng, C., Tan, Y., Yu, L., Chen, M.J., Chen, L. and Wang, Y.Z., 2014. Ammonium polyphosphate chemically-modified with ethanolamine as an efficient intumescent flame retardant for polypropylene. Journal of Materials Chemistry A, 2(34), pp.13955-13965. Available at: https://pubs.rsc.org/en/content/articlelanding/2014/ta/c4ta02778g#!divAbstract

Shaw et al., (2010). Shaw, S.D., Blum, A., Weber, R., Kannan, K., Rich, D., Lucas, D., Koshland, C.P., Dobraca, D., Hanson, S. and Birnbaum, L.S., 2010. Halogenated flame retardants: do the fire safety benefits justify the risks?. Reviews on environmental health, 25(4), p.261. Available at: https://www.shawinstitute.org/sites/default/files/uploaded/PDF/Shaw_et_al_2010_Halogenated_Flame_retardants.pdf

SHEHU, S. (2017). Separation of plastic waste from mixed waste: Existing and emerging sorting technologies performance and possibilities of increased recycling rate with Finland as case study.

SIAM (2020). SIAM submission on decabromodiphenyl ether, short chain chlorinated paraffins and dechlorane plus to the Persistent Organic Pollutants Review Committee of the Stockholm Convention.

SpecialChem, Date unknown. Webpage ‘Flame Retardants for Fire Proof Plastics’ https://polymer-additives.specialchem.com/selection-guide/flame-retardants-for-fire-proof-plastics#content

SPURLOCK, M. (2005). A Hands on Approach to Limit Selection and Uses, Parcitsing Oil Analysis Magazine. Sept-Oct 2005. [Online]. https://www.machinerylubrication.com/Read/804/oil-analysis-data . [Accessed].

Stockholm Convention (2020). Comments on the draft risk profile on Dechlorane Plus – Aerospace Industries Association of Canada (AIAC). Available at: http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC15/POPRC15Followup/CommentsonDechloranePlus/tabid/8366/ctl/Download/mid/23307/Default.aspx?id=0&ObjID=27808

Sverko et al. (2011). Sverko E, Tomy GT, Reiner EJ, Li YF, McCarry BE, Arnot JA, Law RJ and Hites RA (2011). Dechlorane Plus and related compounds in the environment: a review. Environ. Sci. Technol. 45 (12), 5088–5098.

TOMRA, (2019). Removal of flame-retardant plastics from WEEE waste streams. Available at: https://www.recovery-worldwide.com/en/artikel/removal-of-flame-retardant-plastics-from-weee-waste-streams_3356563.html

Troitzsch, J., (2011). Commercially Available Halogen free Alternatives to Halogen-Containing Flame Retardant Systems in Polymers. https://www.flameretardants-online.com/images/itempics/0/6/1/item_18160_pdf_1.pdf

UK EA (2019). Substance evaluation conclusion and evaluation report for Medium-chain chlorinated paraffins /Alkanes, C14-17, chloro EC No 287-477-0, Environment Agency, December 2019, available at: https://echa.europa.eu/documents/10162/a72b228a-e417-5b53-b2b9-3b45c8e6eec5

UK HSE, (2012). Proposal for identification of a PBT/vPvB substance bis(pentabromophenyl) ether (decabromodiphenyl ether); decaBDE).

UNEP (2017). United Nations Environment Programme. *Stockholm Convention on POPs – Text and Annexes. 2017*. Available at: http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx

UNEP (2019). Proposal to list Dechlorane Plus (CAS No. 13560-89-9) and its syn-isomer (CAS No. 135821-03-3) and anti-isomer (CAS No. 135821-74-8) in Annexes A, B and/or C to the Stockholm Convention on Persistent Organic Pollutants. In: POLLUTANTS, S. C. O. P. O. (ed.) *Technical work: consideration of chemicals proposed for listing in Annexes A, B and/or C to the Convention: Dechlorane Plus (CAS No. 13560-89-9) and its syn-isomer (CAS No. 135821-03-3) and anti-isomer (CAS No. 135821-74-8).* Available at: http://www.pops.int/Convention/POPsReviewCommittee/Chemicals/tabid/243/Default.aspx

UNEP (n.d.1). Chemicals listed in Annex A (Elimination). Available at: http://chm.pops.int/Implementation/Alternatives/AlternativestoPOPs/ChemicalslistedinAnnexA/tabid/5837/Default.aspx

UNEP (n.d.2). Chemicals listed in Annex B (Restriction). Available at: http://chm.pops.int/Implementation/Alternatives/AlternativestoPOPs/ChemicalslistedinAnnexB/tabid/5850/Default.aspx

US EPA (2002). Non-confidential Production Volume Information Submitted by Companies for Chemicals Under the 1986-2002 Inventory Update Rule (IUR). Dechlorane Plus (13560-89-9). Available at: http://www.epa.gov/oppt/iur/tools/data/2002-vol.html

US EPA (2012). Estimation Programs Interface Suite™ for Microsoft® Windows, v4.11. U.S. Environmental Protection Agency, Washington, DC, USA.

US EPA (2014). An alternatives assessment for the flame retardant decarbromodiphenyl ether (DecaBDE). Final Report. January 2014. https://www.epa.gov/sites/production/files/2014-05/documents/decabde_final.pdf

US EPA (2021). Diprop-2-en-1-yl 1,4,5,6,7,7-hexachlorobicyclo[2.2.1]hept-5-ene-2,3-dicarboxylate – properties. https://comptox.epa.gov/dashboard/dsstoxdb/results?search=DTXSID60954116#properties .

