ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION

Annexes

SUBSTANCE NAME(S): 1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene ("Dechlorane Plus"™) [covering any of its individual anti- and syn-isomers or any combination thereof]

IUPAC NAME(S):

1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene (CAS no. 13560-89-9)

(1S,2S,5S,6S,9R,10R,13R,14R)-1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene (CAS no. 135821-74-8)

(1S,2S,5R,6R,9S,10S,13R,14R)-1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene (CAS no. 135821-03-3)

EC NUMBER(S): 236-948-9; -; -

CAS NUMBER(S): 13560-89-9; 135821-74-8; 135821-03-3

CONTACT DETAILS OF THE DOSSIER SUBMITTER:

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VERSION NUMBER: 2.0

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
AC	Article Category
ACEA	European Automobile Manufacturers’ Association
ACEM	European Association of Motorcycle Manufacturers
AIA	Aerospace Industries Association
AIAC	Aerospace Industries Association of Canada
APP	Ammonium Polyphosphate
ASR	Auto Shredder Residue
ATH	Aluminium Trihydrate
ATO	Antimony trioxide
BCF	Bioconcentration Factor
BIR	Bureau of International Recycling
BM	Biomagnification Factor
BSAF	Biota to Soil or Sediment Accumulation Factor
BTPP	Butylated Triphenyl Phosphate
C	Coatings
CAGR	Compound Annual Growth Rate
CAS no	Chemical Abstract Service registry number
CEMC	Canadian Centre for Environmental Modelling and Chemistry
CfE	Call for Evidence
Cl	Chlorine
CLEPA	European Association of Automotive Suppliers
CLP	Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006
CMR	Carcinogenic, Mutagenic or Toxic for Reproduction
CoRAP	Community Rolling Action Plan
CPs	Chlorinated Paraffins

CSR	Chemical Safety Report
CTI	Comparative Tracking Index
DAP	Diallyl phthalate
DBDPE	Decabromodiphenyl ethane
DecaBDE	Decabromodiphenyl ether
DP	Dechlorane Plus
DPMA	Dechlorane monoadduct
EA	Environment Agency
EAV	Equivalent Annual Value
EBP	Ethane-1,2-bis (pentabromophenyl)
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Economic Area
EEE	Electrical and Electronic Equipment
EFTA	European Fair Trade Association
EiF	Entry into Force
ELVs	End-of-life Vehicles
EP	Extreme Pressure
EPA	Environmental Protection Agency
EPDM	Ethylene propylene diene monomer rubber
EPR	Ethylene propylene rubber
ERC	Environmental Release Categories
ESD	Emission Scenario Documents
EU	European Union
EUSES	European Union System for the Evaluation of Substances
EVA	Ethylene-vinyl acetate
FEICA	Association of the European Adhesive and Sealant Industry
FR	Flame retardant
GC-HRMS	Gas chromatography/high-resolution mass spectrometry
GC-LRMS	Gas chromatography coupled to low resolution mass spectrometry

GCMS	Gas chromatography mass spectrometry
HBCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HIPS	High Impact Polystyrene
HLC	Henry’s Law Constant
HRMS	High Resolution Mass Spectrometry
HRR	Heat Release Rate
JAPIA	Japan Auto Parts Industries Association
KEMI	The Swedish Chemicals Agency
LCCP	Long Chain Chlorinated Paraffins
LCD	Liquid Crystal Display
LoQ	Limit of Quantification
LRET	Long-range environmental transport
LRTP	Long-range transport potential
LSFR	Low Smoke Flame Retardant
MCCP	Medium Chain Chlorinated Paraffins
MSC	Member State Committee
NACE	European Classification of Economic Activities
NEA	Norwegian Environment Agency
OC	Operational Conditions
OECD	Organisation for Economic Co-operation and Development
OEMs	Original Equipment Manufacturers
OxyChem	Occidental Chemical Corporation
P	Plastics
PA	Polyamide
PBDE	Polybrominated diphenyl ether
PBT	Persistent Bioaccumulative and Toxic
PC	Product Category
PCB	Polychlorinated biphenyl

PE	Polyethylene
PECs	Predicted Environmental Concentrations
PNEC	Predicted No Effect Concentration
POP	Persistent Organic Pollutants
POPRC	Persistent Organic Pollutants Review Committee
PP	Polypropylene
PPO	Polyphenylene oxide
PPS	Polyphenylene sulphide
PROC	Process Categories
PST	Post Shredder Treatment
PU	Polyurethane
PVC	Polyvinyl chloride
RAC	Risk Assessment Committee
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
RMM	Risk Management Measure
RMO	Risk Management Option
RO	Restriction Option
SBR	Styrene butadiene rubber
SBS	Structural Business Statistics
SCCP	Short Chain Chlorinated Paraffins
SDA	Small domestic appliances
SEAC	Committee for Socio-Economic Analysis
SEv	Substance Evaluation
SME	Small and Medium Enterprises
SPERCs	Specific Environmental Release Categories
SPIN	Substances in Preparations in Nordic Countries
STC	Supplemental Type Certificate
STP	Sewage Treatment Plant
SU	End use sector

SVHC	Substance of Very High Concern
T	Textiles
TCP	Tricresyl Phosphate
TMF	Trophic Magnification Factor
TPE	Thermoplastic elastomers
TV	Television
UNEP	United Nations Environment Programme
UVCB	Substances of unknown or variable composition, complex reaction products or biological materials
vB	very Bioaccumulative
vLCCP	very Long Chain Chlorinated Paraffins
vPvB	very Persistent and very Bioaccumulative
WEEE	Wastes from electrical and electronic equipment
WVTA	Whole Vehicle Type Approval
WW	Wet Weight
WWTP	Wastewater Treatment Plant
XRF	X-Ray Fluorescence spectroscopy
ZDDP	Zinc Dialkyldithio-phosphates

Annexes

Annex A: Manufacture and uses

A.1. Manufacture

Companies are responsible for collecting information on the properties and uses of Dechlorane Plus (DP) if they manufacture or import into the EU above one tonne a year. This information is communicated through a REACH registration dossier.

There is one active registration of DP: a company based in the Netherlands called *ADAMA Agriculture BV (Adama)*. They first registered as a supplier in 2017, and updated their registration dossier in 2018, 2019 and 2020. *ADAMA* is the 'only representative'[1] for the Chinese company *Jiangsu Anpon Electrochemical Company Ltd,* which they recently acquired (ADAMA, 2019).

There is also one inactive registration by Occidental Chemical Belgium BVBA, which was an 'only representative' for the US-based company *Occidental Chemical Corporation,* also known as *OxyChem*. OxyChem registered DP in 2013 but ceased their supply to the EU market in 2017. It can be assumed that the total volume of DP placed on the market in the EU is currently manufactured in China and imported into the EU.

Publicly available 2020 registration data accessed in April 2020 when the Call for evidence (CfE) and stakeholder consultation for the present proposal were launched indicated that the total tonnage placed on the EU market is in the range of 100 – 1 000 tonnes/year. 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).

Table 1 provides a summary of the publicly available REACH registration data from 2020.

Table 1: Registration data from ECHA's website

Substance	EC/CAS/List No	Company	Status	Location	Tonnage
Dechlorane Plus	EC: 236-948-9	ADAMA Agriculture BV	Active	Netherlands	100 – 1 000 tonnes/year
	CAS: 13560-89-9	Occidental Chemical Belgium BVBA	Inactive	Belgium	n/a

Source: ECHA - REACH registration data (accessed April 2020)

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[1] Companies based outside the EEA can appoint a European-based only representative to take over the tasks and responsibilities of importers for complying with REACH. (https://echa.europa.eu/support/getting-started/only-representative)

When ADAMA entered the market in 2017 their registered tonnage band was 10 – 100 tonnes/year. When 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 tonnes/year in April 2020.

Section A.1.2. Information from stakeholders presents a narrower tonnage band provided by ADAMA in the stakeholder consultation. The Dossier Submitter also notes that the REACH registrant recently (October 2020) has downgraded the tonnage band to 10 – 100 tonnes/year in their registration data (ECHA, 2020b). This does not, however, necessarily mean that the overall total import volume has changed significantly over time.

A.1.1. Information in available literature

Information on the volumes of DP manufactured, imported and exported is sparse in available literature, with only a few underlying sources frequently being quoted in most studies, articles and regulatory documents. Some but not all of these underlying sources have been scrutinised. Whilst these sources are quoted/used in newer reports, this does not mitigate for the risk that some of the data is old and is unlikely to be representative/accurate of the situation in 2020.

No manufacture of DP in the EU has been reported to date (ECHA, 2019b, ECHA, 2018b, ECHA, 2017b). Results from the Swedish National Screening Programme 2009 (IVL, 2010) reveal import/use volumes in Europe in 2000 of 800 tonnes/year, which is the earliest reported import volume for Europe found in the 43 reviewed sources. Results from this screening programme included import volumes of 4 – 11 tonnes/year for Sweden between 2003 and 2006, whilst there was no evidence of import of this substance into Scandinavia in 2008. No other evidence on use/non-use of DP in the EU was found for the years 2001 - 2008.

The UK Environment Agency (EA) reported that DP was imported into the EU as the substance itself with one active REACH Registrant supplying quantities of 10 – 100 tonnes/year (EA, 2018a). It was noted by the UK EA 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 tonnes/year". Several studies have reported import volumes (based on REACH registrations) of 100 – 1 000 tonnes per year (ECHA, 2017b, ECHA, 2018b, ECHA, 2020b, UNEP, 2019).

The most precise and most recent information on EU import volumes is found in the comments received during the public consultation on ECHA's draft 9th recommendation to include DP in Annex XIV of the REACH regulation, which reports a total tonnage of 300 tonnes/year (ECHA, 2019a).

Table 2 gives an overview of all import and/or use volumes found in literature, over the period 2000 to 2019. Blank cells in the table indicate that no data was found on imports for that year. The European countries included in the table are the only countries for which data on the import of DP was found.

Table 2: DP imported into the EU, in tonnes/year

Region	**2000**	**2003-2006**	**2008**	**2017**	**2018**	**2019**
Sweden		4 - 11[2]	0[2]			
Finland			0[2]			
Norway			0[2]			
EU	**800[2]**		**200 – 5 000[3]**	**100 - 1 000[4]**	**10 - 100[5]** **100 - 1 000[6]**	**300[7]**

Table notes:

- 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.

A.1.1.1. Dechlorane Plus traded in articles

A recent study by the Norwegian Environment Agency analysed 67 different textile and plastic articles for various hazardous substances, including DP. DP was not detected in any of these consumer products (LoD[8] <0.1 - 1.5 μg/g) (Norwegian Environment Agency, 2019b). The background document for the ninth recommendation for the inclusion of substances in Annex XIV (ECHA, 2019b) states that "*the substance is used in articles in volumes > 10 t/y, e.g. computers, electronics*", but it is not specified whether this refers to imported articles or articles manufactured within the EU.

In the REACH restriction proposal on decabromodiphenyl ether (decaBDE) prepared by ECHA in collaboration with Norway, it was assumed that an additional 10% of the use volumes for the substance would enter the EU market in imported articles (ECHA, 2015b). If a similar logic is applied for DP, this implies that around 30 tonnes DP were imported to the EU in articles in 2019. This is in the same order of magnitude as cited in ECHA (2019b). However, no other source corroborating these volumes has been found. Due to the lack of information on imported articles, these will be grouped with overall use in articles and other uses not accounted for – see A.2.4. Summary and conclusions.

No information has been found related to export of articles from the EU.

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[2] IVL (2010)
[3] UK EA (2018b)
[4] ECHA (2017b)
[5] UK EA (2018a)
[6] ECHA (2018b)

[7] ECHA (2019a)
[8] Limit of detection

A.1.1.2. Global data

Table 3 shows that the global data on the manufacture of DP found in literature is all from 2010 or earlier. The most recent global production volumes from 2008 - 2010 are reported to be between 4 500 – 5 000 tonnes/year (ECHA, 2020b) of which 300 – 1 000 tonnes/year (Canada, 2019, ECHA, 2020b, Wang et al., 2010b) were manufactured in China, where the only known manufacturer is and was *Jiangsu Anpon Electrochemical Company Ltd*. Since 2011, OxyChem has "withheld" their production volumes, but historic volumes manufactured by this company lie in the range of 450 – 4 500 tonnes/year (Qiu et al., 2007, Ren et al., 2009, US EPA, 2002).

Table 3: Global production volumes for DP, in tonnes/year

Region	**1986 - 2002**	**2003 - 2008**	**2008 - 2010**	**> 2011**
USA	450 – 4 500[9]	450 – 4 500[10]	n/a	withheld[10]
China	0	300 – 1 000[11]	300 – 1 000[11]	n/a
Global	**450 – 4 500**	**750 – 5 500**	**4 500 – 5 000[12]**	**n/a**

Table notes:

- Global production volumes between 1986-2008 are calculated from production volumes in the USA and China.

According to UK Environment Agency, i.e. EA (2018a), there was a small number of other companies that offered DP for sale on their websites in 2018, but it did not confirm whether they manufactured DP in any significant quantity.

A.1.1.3. Historic and future trends

The publicly available data on manufacture in and import of DP into the EU is not detailed enough to conclude on any historic trends in the EU market, and no information on future volumes has been found.

DP has been marketed as an alternative to decaBDE, which means that developments in the market for decaBDE may impact the sales of DP. In 2019, a REACH restriction came into force [for decaBDE] and decaBDE was listed as a POP in the Stockholm Convention, which may lead to an increase in the import of DP as substance, in mixture or in articles in the near future.

In the Annex XV restriction proposal for decaBDE (ECHA, 2015b), it was estimated that 4 000 tonnes of decaBDE were used in the EU annually. The DP draft risk profile (POPRC, (2021b) citing Hoh et al. (2006)) confirms that DP is viewed as an alternative to decaBDE and substitute for Mirex, however, this does not allow for a conclusion on the share of this

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[9] ECHA (2020b); Qiu et al. (2007)

[10] US EPA (2016)

[11] Canada (2019); ECHA (2020b); Wang et al. (2010b)

[12] Wang et al. (2010b); Feo et al. (2012); Ren et al. (2009)

use volume that can potentially be replaced by DP (DP was listed as one of several alternatives to decaBDE).

A.1.2. Information from stakeholders

This section presents information received from stakeholders on the manufacture and import of DP. As set out in Annex G: Stakeholder information), despite significant effort to engage with potentially affected stakeholders, the overall number of respondents is limited. Information was gathered through:

- A Call for Evidence (CfE);
- A stakeholder survey;
- Stakeholder interviews; and
- Other communications with stakeholders.

Concerning manufacture and import of DP a few key stakeholders provided information – see Section A.2.3. Information from stakeholders. OxyChem previously manufactured DP but confirmed that their production ceased in 2017. The sole REACH registrant, ADAMA, recently acquired *Jiangsu Anpon Electrochemical Company Ltd* (ADAMA, 2019) and several downstream users confirmed in the stakeholder consultation that ADAMA is currently the only manufacturer of DP globally. *Velsicol*, a global company that manufactures and distributes specialty and commodity chemicals, is the sole importer in the EU according to information from stakeholders.

The Dutch authorities participated in the open commenting round for the draft risk profile on DP under the Stockholm Convention on POPs, informing that the highest volume imported to the EU was 300 - 400 tonnes/year, and that the import volumes were below 100 tonnes in 2019 (POPRC, 2021b). Data per region and per application was provided by ADAMA in the stakeholder consultation associated with the preparation of this restriction dossier, but this was claimed confidential. The exact information provided can be found in the Confidential Annex H.

Downstream user sector groups, representing automotive OEMs and their supply chain, who provided data, i.e. the European Automobile Manufacturers' Association (ACEA), the European Association of Automotive Suppliers (CLEPA) and the Japan Auto Parts Industries Association (JAPIA), all cited significantly higher global and EU use volumes than what was provided by ADAMA. Based on information from their supply chains, it was stated that the global use of DP was around 1 000 tonnes/year of which 200 – 260 tonnes/year was imported into the EU. ACEA in their last statement wrote: "*we have double checked with the Chinese supplier (only one producer of DP in the world) through a Japanese trading company and they confirmed that average 200 t/year exported into the EU*". The industry is supplied by one manufacturer in China – not named, but since ADAMA comprises 100% of the global market, it is reasonable to assume that the supplier referred to is ADAMA.

One possible reason for the discrepancies in the cited tonnage data is that the stakeholders might be referring to different years, as it is understood that there have been large variations in volumes supplied to the EU over the last few years. Table 4 sets out the information on supply volumes provided by stakeholders.

Table 4: Global manufacture data and volumes placed on the EU market

Stakeholder	**Global manufacture volumes**	**Placed on the EU market**
ADAMA (Stakeholder consultation, July 2020)	Confidential	Confidential
Information submitted in relation to the REACH Annex XIV process and the Stockholm convention (ECHA, 2019a, POPRC, 2021b)	2019: 300 tonnes/year	2019: 100 tonnes/year Highest recorded: 300 – 400 tonnes/year
ACEA, CLEPA and JAPIA	1 000 tonnes/year	200 tonnes/year – 260 tonnes/year

Note: Confidential tonnage information is presented in Table H1 in the Confidential Annex H

A.1.3. Summary and conclusions

There is no EU manufacture of DP, but it is imported into the EU. The information provided in literature indicates higher DP tonnages than information provided by stakeholders - ADAMA (the only known global supplier of DP) and their downstream users. The tonnages reported by stakeholders are deemed more reliable and reflective of the current situation than the information found in literature, as the data in literature is older. Thus, the stakeholder data will be used to derive the baseline in Annex D: Baseline.

To reflect the large variations in reported EU (and global) supply of DP, a broad volume band will be used to derive emissions and impacts of a potential restriction. Table 5 summarises the final volume data used in the Annex XV dossier (for both estimating costs and emission reductions associated with a possible REACH restriction). The chosen volume range is based on both confidential and non-confidential data provided by stakeholders. More details can be found in H.1. Manufacture and use.

Table 5: Summary of best estimate for global volumes of DP manufactured and volume imported into EU (used in the analysis carried out)

	Low use scenario (tonnes/year)	**High use scenario (tonnes/year)**
Volumes manufactured in the EU (tonnes/year)	0	0
Volumes imported into the EU (tonnes/year)	90	230
Global volumes manufactured	300	1 000

A.2. Uses

According to the Annex XV SVHC Report for Dechlorane Plus (DP) submitted by the United Kingdom in 2017, DP is an additive chlorinated flame retardant used in a variety of polymeric systems (ECHA, 2019b; ECHA, 2020b). It has been used as an alternative to Dechlorane ("Mirex") and decaBDE since the 1960s (ECHA, 2019b; ECHA, 2020b; UNEP, 2019). The market for DP is reported as being mature and presumably relatively stable (ECHA, 2017b, ECHA, 2019b). 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 decaBDE for use with polyolefin compositions due to a lower production of smoke (ECHA, 2017b).

A.2.1. REACH Registration data

The Annex XV report for DP (ECHA, 2017b) showed that previous registration data provided in response to the reporting obligations of manufacturers and importers of DP shows that DP, in its use as a flame retardant, is not registered for use as an intermediate. According to the most recent registration data, uses of DP include uses in formulations or re-packaging, at industrial sites and by professional users as well as consumer uses of DP when contained in articles (ECHA, 2020b, ECHA, 2019b).

Table 6 provides a summary of the uses reported in REACH registration dossiers.

Table 6: Uses according to REACH registrations (2020)

Registered uses	**End use/final product and articles (according to use descriptions explicitly listed in registration dossiers)**
Formulation	Relevant chemical product categories for which Dechlorane Plus is used in pure form: PC 1: Adhesives, sealants PC 32: Polymer preparations and compounds PC 33: Semiconductors
Uses at industrial sites	Relevant sectors of end use for which Dechlorane Plus is used, whereby subsequent service life is not relevant for this use: SU 10: Formulation [mixing] of preparations and/or re-packaging (excluding alloys) SU 12: Manufacture of plastics products, including compounding and conversion SU 16: Manufacture of computer, electronic and optical products, electrical equipment

Registered uses	End use/final product and articles (according to use descriptions explicitly listed in registration dossiers)
Article service life	Article category related to subsequent service life of articles at consumer use stage: AC 1: Vehicles AC 2: Machinery, mechanical appliances, electrical/electronic articles AC 3: Electrical batteries and accumulators AC 5: Fabrics, textiles and apparel AC 13: Plastic articles Article category related to subsequent service life of articles at industrial sites (by workers): AC 1: Vehicles AC 2: Machinery, mechanical appliances, electrical/electronic articles

Source: ECHA (2020b)

A.2.2. Information found in publicly available sources

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 7 provides a summary of uses of DP found in publicly available sources. Note that the table does not include information on uses from the stakeholder consultation; this is presented in Section A.2.3. Information from stakeholders below.

Table 7: Summary of uses of DP found in literature

Industry	Sector	Article / Component
Automotive	Electrical and electronic equipment	Wires and cable plastic coatings, coil bobbins[13], 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[13], cable straps
		Switches, and small electronic appliances including cameras, computers (motherboards, chargers and hard-plastic connectors)

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[13] 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.