Vaziri, H.S., Omaraei, I.A. Abadyan, M., Mortezaei, M. Yousef, N. (2011). Thermophysical and rheological behavior of polystyrene/silica nanocomposites: Investigation of nanoparticle content. Materials & Design. 32(8-9): p. 4537-4542.

Velsicol (2020). High performance flame retardant for polyester and related systems. https://www.velsicol.com/products/chlorendicanhydride?gclid=Cj0KCQjwvIT5BRCqARIsAAwwD-T684B3Zaw8Jp2KtksT4mY68GsK18QtI676C5Mm2ni-7nAp2EUsXlcaAmdUEALw_wcB

VOJTA, S., BETANOVA, J., MELYMUK, L., KOMPRDOVA, K., KOHOUTEK, J., KUKUCKA, P. & KLANOVA, J. (2017). Screening for halogenated flame retardants in European consumer products, building materials and wastes. Chemosphere, 168, 457-466.

Wang et al. (2010). De-Gao Wang, Meng Yang, Hong Qi, Ed Sverko, Wan-Li Ma, Yi-Fan Li, Mehran Alaee, Eric J. Reiner, Li Shen. An Asia-specific source of Dechlorane Plus: concentration, isomer profiles, and other related compounds. Environmental Science and Technology 44(17):6608–6613. 2010. Available at: https://pubs.acs.org/doi/10.1021/es101224y

WANG, P., ZHANG, Q., ZHANG, H., WANG, T., SUN, H., ZHENG, S., LI, Y., LIANG, Y. & JIANG, G. (2016). Sources and environmental behaviors of Dechlorane Plus and related compounds—A review. Environment international, 88, 206-220.

Wang et al. (2020). Yan Wang, Andrea Peris, Mohammad Rashidujjaman Rifat, Syed Ishtiaque Ahmed, Nirupam Aich, Linh V. Nguyen, Jakub Urík, Ethel Eljarrat, Branislav Vrana, Liisa M. Jantunen, Miriam L. Diamond. Measuring exposure of e-waste dismantlers in Dhaka Bangladesh to organophosphate esters and halogenated flame retardants using silicone wristbands and T-shirts. Science of the Total Environment 720:137480. 2020. Available at: https://www.sciencedirect.com/science/article/pii/S0048969720309918

Washington State, (2006). Polybrominated Diphenyl Ether (PBDE) - Chemical Action Plan: Final Plan. http://www.chemicalspolicy.org/downloads/StateofWashingtonDepartmentofEcology-PBDEChemicalActionPlan.pdf

Weil and Levchik (2009). Weil, E.D. and Levchik, S.V., 2015. *Flame retardants for plastics and textiles: practical applications*. Carl Hanser Verlag GmbH Co KG. Available at: http://dl.booktolearn.com/ebooks2/engineering/textile/9781569904541_flame_retardants_for_plastics_and_textiles_2cbf.pdf

WRIGHT, J. (2008). Extreme Pressure Additives in Gear Oils. Machinery Lubrication, 9. [Online]. https://www.machinerylubrication.com/Read/1406/extreme-pressure-additives [Accessed].

Wu, Wang and Liang (2008). Wu, K., Wang, Z. and Liang, H., 2008. Microencapsulation of ammonium polyphosphate: preparation, characterization, and its flame retardance in polypropylene. Polymer Composites, 29(8), pp.854-860. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/pc.20459

Xiao and Kibble (2008). Xiao, W.D. and Kibble, K.A., 2008. Comparison of aluminium hydroxide and magnesium hydroxide as flame retardants in SEBS-based composites. Polymers and Polymer Composites, 16(7), pp.415-422. Available at: https://journals.sagepub.com/doi/10.1177/096739110801600702

Yang, Yu, Li, Zheng, Luo, Suo and Jiang (2019). Yang, J., Yu, Y., Li, Y., Zhang, Q., Zheng, L., Luo, T., Suo, Y. and Jiang, J., 2019. Inerting effects of ammonium polyphosphate on explosion characteristics of polypropylene dust. Process Safety and Environmental Protection, 130, pp.221-230. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0957582019309206

Yeo, Wang, Guan, Fu, Zhang, Dou (2017). Yao, W., Wang, H., Guan, D., Fu, T., Zhang, T. and Dou, Y., 2017. The effect of soluble ammonium polyphosphate on the properties of water blown semirigid polyurethane foams. Advances in Materials Science and Engineering, 2017. Available at: https://www.hindawi.com/journals/amse/2017/5282869/

YU, Z., LU, S., GAO, S., WANG, J., LI, H. & ZENG, X. (2010). Levels and isomer profiles of Dechlorane Plus in the surface soils from e-waste recycling areas and industrial areas in South China. Environ. Pollut., 158, 2920.

Zauba.com (2015). Zauba – Detailed Import Data of Chlorendic Anhydride. Available at: https://www.zauba.com/import-chlorendic-anhydride-hs-code.html

Zauba.com (2016). Zauba – Detailed Import Data of ammonium polyphosphate. Available at: https://www.zauba.com/import-ammonium-polyphosphate/hs-code-28353900-hs-code.html

Zhang et al. (2016). Zhang X, Sühring R, Serodio D, Bonnell M, Sundin N, Diamond ML (2016). Novel flame retardants: Estimating the physical-chemical properties and environmental fate of 94 halogenated and organophosphate PBDE replacements. Chemosphere. 144:2401-7.

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