Industry	**Sector**	**Article / Component**
	Engines	2-part epoxy-void fillers
Electrical and electronic equipment	Wire 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 (2021b), ECHA (2019a; 2020b) and OxyChem (2007)

As of October 2019, information on the number of industrial sites using DP is not available (ECHA, 2019a). According to the registration dossier, DP is **not used as an intermediate** during industrial manufacturing processes in the EU. However, information from US EPA (2002) suggests that industrial uses in the US include use of DP as an intermediate. DP is also reported to be a relevant material for the production processes of various industries, e.g. chemical manufacturing, production of metals, the cosmetics industry, and for production of a variety of products (US EPA, 2002).

Downstream users of DP are reported to be **widely spread across the EU** (EC, 2019). Information on the volume of DP used in Sweden based on information from the SPIN (Substances in Preparations in Nordic Countries) database from 2010 (cited in ECHA, 2017b, IVL, 2010) is shown in Table 8 below. As of 2010, this database did not report any uses of DP for the EU Member States Finland, Denmark and Norway, which is part of the European Economic Area (EEA).

Table 8: Use of DP in Sweden, 1999 – 2006, in tonnes/year

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Volume used in Sweden	2	-	-	-	4	7	11	5

In 2008, one registration for the use of DP as a raw material for the production of plastic material existed in Sweden, but no sale of DP was identified. The Swedish Chemicals Agency – KEMI – concluded that this likely implies that, as of 2008, DP was only imported in products in Sweden and not used for manufacturing activities (IVL, 2010).

DP is furthermore used as a non-plasticizing flame retardant for various **polymeric systems**, e.g. in moulded or extruded electrical/electronic systems, wires and cables (ECHA, 2017b, ECHA, 2020b; Canada, 2019; UNEP, 2019). Typically, these polymers systems are either thermoplastics, whose curing process is reversible, or thermosets, whose curing process is irreversible (ECHA, 2020b; Canada, 2019; UNEP, 2019). Examples of thermoplastics commonly containing DP are:

- Acrylonitrile butadiene styrene, also referred to as ABS[14];
- Natural rubber[14];
- Nylon[14];
- Polybutylene terephthalate[14];
- Polyester[14];
- Polypropylene[14]; and
- Styrene butadiene rubber (SBR) block copolymer[14].

Examples of relevant thermosets are:

- Epoxy resins[14];
- Ethylene propylene diene monomer rubber, also referred to as EPDM[14];
- Neoprene[14];
- Polyester resins[15];
- Polyethylene[14];
- Polyurethane foam[15];
- Polyurethane rubber[14]; and
- Silicon rubber[14].

According to (OxyChem (2007), cited in ECHA, 2020b; Canada, 2019 and UNEP, 2019), the concentration of DP, when detected (i.e. when concentrations of DP is found > 0%), in these polymer systems ranges from 8% in Polybutylene terephthalate up to 40% in silicon rubber.

Additional information on the concentration of DP in different types of polymers systems is provided in Table 9 for both thermoplastics and thermosets. This table, which covers information from (OxyChem, 2007) as well as other sources, suggests that the concentration of DP in some thermoplastics, i.e. nylon and polyester, can lie below 8%.

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[14] ECHA (2017b); ECHA (2020b); CANADA (2019); UNEP (2019)

[15] ECHA (2020b); CANADA (2019); UNEP (2019)

Table 9: Concentration of DP in thermoplastics and thermosets, based on information from 2007 and 2009

Type of polymeric system	**Product type**	**Concentration of Dechlorane Plus**	**Reference**
Thermoplastic	ABS	16.9%	OxyChem (2007)
	Natural rubber	18.7%	
	Nylon	0 – 35%	KemI (2007) and Weil and Levchik (2015)
	Polybutylene terephthalate	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%	
	Polyurethane foam	17.5 – 35%	
	Polyurethane rubber	20 – 30%	
	Silicon rubber	18.8 – 40%	

Source: CANADA (2019)

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

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

Whether all of these polymer types are relevant to manufacturing processes in the EU is unknown (ECHA, 2017b). 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 (Canada, 2019). As of 2013, OxyChem names the use of DP in, firstly, 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).

A concentration of the substance in finished **articles** of 20% was reported by the summary document prepared in relation to the *32nd Meeting of Competent Authorities for REACH and CLP*. The document however highlights uncertainty about whether this share refers to the share of DP per mass or per weight of the article (ECHA, 2019d).

Electric applications are one of the main areas of application for the aforementioned polymer systems/materials containing DP. Examples of applications are the coatings of commercial electrical wires and cables (ECHA, 2017b, ECHA, 2020b, Canada, 2019, US EPA, 2002, IVL, 2010, UNEP, 2019), the polymeric compounds for cable insulation (ECHA, 2020b) and coil bobbins (Canada, 2019). Polymer systems containing DP are also reported to be used in switches, cable straps, power tool housing and wall plates (Canada, 2019) as well as niche applications such as nuclear power plant control cables (ECHA, 2017b). The draft POPs risk profile (POPRC, 2021b) reiterates the use of DP in wire and cable, and as a flame retardant for electrical connectors used in computers and other electronic devices.

Additionally, the use of DP in **automobiles, aerospace and defence engines** is reported in relation to the use of the substance in articles (ECHA, 2019b; ECHA 2020b). The substance is also used in other aircraft components, including adhesives, binding agents, syntactic foams and potting compounds (ECHA, 2017b, ECHA, 2019b, ECHA, 2020b). The Aerospace Industries Association of Canada (AIAC) confirmed, in their input to the consultation on the draft risk profile for DP under the Stockholm Convention, that DP is used extensively in the aerospace industry as a flame retardant and in other functions. They state 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, 2020). 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, Canada, 2019, UNEP, 2019, POPRC, 2021b), but also for EU countries. Information from the Netherlands reports its use for powertrain, cooling, chassis and bodywork parts (ECHA, 2020b).

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

A submission by Rolls-Royce PLC[16] to ECHA's public consultation on the *Draft 9th recommendation for inclusion of substances in Annex XIV of REACH for Dechlorane Plus*, which took place between September and December 2018, confirmed that DP is used in aerospace and defence engines. Rolls-Royce PLC 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

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

are reported to be relevant for both the manufacture and repair of engines. Rolls-Royce PLC stressed that the use of formulations containing DP is essential for manufacturing the engines due to a lack of suitable alternatives meeting the stringent qualification requirements faced by the industry sector (Comref, 2019).

The use of DP in the manufacture of **electronic devices and optical products**, referred to as end use sector SU 16 in the registration dossier, includes electronic equipment of all types, e.g. cameras, computer 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 according to substance information provided on the ECHA website (ECHA, 2020b).

With respect to the manufacture of **plastic products**, reported as end use sector SU 12 in the registration dossier, plastic roofing material used for commercial building, hard plastic connectors in television and computer monitors are examples of applications of DP (ECHA, 2017b, ECHA, 2020b, Canada, 2019, US EPA, 2002, IVL, 2010, UNEP, 2019). Substance information on the ECHA website also points to the use of DP in plastic toys (ECHA, 2020b). 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).

A submission by the US company Velsicol Chemical[17] to ECHA's public consultation on the *Draft 9th recommendation for inclusion of substances in Annex XIV of REACH for Dechlorane Plus* states that DP "has one significant use whereby it is used as a flame retardant within plastic products such as cabling". It is also mentioned that it is used as a flame retardant in the manufacture of fire-resistant plastic articles. Velsicol Chemical further states that around 15 industrial sites in the EU uses the substance in their manufacturing process (ECHA, 2019a).

According to substance information provided on the ECHA website, DP can also be found in **food packaging** and storage (ECHA, 2020b). 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 (Canada, 2019).

In China, DP has been identified in various types of **building material**, 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 3270 ± 5423 ng/g and 1425 ± 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, 2020b). To what extent the uses identified in China are relevant to the EU is unknown.

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

In addition to its use in flooring, wooden building materials and insulation, DP is also reported to be used in caulk, tile and glass (US EPA, 2002). While the use in tile and glass coincides with the information in the registration dossier with respect to article category AC 4, which incorporates stone, plaster, cement, glass and ceramics, the use of DP in caulk is an addition to the list in the registration dossier. DP is also reported to be used in furniture (ECHA, 2020b; UNEP, 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.

In line with information from the registration dossier listing the use of DP in **fabrics, textiles and apparel** (through article category AC 5), DP is reported to be used as an additive or as a coating for textiles to prevent flammability (US EPA, 2002). According to substance information provided on the ECHA web site, DP can be found in clothing, mattresses, curtains, carpets and textile toys (ECHA, 2020b). A minor application of DP in relation to this article category are military textiles (Canada, 2019).

While US EPA (2002) identifies the use of DP in the **cosmetics industry**, no use of DP in cosmetics has been indicated in REACH registration dossiers or the COSING database[18], which implies that no such use exists 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 (Canada, 2019).

The manufacture of **fireworks** is an additional, yet minor, use of DP (ECHA, 2020b). Velsicol promotes their DP-containing product *Pyrovex SG* as a chlorine donor for fireworks which 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.*" (ECHA, 2019a).

Another use that is mentioned in literature but not covered in the registration dossier is the use of DP as an additive flame retardant in various types of **paints** (US EPA, 2002).

Figure 1 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 are shown in Table 9, whilst more industry uses are covered in Table 7.

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[18] See https://ec.europa.eu/growth/sectors/cosmetics/cosing_en

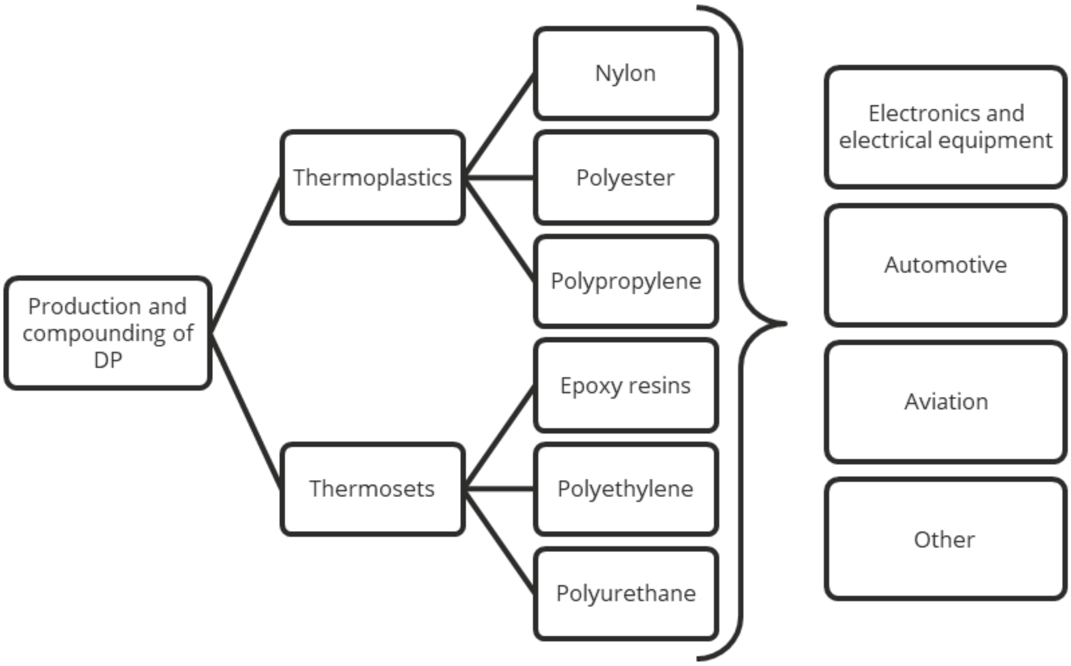

Figure 1: Flow chart of DP production and polymer compounding through to end uses identified during the literature review (non-exhaustive).

A.2.3. Information from stakeholders

This section presents information received from stakeholders on the uses of DP. As set out in Annex G: Stakeholder information despite significant effort to engage with potentially affected stakeholders, the overall number of respondents is limited. Information was gathered through:

- A Call for Evidence (CfE);
- A stakeholder survey;
- Stakeholder interviews; and
- Other communications with stakeholders.

Concerning the use of DP, key stakeholders provided some information which helps build on the evidence available in the literature, but some important uncertainties remain on tonnages used per application. This is explained further below.

ADAMA, provided information on specific applications of DP and corresponding global sales volumes, which can be found in Table H2 in the Confidential Annex H.

A.2.3.1. Data received from automotive industry

The stated total tonnage used by the automotive industry is 130 tonnes/year in the EU and it was stated in a stakeholder interview that about 50% of total DP volumes in the EU and globally are used in the automotive industry. Using ACEA’s estimated global tonnage (~1 000 t/y) this implies a total global use of 500 t/y in the automotive industry. On the other hand, using ADAMA's provided volume data, the automotive sector uses significantly less.

The main uses of DP mentioned by the automotive industry are in:

1. Electric wire (wire harnesses specifically mentioned): 80% of total tonnage used;
2. Plastic and rubber parts: 8% of total tonnage used;
3. Tape and adhesive: 10% of total tonnage used;
4. Grease: 2% of total tonnage used.

The two key functions for the automotive sector are flame retardance (avoids the start or slows down the growth of fire) and seizure resistance (to prevent seizure of metal parts in sliding parts).

A.2.3.2. Data received from aviation industry

The uses of DP named by the aerospace industry stakeholders are:

1. Epoxy adhesives;
2. Syntactic foams;
3. Potting compounds;
4. 2-part epoxy void filler;
5. Manufactured items for the production and maintenance of aircraft and aircraft components (e.g. – aircraft engine);
6. Connectors;
7. Wire/cables: and
8. Other plastic components made from polypropylene, nylon, ABS etc.

Important substance properties mentioned by Aerospace Industries Association (AIA) and Aerospace Industries Association of Canada (AIAC) that make DP suitable for aerospace uses are "*excellent flame-retardancy performance and thermal stability, along with its unique electrical performance*". However, they also state 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.*" Rolls Royce highlights density, compressive strength, operating temperature, fluid resistance and shear strength as important substance properties.

No tonnage estimates for the EU or global aerospace sector was 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.

A.2.3.3. Data received from wires and cables industry

The wires and cables manufacturers are suppliers for automotive, aerospace and consumer electronics. Europacable states that only one of its members use 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 need to be small, whilst being flame retardant and highly flexible.

In the public consultation on the *Draft 9th recommendation for inclusion of substances in Annex XIV of REACH for Dechlorane Plus*, the two Swiss companies Impag AG and Huber+Suhner AG confirmed the use of DP as a flame retardant in cable applications (Comref, 2019). Both companies provided confidential use information, volume data and socio-economic considerations to the public consultation for the Annex XIV process (see Confidential Annex H.1. Manufacture and use for more information). It should be noted that both companies were contacted in the stakeholder consultation of the present proposal without responding.

A.2.3.4. Data received from consumer electronics industry

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

A.2.3.5. Data received from explosives industry

The respondent manufacturing or supplying for manufacturers of explosives informed that > 90% of the DP used for explosives falls under the category *formulation*. The respondent also included information indicating the 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 use of DP of 0 – 2% per year. The stakeholder did not provide any information on the function of DP.

It was not stated what the explosives were used for but based on information from other sources (see Section A.2.2. Information found in publicly available sources); it seems likely that it relates to fireworks.

A.2.3.6. Data received on end-of-life disposal and recycling

European Association of Motorcycle Manufacturers (ACEM) provides guidance to end users on end-of-life disposal of each type of product containing DP, while Japan Auto Parts Industries Association (JAPIA) states that their guidance is provided by the final products manufacturers. Rolls Royce states 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.

Bureau of International Recycling (BIR) represents directly or indirectly 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:

1. Lack of knowledge of which chemicals are present in products or in wastes;
2. 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. Furthermore, there are legacy issues from these chemicals already on the market when they then become waste.

A.2.3.7. Concentrations of Dechlorane Plus in products/components

Stakeholders were asked to provide information on concentrations of DP in the relevant products/article/material. Table 10 summarises the information received.

Table 10: Concentration of DP in components

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[19].	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%	

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

A.2.4. Summary and conclusions

Due to the conflicting information provided by different stakeholders, 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 – which has been developed based on all the information received. Table 11 presents volume data (low and high) per sector, whilst Table 12 shows the breakdown per application. The volume data presented in these tables will be used to derive the baseline in Annex D: Baseline.

Table 11: Volumes of DP used in the EU (by sector)

Sectors	**Low volume scenario**		**High volume scenario**	
	Share of total	**EU volume (t/y)**	**Share of total**	**EU volume (t/y)**
Automotive	75%	68	57%	130
Aviation	10%	9	10%	23
Other, including computer, electronics and imported articles etc.	15%	13.5	33%	77
All	**100%**	**90**	**100%**	**230**

Note: Due to the use of information from differing sources, the market shares as well as the tonnages of the sectors vary between the two scenarios.

Table 12: Volumes of DP used in the EU (by use application)

Uses		**Share of total**	**Low-volume scenario (t/y)**	**High-volume scenario (t/y)**
Polymers	Wire and printed circuit board housing, other plastics and rubber parts	93%	84	214
Adhesives	Tape, adhesives, sealants	5%	5	12
Greases	Lubricant	2%	2	5
All		**100%**	**90**	**230**

Note:

- A more detailed breakdown of volume per application is presented in Table H3 in the Confidential Annex H, Section H.1. Manufacture and use.
- Sums may not add up due to rounding.

A.2.5. Recycling

As noted in a Restriction Task Force note on the approach of Dossier Submitters and Committees on recycling, a REACH restriction on use by default also applies to recycled material. As a result, the note calls for Dossier Submitters to consider how to treat recycled material in a restriction, while balancing the risks associated with continued use and the benefits of recycling (ECHA, 2020c). This is especially important as recycling is of paramount importance in the EU.

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 around 61.8 million tonnes (used in 2018), it is still rapidly increasing in other parts of the world (EEA, 2021). In the EU, the plastics sector employs 1.5 million people and generated a turnover of €340 billion in 2015 (EC, 2018b). The largest end-use plastic markets account for almost 70% of all plastic used in the EU and are (1) packaging; (2) building and construction; and (3) the automotive industry (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%) and electrical and electronic equipment (EEE) (9%), agriculture (5%), automotive (5%), construction and demolition (4%) and non-packaging household waste (4%) (EC, 2018a). DP-containing plastics are present in the automotive industry and waste electrical and electronic equipment (WEEE) (as well as other smaller groupings), but it is not expected to be a significant share of the total plastic used in the EU.

In the EU, the potential for recycling plastic waste remains largely unexploited; in 2018, Europe collected 29 milllion tonnes of plastic waste, of which 32% was sent to recycling , 43% was incinerated and 25% was sent to landfill (EEA, 2021). Furthermore, the plastic waste destined to be recycled often leaves the EU to be treated in other countries where different environmental standards apply (EC, 2018a).

The European Commission presents the vision for Europe's new plastics economy in the European Strategy for Plastics in a Circular Economy (EC, 2018a):

"*A smart, innovative and sustainable plastics industry, where design and production fully respects the needs of reuse, repair, and recycling, brings growth and jobs to Europe and helps cut EU's greenhouse gas emissions and dependence on imported fossil fuels.*"

It is also highlighted that construction, automotive, furniture and electronics sectors are significant sources of plastics waste that could be recycled. One of the barriers for increasing the recycling rates in these sectors is the lack of information regarding the possible presence of chemicals of concern, including flame retardants. To address this issue the European Commission is accelerating its work on the interface between chemicals, waste and product policy in order to identify possible ways to improve the traceability of chemicals and address the issue of legacy substances in recycled streams (EC, 2018a).

The *Circular Economy Action Plan* identifies plastics as a key priority and commits to prepare a strategy addressing the challenges posed by plastics (EC, 2020b). In 2017, the EC confirmed it would focus on plastics production and use and work towards the goal of ensuring that all plastic packaging is recyclable by 2030. This intent is reinforced through more ambitious recycling targets for plastics in general as well as in specific directives such as the Directive on waste electrical and electronic equipment (WEEE), i.e. Directive 2012/19/EU, and Directive 2000/53/EC on end-of-life vehicles (ELVs), which sets out regulations for the dismantling and recycling of vehicles in order to reduce their environmental impact.

As concluded in A.2.4. Summary and conclusion, DP is found in plastics commonly used in the automotive and aerospace sector and in other applications including electrical and electronic equipment (EEE). 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). A consideration of how to treat recycled material containing DP under the restriction is therefore crucial. A restriction of DP under REACH would, depending on the limit values set by this restriction, prevent all or a certain percentage of recycled materials containing DP to re-enter the market. It might also temporarily (until the supply chain is free from DP due to the proposed restriction) render the achievement of recycling targets more difficult and increase the use of primary materials in the EU. On the other hand, if recycled materials containing DP are not adequately regulated it might however also have a negative impact on the EU ambitions for a move towards toxic-free material cycles and for establishing a circular economy. The EU Chemicals Strategy for Sustainability specifies that:

"To move towards toxic-free material cycles and clean recycling and ensure that "Recycled in the EU" becomes a benchmark worldwide, it is necessary to ensure that substances of concern in products and recycled materials are minimised. As a principle, the same limit value for hazardous substances should apply for virgin and recycled material. However, there may be exceptional circumstances where a derogation to this principle may be necessary. This would be under the condition that the use of the recycled material is limited to clearly defined applications where there is no negative impact on consumer health and the environment, and where the use of recycled material compared to virgin material is justified on the basis of a case by case analysis."

Based on the confirmed uses of DP in the EU, the waste streams that will most likely be affected by a restriction of DP under REACH are ELVs and WEEE.

A.2.5.1. End-of-Life Vehicles (ELVs)

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.

Directive 2000/53/EC on ELVs sets a re-use and recycling rate of 85% and a re-use and recovery rate of 95% of the vehicle weight, meaning that a maximum of 5% of ELVs should end up in landfill. The quota achievements must be proven under the Whole Vehicle Type Approval (WVTA) process (ACEA, 2015). Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste prohibits the export of waste for disposal to non-OECD countries, with the exception of EFTA countries that are party to the Basel Convention (EC, 2006). However, 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 be altered in the future.

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[20].

In the EU, around 15 million new passenger cars were registered in 2019 (ACEA, 2020). ELVs had an EU-average recycling rate of 87.9% and a recovery rate of 93.7% (Eurostat, 2020a). Recycling of ELVs is defined, in this context, as "*the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery*" (ECHA, 2019d). The recovery rate includes both the recycling rate and the share of ELVs used for energy recovery. ACEA (2020) shows that ~ 5.3 million cars were registered as ELVs in the EU in 2017, and 88% of the weight of these vehicle was recycled. ACEA informed in the stakeholder consultation that each car contains between 2 g and 35 g DP. By combining these data points, it can be estimated that 9 – 163 tonnes of DP may have entered recycling waste streams from ELVs in 2017. This is in the same orders of magnitude as the estimated DP entering the automotive industry supply chain of 68 – 130 tonnes/year of DP being used annually. However, the Dossier Submitter notes that according to the "state of the art vehicle recycling" presented in (ACEA, 2015), as much as 75% of the vehicle weight constitutes metals and only up to 15% would be relevant materials for plastic recycling. It is therefore highly unlikely that all DP-containing parts will be recycled, which means that the actual DP volumes potentially being recycled from ELV is probably much lower.

A.2.5.2. Waste Electrical and Electronic Equipment (WEEE)

The global volume of WEEE, which reached 44.7 million metric tonnes in 2016, is consistently increasing between 3 and 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; it is reported that at least 50% - 80% of WEEE arising in developed countries is shipped to developing countries (ILO, 2012, Kumar et al., 2017). 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).

In the EU, WEEE is regulated by the Directive on waste electrical and electronic equipment (Directive 2012/19/EU) and the Directive on the restriction of the use of certain Hazardous

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[20] 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

Substances in EEE (RoHS Directive 2011/65/EU). In 2017, the EU collected 3.7 million tonnes of WEEE and recycled 39.4% (Eurostat, 2020a, Eurostat, 2020b). Approximately 20% of WEEE is plastic, which equates to just under 19 000 tonnes of WEEE plastic that is recycled[21] if the general recycling rate of 39.4% is assumed. In reality this is likely to be an overestimate as rates of plastic recycling are below that of metal, glass and wood.

Directive 2012/19/EU increases the WEEE target collection rate as a share of total EEE from 45% in 2016 to 65% in 2019 (Eurostat, 2020b) and this is expected to lead to an overall rise in the WEEE recycling rates.

The percentage of recycled WEEE plastics potentially containing DP and the total volume of DP contained in these recycled plastics in the EU/EEA is unknown. Some information on the extent to which flame retardants, contained in WEEE, are recovered at the waste stage is however available for Switzerland. According to (BAFU, 2017), approximately 70 000 tonnes of e-waste is accumulated in Switzerland each year. This includes, but is not limited to, a fairly even split between small household appliances (25%), consumer electronics (36%) and data processing and electronic office equipment (36%). Of the flame retardants analysed in the study, the proportion of recovery was between 30 and 45%.

A.2.5.3. Recycling processes

As mentioned above, plastic is the most likely recycled material to contain DP. A restriction on DP would thus have implications on the handling of plastic waste streams.

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, 2018a). Effective sorting processes are therefore important tools to increase the output value of the recycled materials as well as ensuring compliance with chemicals regulations.

The recycling process typically involves similar stages and techniques for plastics contained in both ELVs and WEEE. The four general stages are (i) pre-treatment and dismantling, (ii) shredding, (iii) post-shredder treatment and (iv) recycling and recovery (Plastics Market Watch, 2016). According to ECHA (2012), 210 installations in the EU carry out shredding operations. Shredding is reported to be widely used as part of ELV treatment (Krinke et al., 2006, Plastics Market Watch, 2016) and is increasingly used as part of the recycling of WEEE (e.g. Maisel et al. (2020)). According to Plastics Europe (2021), mechanical recycling is currently the main form of plastics recycling in Europe, representing more than 99% of the recycled quantities.

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[21] 20% * 39.4% * 3.7 million tonnes = 18 782 tonnes.

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 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.

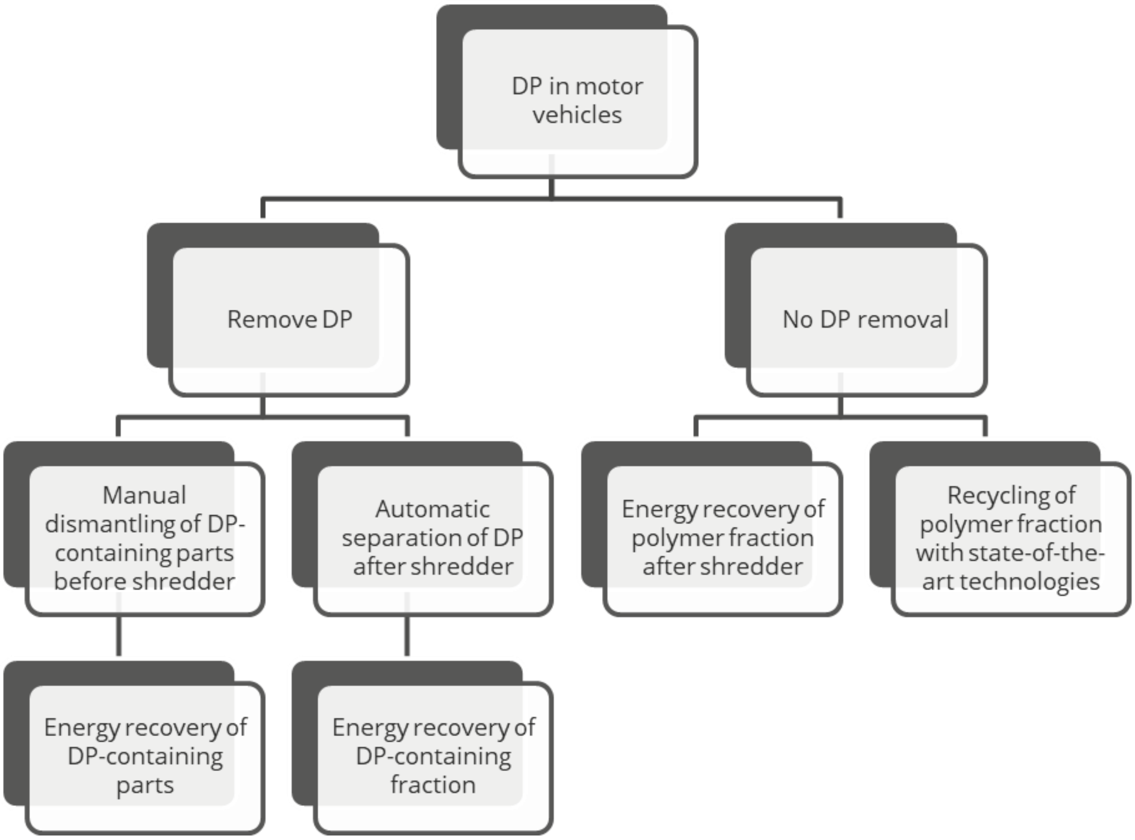

Figure 2: Waste treatment options for motor vehicles (adapted from figure in ACEA, 2015)

As shown in Figure 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 could be found in a recent study on substances of concern in post-consumer plastics performed by Ramboll Deutschland on behalf of the Dossier Submitter (Norwegian Environment Agency, 2021b).

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.

The need for elaborated technologies for recycling plastics that contain hazardous substances is confirmed by (EC, 2018a), 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.

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 is determined by the allowed concentration limit in the recycled material (ACEA, 2015). It is not known to what extent this technology is widely adopted in the EU.

While incineration is a technically feasible option for treating waste containing DP, which could be employed if DP-containing waste cannot be removed from waste streams in a technically and economically feasible way, large-scale incineration is not desirable and poses its own challenges. ACEA highlights that the high recycling rates required for end-of-life vehicles in the EU prohibit large-scale incineration. Furthermore, the capacity of high-temperature incineration could be an issue due to the large volumes of wastes from EEE and the automotive sector (ACEA, 2015).

A.2.5.4. Analysis of DP in post-consumer plastics

To support the ongoing regulatory processes for DP under REACH and the Stockholm Convention on POPs, the Norwegian Environment Agency has recently carried out a project to obtain more knowledge on DP and other substances of concern in post-consumer waste destined for recycling and related secondary raw materials (Norwegian Environment Agency, 2021b).

Waste samples of post-consumer plastics from 8 recycling facilities in Norway, Sweden, Germany and the Netherlands were collected and analysed for the contents of DP and the other pollutants in question. The selected facilities were known to treat different types of waste and to employ state of the art sorting and separation technologies. The collected samples were taken from three targeted waste streams, i.e. ELV, WEEE and building and construction waste (B&CW).

The samples were first subjected to XRF screening to identify samples with high levels of halogenated substances followed by targeted analysis using mass spectrometry to identify selected hazardous substances, including DP. The waste streams with increased chlorine levels were fridges, small domestic appliances (SDA) and ELV as well as PVC flooring, pipes and cables. The results from the targeted analysis showed that only low levels of DP (below 20 mg/kg) in a few samples were detected by GC/MS in fridges, SDA and ELV. It should be noted that the results do not nescessarly give a good picture of the use of chemicals in these products today, for example ELV in current waste streams were constructed at least 10 – 15 years ago.

In general, the project did not indicate any mismanagement of waste streams containing increased levels of the investigated substances. None of the waste fractions intended for recycling contained elevated levels of contaminants whereas increased substance concentrations were found in rejects of one company, indicating the efficiency of their separation process. It should be noted that the results of the project only have a limited representativity. However, the findings suggest that existing waste regulations, including concentration limits established for POPs as set out in the POPs Regulation (EU) 2019/1021, do not pose a barrier to state of the art recycling activities. As regards to the waste flows considered in the project, i.e. plastic fractions from ELVs, WEEE and B&CW, state of the art recycling technologies enable an efficient removal of halogen-containing plastics from other fractions to a certain degree (Norwegian Environment Agency, 2021b).

A.3. Uses advised against by the registrants

The registrant(s) advise against the use of DP in pyrotechnics and abrasive materials.

Annex B: Information on hazard and risk

B.1. Identity of the substance(s) and physical and chemical properties

The information in section B.1.1, B.1.2 and B.1.3 is based on the identity, physical and chemical properties of Dechlorane Plus^{TM} as presented in the SVHC support document for DP (ECHA, 2017d).

B.1.1. Name and other identifiers of the substance(s)

The substance 1,6,7,8,9,14,15,16,17,17,18,18-dodecachloropentacyclo-[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene has two isomers, named anti- (see Figure 4 and Table 14 for structural formula and details) and syn- (see Figure 5 and Table 15 for structural formula and details). This dossier covers the individual anti- and syn- isomers (monoconstituent substances) and all possible combinations of the syn- and anti-isomers (see Figure 3 and Table 13).

This dossier does not constitute a comprehensive record of all relevant numerical identifiers available. Please note that a substance identified by a numerical identifier other than those specified in this dossier may still be covered by this restriction. Similarly, a substance for which no numerical identifier is available may also be covered by this restriction.

Table 13: Substance identity 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 (Figure 3)

EC number:	236-948-9
EC name:	1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloro-pentacyclo[12.2.1.$1^{6,9}$.$0^{2,13}$.$0^{5,10}$]octadeca-7,15-diene
CAS number (in the EC inventory):	13560-89-9
CAS number: **Deleted CAS numbers:**	13560-89-9 -
CAS name:	1,4:7,10-Dimethanodibenzo[*a*,*e*]cyclooctene, 1,2,3,4,7,8,9,10,13,13,14,14-dodecachloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-dodecahydro-
IUPAC name:	1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.$1^{6,9}$.$0^{2,13}$.$0^{5,10}$]octadeca-7,15-diene
Index number in Annex VI of the CLP Regulation	Not applicable
Molecular formula:	$C_{18}H_{12}Cl_{12}$
Molecular weight range:	653.73 g/mole
Synonyms:	Bis(hexachlorocyclopentadieno)cyclooctane; 1,2,3,4,7,8,9,10,13,13,14,14-Dodecachloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-dodechydro-1,4:7,10-dimethanodibenzo[a,e]cyclooctene; Dodecachlorododecahydrodimethanodibenzocyclooctene; Dechlorane Plus 25 (Dech Plus); Dechlorane Plus 35 (Dech Plus-2); DP-515; Dechlorane 605; DP; DDC-CO

Note: The academic literature usually refers to this substance by a registered trade name "Dechlorane Plus" (often abbreviated as DP, but sometimes DDC-CO), and this is the name used throughout this Annex XV report and the Annexes for convenience.

Table 14: Substance identity of (1S,2S,5S,6S,9R,10R,13R,14R)-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, anti- (or exo) Dechlorane Plus (Figure 4)

EC number:	-
EC name:	-
CAS number: **Deleted CAS numbers:**	135821-74-8 -
CAS name:	1,4:7,10-Dimethanodibenzo[*a*,*e*]cyclooctene, 1,2,3,4,7,8,9,10,13,13,14, 14-dodecachloro-1,4,4a,5,6, 6a,7,10,10a,11,12,12a-dodecahydro-, (1*R*, 4*S*,4a*S*,6a*S*,7*S*,10*R*,10a*R*,12a*R*)-*rel*-
IUPAC name:	(1S,2S,5S,6S,9R,10R,13R,14R)-1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene
Index number in Annex VI of the CLP Regulation	Not applicable
Molecular formula:	$C_{18}H_{12}Cl_{12}$
Molecular weight range:	653.73 g/mole
Synonyms:	anti-DP, anti-Dechlorane plus, anti-Dodecachloropentacyclooctadecadiene

Table 15: Substance identity of (1S,2S,5R,6R,9S,10S,13R,14R)-1,6,7,8,9,14,15,16,17,17,18,18-dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene, syn- (or endo) Dechlorane Plus (Figure 5

EC number:	-
EC name:	-
CAS number: **Deleted CAS numbers:**	135821-03-3 -
CAS name:	1,4:7,10-Dimethanodibenzo[a,e]cyclooctene, 1,2,3,4,7,8,9,10,13,13,14,14-dodecachloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-dodecahydro-, (1*R*,4*S*,4a*S*,6a*R*,7*R*,10*S*,10a*S*,12a*R*)-*rel*-
IUPAC name:	(1S,2S,5R,6R,9S,10S,13R,14R)-1,6,7,8,9,14,15,16,17,17,18,18-Dodecachloropentacyclo[12.2.1.1^{6,9}.0^{2,13}.0^{5,10}]octadeca-7,15-diene
Index number in Annex VI of the CLP Regulation	Not applicable
Molecular formula:	$C_{18}H_{12}Cl_{12}$
Molecular weight range:	653.73 g/mole
Synonyms:	syn-DP, syn-Dechlorane plus, syn-Dodecachloropentacyclooctadecadiene

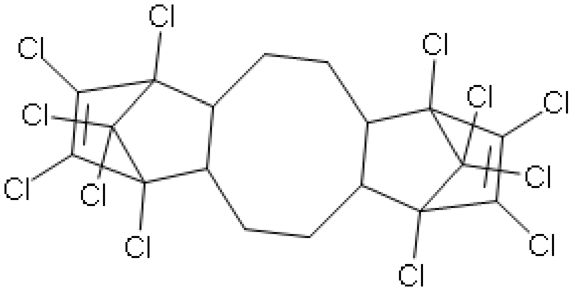

Figure 3: Structural formula

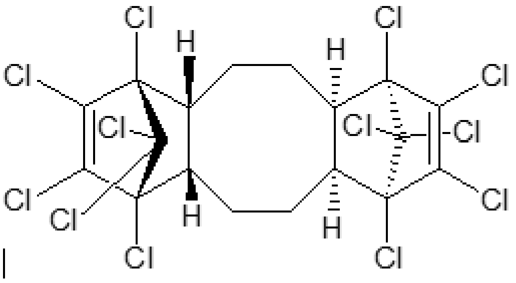

Figure 4: anti- (or exo) Dechlorane Plus

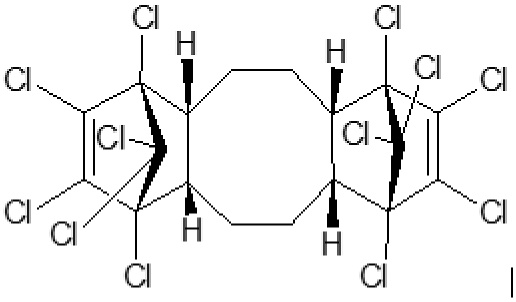

Figure 5: syn- (or endo) Dechlorane Plus

B.1.2. Composition of the substance(s)

Name: Dechlorane Plus^{TM}

Substance type: not applicable (group entry)

The information in this section is for the substance containing both the anti- and the syn-isomers as main constituents.

Table 16: Constituents other than impurities/additives

Constituents	Typical concentration	Concentration range (w/w)	Reference
anti- (or exo-)Dechlorane Plus (CAS no. 135821-74-8)	-	60-80%	Ben et al. (2013)
syn- (or endo-)Dechlorane Plus (CAS no. 135821-03-3)	-	20-40%	Ben et al. (2013)

The substance is described as mono-constituent by the Registrant. However, two geometric isomers are present in the commercial substance (e.g. (Chou et al., 1979) (OxyChem, 2013) This means that it is multi-constituent. The structures of the two isomers are provided in Figure 6.

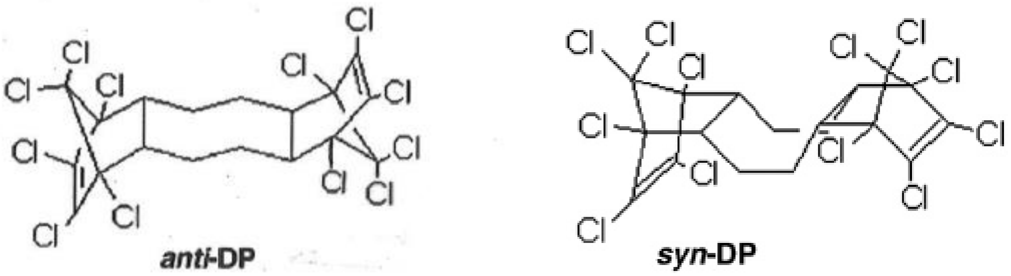

Figure 6: Geometric isomers of Dechlorane Plus (reprinted from Muñoz-Arnanz et al. (2010). Copyright 2010: International Symposium on Halogenated Persistent Organic Pollutants)

Ben et al. (2013) reported that the anti- isomer fractional abundance (f_{anti}) value (defined as [anti- isomer]/([anti- isomer] + [syn- isomer])) is not constant in Chinese commercial products, and varies from 0.60 to 0.80. The f_{anti} value of OxyChem commercial products has also been reported by several authors to be in the range 0.64 to 0.80 (e.g. see references in Wang et al. (2010b)).

The substance is made by a Diels-Alder reaction between 1,5-cyclooctadiene and hexachlorocyclopentadiene in a molar ratio of 2:1. Cyclooctadiene can also exist as 1,4- and 1,3- isomers, and both these, 4-vinylcyclohexene and 1,2-divinylcyclobutane might be present as impurities in, or formed via thermal rearrangement of, the starting materials (Sverko et al., 2010). Consequently, they can produce Diels-Alder reaction products with the same molecular weight as Dechlorane Plus. Sverko et al. (2010) analysed a technical

Dechlorane Plus product and detected four minor chromatographic peaks that are potentially related to these other substances.

Compounds with a smaller number of chlorine atoms may also be impurities in the commercial substance. For example, (Li et al., 2013a) found a mono-dechlorinated substance (DP-1Cl) in the commercial substance produced by Jiangsu Anpon Co. Ltd., China; in contrast, (Peng et al., 2014) could not detect DP-1Cl in samples from the same source (although this might reflect differences in detection limits).

B.1.3. Physicochemical properties

An overview of DP's physiochemical properties is given in Table 17. Unless otherwise stated, the data are taken from the REACH registration on the ECHA public dissemination website (ECHA, 2020b). There is no information available for the individual syn- and anti-isomers. Therefore, it is not possible to conclude whether there are physicochemical differences between these or not.

Table 17: Overview of physicochemical properties

Property	**Value [Unit]**	**Reference/source of information/remarks**
Physical state at 20°C and 101.3 kPa	The substance is a free flowing solid	
Melting/freezing point	Decomposition from 340 – 382 °C (no melting observed)	
Boiling point	*Data waived on the basis of a melting point > 300 °C*	
Vapour pressure	*Data waived on the basis of a melting point > 300 °C*	A vapour pressure of approximately 9.4E-08 Pa at 25 °C is predicted using MPBPVP v1.43 (U.S. EPA, 2012, modified Grain method, recommended for solids). This is highly uncertain (approximately ±1 log unit) as it is close to the lower limit of the range of the model, where there is some scatter in the training set. However, the molecular weight of the substance is within the range of the model's training set. Also, structural analogues are part of the MPBPVP training and test sets. A measured vapour pressure of approximately 0.008 hPa (0.8 Pa) at 200 °C was reported by Occidental Chemical Company (2003). An extrapolated vapour pressure of 4.6E-04 Pa at 25 °C can be estimated from this result using EUSES v2.1.2, and this is preferred for assessment purposes. There is some uncertainty due to the extrapolation from very high temperature, and the unknown reliability of the underlying result. The substance has a very low vapour pressure at environmentally relevant temperatures.
Surface tension	*Data waived on the basis of low water solubility (<1 mg/L).*	

Property	Value [Unit]	Reference/source of information/remarks
Dissociation constant	*Data waived on the basis of low solubility in water.*	The substance does not contain any acidic or basic functional groups.
Water solubility	< 1.67 ng/L at 20 °C (below the limit of quantitation)	Reliability 1: OECD Test Guideline 105 (column elution method) and GLP (ECHA website, 2017)). Dechlorane Plus (>99% purity) was coated onto the column using dichloromethane. HPLC grade reagent water was pumped through the column at two different flow rates, and analysed using gas chromatography with micro electron capture detection (GC-ECD). There is some uncertainty in the precise value for water solubility. However, all available measurements and predictions[22] are in agreement that the substance is very poorly water soluble.

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[22] Chou *et al*. (1979) reported mean water solubilities of 207 and 572 ng/L for the two isomers at 22±2.5°C using radiolabelled substance in equilibration with water by slow stirring for six weeks. This is considered unreliable by the Registrant. No reason is provided, but the report concluded that samples in the solubility experiment may have contained particulates, and so estimated a solubility of 44.1±2 ng/L at 22 °C (total for both isomers).

Water solubilities estimated based on a log K_{OW} range of 7 to 9 using WSKOWWIN v.1.42 (U.S. EPA, 2012) are 7.5E-05 – 1.5E-06 mg/L [75 – 1.5 ng/L]. The substance is outside the estimation domain of the model because both molecular weight and log K_{OW} are outside the ranges of these parameters in the training and test sets for the method. A water solubility of 6.5E-07 mg/L [0.65 ng/L] can be estimated using the WaterNT v1.01 fragment method (U.S. EPA, 2012), which does not use log K_{OW} as an input. The molecular weight is outside the range of this parameter in the training set, but not the test set. The number of aliphatic attached chlorines exceeds the maximum occurrences of this fragment in a single compound in the training set (8 in Dechlorane Plus, maximum 6 in the training set). Therefore, the substance is not considered to be within the estimation domain of the model.

U.S. EPA (2011) reported another measured value of 2.49E-04 mg/L [240 ng/L] at 25 °C (Scharf, 1978). In EPI Suite (U.S. EPA, 2012), a measured water solubility of 4.4E-08 mg/L at 25 °C is reported citing a HPV Robust Summary as the source; this result is discounted given the discrepancy between the value quoted and the original source (4.4E-05 mg/L, Chou *et al*., 1979).

Property	Value [Unit]	Reference/source of information/remarks
Partition coefficient n-octanol/water (log value)	*Waived by Registrant due to low water solubility.*	Chou *et al*. (1979) reported a log K_{OW} of 9.3 (also reported by the U.S. EPA, 2012). This is a calculated value; its validity has not been assessed. A log K_{OW} of 11.3 is predicted using KOWWIN (U.S. EPA, 2012). This result was also reported in the U.S. EPA (2001) review. The predicted result is considered to be within the validity range of the model because the molecular weight of the substance is within the range for this parameter for both the training and test sets. The number of aliphatic chlorines exceeds the maximum occurrences of this fragment in a single compound in the training set (8 in Dechlorane Plus, maximum 6 in the training set). The value is above the log K_{OW} values used in the training and tests sets and above the normal experimental range, but is indicative of the expected lipophilic character of the substance. It would be unusual to expect to quantify values above approximately 9 experimentally. The log of the ratio of n-octanol and water solubilities is >8.4, using a solubility of < 2 ng/L at 20 °C for water (ECHA website, 2017) and 470 mg/L at 25 °C for n-octanol (see below). Additional estimation methods give similar values. For example, the ACD/Percepta platform gives the following results: LogP Classic: 9.51±0.67; LogP GALAS: 9.16 (Reliability: Borderline; RI = 0.41. Chlordene and different chlordane isomers are in the training set). Whilst there is clearly uncertainty in the value of log K_{OW}, the value is assumed to be ≥9.
Partition coefficient air/water (log value) **[log K_{AW}]**	*No data were provided by the Registrant.*	The following log K_{AW} values at 25 °C are estimated based on the Henry's Law constant: -3.2 (from measured water solubility and estimated vapour pressure) 0.44 (from measured water solubility and vapour pressure) -2.8 (from EPIWIN predicted water solubility using log K_{OW} of 9 and vapour pressure) -3.5 (from HENRYWIN v.3.20, predicted from structure using Bond Method). See discussion of Henry's Law Constant (Section 3.2.2 of Appendix 1 in the SVHC Support document for DP) for further details (ECHA, 2017c).
Partition coefficient n-octanol/air (log value) [log K_{OA}]	*No data were provided by the Registrant.*	A log K_{OA} of 14.8 is estimated using KOAWIN (U.S. EPA 2012). This is a simple ratio of the octanol-water (log K_{OW} 11.3) and air-water (log K_{AW} -3.5) partition coefficients calculated within EPI Suite. There is uncertainty in this value resulting from uncertainty in the estimated K_{OW} and K_{AW} (see above). Using a log K_{OW} of 9, a log K_{OA} of 12.5 is estimated with a log K_{AW} of -3.5, or 8.6 with a log K_{AW} = 0.44.

Property	Value [Unit]	Reference/source of information/remarks
Henry's Law Constant	*No data were provided by the Registrant.*	The following values were obtained using a range of estimation methods (including a structural fragment based QSAR method) in light of the uncertainty in vapour pressure and solubility measurements and predictions: 1.4 Pa.m^3/mol at 25 °C (from measured water solubility and estimated vapour pressure) 6800 Pa.m^3/mol at 25 °C (from measured water solubility and extrapolated vapour pressure) 41 Pa.m^3/mol at 25 °C (from EPIWIN predicted water solubility using log K_{OW} of 9 and vapour pressure) 0.75 Pa.m^3/mol at 25 °C (from HENRYWIN v.3.20, predicted from structure using Bond Method). The Bond method training set comprises much smaller molecules than Dechlorane Plus, which are generally much more soluble and of higher vapour pressure than the substance, although the predicted Henry's Law constant is mid-range for the method. It is therefore difficult to estimate the uncertainty of the predicted values. See also Section 3.2.2 of Appendix 1 in the SVHC Support document for DP for further discussion (ECHA, 2017c).
Solubility in organic solvent[23]	n-Octanol solubility: 470 mg/L (to the nearest 10 mg/L) at 25 °C	Reliability 1: non-guideline study conducted in a GLP facility but not formally to GLP (reference not provided, but it appears to have been conducted in the UK in 2013) Approximately 2 g sample was weighed into a 125 mL conical flask and 20 mL n-octanol was added. A magnetic stirrer was placed on a thermostatic water bath overnight followed by slow stirring. Stirring was stopped and test solutions containing insoluble test substance were allowed to settle for 30 minutes before filtration under gravity. Clear colourless filtrates were obtained and test solution was analysed using GC-ECD without further dilution. The solubility in octanol is used as part of the assessment of octanol-water partitioning and also bioaccumulation. Although the test solution was filtered, it is not known whether the reported result represents truly dissolved substance.

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[23] Occidental Chemical Company (2004) refers to a study from 1978 that mentions a solubility in n-octanol of 264 - 346 (average 305) ppb (µg/L) at 25 °C. No further details are available, but the result was obtained "after partitioning" (presumably with water, as the data entry is for the water solubility end point) so this is probably not a true solubility value.

Product literature (OxyChem, 2007) provides further values (all in units of g/100 g solvent at 25 °C) as follows: benzene 2.0, xylene 1.0, styrene 1.8, trichloroethylene 1.4, methyl ethyl ketone 0.7, n-butyl acetate 0.7, hexane 0.1, methyl alcohol [methanol] 0.1. The analytical information provided in the REACH registration dossier mentions that the substance is "insoluble" in methanol, but "soluble" in tetrachloroethane, dichloromethane and tetrahydrofuran.

B.1.4. Justification for grouping

As described in Section B.1.2. Composition of the substance(s) two geometric isomers are present in the commercial substance (Chou et al., 1979, OxyChem, 2013), and hence DP is defined as a multi-constituent. DP is produced by the Diels−Alder condensation of hexachlorocyclopentadiene and 1,5-cyclooctadiene in a 2:1 molar ratio (Sverko et al 2011). Formation of geometric isomers occurs naturally during synthesis of DP and as a result of the thermodynamically and sterically most favorable reaction. It is also demonstrated that the reaction stereoselectivity can be affected by solvent nature and reaction temperature (Pavelyev et al., 2016).

There is no information available for the individual syn- and anti- isomers. Therefore, it is not possible to conclude whether there are physicochemical differences between these or not. The two isomers are not expected to have significant differences in physiochemical properties, and it is generally accepted to consider geometric isomers as similar substances.

The justification for grouping is underpinned on the basis of the similarity of the two isomeric forms.

B.2. Manufacture and uses (summary)

The data on manufacture and uses are described in Annex A: Manufacture and uses.

B.3. Classification and labelling

No harmonised classification is reported for Dechlorane Plus (CAS 13560-89-9) in Annex VI of Regulation (EC) No. 1272/2008 (CLP Regulation).

There are no proposals for new or amended harmonised classification of Dechlorane Plus (CAS 13560-89-9) on the Registry of Intention.

The Registrant has not proposed classification for any hazard.

The European Chemical Agency (ECHA) online Classification & Labelling (C&L) Inventory database, which was checked on 8 March 2021, reports a joint submission (consisting of 151 notifiers) indicating no classification according to the CLP criteria. In addition, 99 notifiers have classified the substance as Acute Toxicity Category 4, H332 Harmful if inhaled.

B.4. Environmental fate properties

The environmental fate properties of DP have been summarised previously (ECHA, 2017c, ECHA, 2017d) and were the key arguments leading to the identification of DP as an SVHC. The following sub-sections on the environmental fate properties of DP are therefore limited to a discussion of significant new information that has become available after the publication of the DP SVHC support document. Furthermore, the following sub-sections are coordinated with activities on DP under the Stockholm convention.

B.4.1. Degradation

The Member State Committee's (MSC) support document for the identification of (DP) as substance of very high concern because of their vPvB properties (Article 57e) (ECHA, 2017d), concludes as follows:

"Based on the weight of evidence of the data available, it is concluded that Dechlorane Plus meets the criteria for vP in Annex XIII of REACH. This is based on:

- *modelling of degradation potential and microbial metabolic pathways which suggests that biodegradation is likely to be very slow; and*

- *a low probability that it will degrade any faster than structural analogues that are considered to be very persistent under the Stockholm Convention.*

This conclusion is also supported by the very low water solubility (suggesting limited bioavailability to micro-organisms once bound to solid matrices), monitoring data indicating that the substance can persist in sediments (a major sink) for many years, lack of evidence of biotransformation in fish (supporting the premise that the molecule is metabolically recalcitrant) and widespread occurrence in remote regions".

The Draft POPs risk profile for DP and its syn- and anti-isomers has the following description of the degradation of DP (POPRC, 2021b):

"47. DP is chemically stable in various environmental compartments with minimal or no abiotic degradation (reviewed in Wang et al., 2016, ECHA, 2017d, Canada, 2019. Due to a very low water solubility and high log K_{ow}, DP is expected to bind to organic carbon in soil and sediments (Wang et al., 2016), reducing the bioavailability of DP for microorganisms and hence the potential for biodegradation. There are no measured half-life data for degradation of DP in surface water, sediment or soil (ECHA, 2017d). However, physical-chemical properties of DP were predicted using three different models (EPISuite, SPARC and Absolv) and the estimated half-lives in water, soil and sediment were predicted to be 180, 3650 and 1621 days, respectively (Zhang et al., 2016).

48. DP does not contain any functional groups that are susceptible to hydrolysis and hydrolysis is not expected to be a relevant degradation process (Canada, 2019; ECHA, 2017b). Data on photodegradation of DP in air (e.g. Sverko et al., 2008; Wang et al., 2011; Li et al., 2013b; Wang et al., 2013; Tao et al., 2015), water (Chou et al., 1979) and soil (only modelled data), are reviewed in ECHA (2017d) and Canada (2019). Most of the experimental data are from controlled lab studies that cannot be directly related to natural conditions due e.g. to the use of solvents and differences in light intensities.

49. The studies on photo-degradation suggest that anti-DP might be more photodegradable in air than syn-DP. Furthermore, DP is considered to be relatively photo-stable in air under natural conditions although photodegradation and formation of lower chlorinated dechloranes and other degradation products are reported in some of the studies. Under natural conditions sorption of DP to airborne particles is expected, which would lower the photolysis rate and result in a longe r half-life in air (Canada, 2019). Furthermore, the study of Wang et al. (2013) indicates that DP should be photo-stable in the environment and only undergo limited degradation undernatural light conditions at the terrestrial surface. Wang et al. (2013), who investigated the photodegradation of DP (anti-DP, syn-DP, and commercial DP) in n-nonane by irradiation using a xenon lamp, observed rapid photodegradation by dechlorination under 200–750 nm light. During the first 5 minutes >50% was degraded, and after 30 minutes 99% had been degraded. The degradation was much slower in 280–750 nm light, and only 20% loss was observed after 4 hours. The quantum yields of dechlorination by-products at 200–280 nm (UV-C) were about 2–3 orders of magnitude higher than at 280–320 nm, and no yields were detected in the 320–750 nm range (Wang et al., 2013). Hence, both in visible light (>400 nm) and UV-A light (320–400 nm), DP exhibited negligible degradation in n-nonane, while UV-C (200–280 nm) played a significant role in the photodegradation of DP and might provide a potentially effective approach to eliminate DP. As the majority of UV exposure in the environment is UV-A light with a wavelength in the 315-400 nm range, these findings indicate that DP should be photo-stable in the environment and only undergo limited degradation under natural light conditions at the terrestrial surface. A sequential degradation process where one to four chlorines are removed from DP and exchanged with hydrogen was observed and suggested that the main overall reaction was photoreduction, leading to photodechlorination of DP (Wang et al., 2013). Dechlorination was also observed by Li et al. (2013b). In this study, three photolytic degradation experiments were performed by exposing solutions of anti-DP, syn-DP, and commercial DP to UV light. In addition to anti- and syn-DP-Cl$_{11}$, at least two unknown products were identified in all samples following exposure, and in the test substance (Li et al., 2013b)."

Regarding paragraph 49 above, Wang et al. (2013), reported that 4 photodegradation products for each of syn and anti-DP were identified, and in addition two impurities in the commercial mixture, (syn-DP~[−1Cl+1H], syn-DP~[−2Cl+2H], syn-DP~[−3Cl+3H] and syn-DP~[−4Cl+4H], same for anti-DP.

"50. According to ECHA (2017d) photolysis is unlikely to be a significant fate process in natural waters, since light is attenuated with increasing water depth and shading. Radical reactions may also be inhibited by humic substances. They conclude that available information suggests that phototransformation in water is a potential but insignificant removal process for DP. The only controlled laboratory study on photo-degradation in water is by Chou et al. (1979) who measured the phototransformation of DP in an aqueous solution with 5 % acetonitrile using a mercury lamp emitting wavelengths >290 nm for 168 hours. In Canada (2019) a half-life for DP of >24 years is reported for this study, while ECHA (2017d) report that the rate constant for phototransformation in water was calculated as <6 × 10-4/h, equivalent to a half-life of >48 days (Chou et al., 1979). According to ECHA (2017d) the findings from this study are not directly representative of natural conditions as the test solution included a solvent and the initial concentration of DP was 1 ppm (1 mg/L), which is significantly greater than the reported solubility of DP in

pure water. For phototransformation in soil ECHA (2017d) reports that no data were reported by the registrant, and that similar to water, this is unlikely to be a significant removal pathway.

51. Generally, model predictions support experimental findings that aerobic and anaerobic biodegradation of DP is very limited and that DP is expected to be persistent in water, soil, and sediment (Canada, 2019). Predictions using the BIOWIN v4.10 model (US EPA, 2012), Catalogic (2012) and TOPKAT (2004) all indicate that biodegradation of DP will be very slow (Canada, 2019; ECHA, 2017d). ECHA (2017d) concludes, based on the estimated data from the BIOWIN v4.10 model and associated uncertainties, that "DP is unlikely to be biodegradable". The BIOWIN results obtained for DP are the same as a number of hexachloro-norbornene-containing analogue chemicals and indicate that DP is as persistent as analogue chemicals such as mirex, chlordane, heptachlor, dieldrin/endrin, aldrin and endosulfan that are already listed as POPs under the Stockholm Convention. Furthermore, the two possible microbial degradation pathways predicted for DP are the same as for the POP analogues. According to ECHA (2017d) it is unlikely that metabolic rates for these pathways will be more rapid for DP, which is significantly less water soluble than the already listed POPs. The validity of the BIOWIN v4.10 model is discussed in detail in ECHA (2017d). Despite some uncertainties BIOWIN v4.10 is generally considered as a valid model for DP.

52. In line with these modelling results laboratory tests discussed in Canada (2019) have shown that DP is not likely to biodegrade under aerobic conditions; an activated sludge biodegradation test (modified MITI OECD 301C) reported 0.6% biodegradation in 2 weeks (US EPA, 2011; see also Japan J-CHECK, 2020a) and a 21-day test using wastewater biosolids found 0% biodegradation (US EPA, 2009).

53. Monitoring studies provide additional evidence that DP is persistent and that biodegradation in sediment is limited. DP was found to be persistent in suspended sediment with a half-life of approximately 17 years (Sverko et al., 2008). The study of Qiu et al. (2007) suggests that DP can still be present over thirty years after initial deposition. In this study, DP was measured in a sediment core from central Lake Ontario, Canada, and detected in a layer corresponding to around 1980. A linear trend (r2 = 0.739) of increasing fanti values with time was observed, from an average of 0.76 in surficial (recent) sediments to >0.90 in the deeper layers corresponding to around 1980, suggesting that the anti-DP could be more persistent than the syn- isomer in sediment. However, the variation of fanti in commercial batches over this time period is not known, and the findings could also reflect the isomerisation of syn-DP to anti-DP. Similar to the findings of Qiu et al. (2007) other studies on DP and fanti values in freshwater Wang et al. (2010a) and marine sediment (Fang et al., 2014), respectively report possible stereoselective depletion of syn-DP in freshwater sediment and an enrichment of anti-DP. The enrichment of anti-DP is explained as likely being due to preferential biodegradation of the syn- isomer in the sediment.

54. Some data on the degradation of DP in soil are also available. In a controlled laboratory study that was not considered in the Canadian or the EU assessment (Canada 2019; ECHA, 2017d), degradation of DP in top layer agricultural soil with a pH of 7.1 and consisting of 64.2% silt, 25.6% sand, 10.2% clay, and 3.12% organic matter, was investigated by spiking the soil with DP in acetone to obtain initial DP concentrations of 0.1, 1, and 10 mg/kg. After 260 days of incubation at 25 oC 4.2-8.2% of the initial DP had degraded

(Cheng et al., 2019). During the same time the labile fraction of DP decreased from 21.25% to 8.2%, 23.8% to 11.7%, and 25.2% to 16.3% in 0.1, 1, and 10 µg/g DP soil, respectively, indicating that the bioavailability of DP decreased under the influence of aging. Model simulations developed to investigate the transformation indicated that the transformation rates were inconstant and statistically different from one another over time. The half-lives of DP in soils spiked with 0.1, 1, and 10 µg/g DP were extrapolated to 1325, 1909, and 2948 days, respectively. As the authors considered that very little bound-residue DP is formed at the start of the aging process, the loss of DP to bound residues was neglected, and the half-lives was simplified to and calculated as the time required for the combined concentration of labile and stable-adsorbed fractions to reduce to half its initial value (Cheng et al., 2019). It has also been reported that syn-DP varied little with depth down to 100 cm in soil sampled close to the Chinese manufacturing facility (Wang et al., 2010a), possibly suggesting that isomer-specific degradation or preferential adsorption does not play a significant role in soil. The DP concentration was highest in surface soil (0-5 cm; 837 µg/kg dry weight (dw)), decreasing to 9.16 µg/kg dw at a depth of 60-70 cm and 3.84 µg/kg dw at a depth of 90-100 cm. The fanti value varied little with soil depth but ranged from 0.75 in the surficial layer to 0.67 in the deepest layer (90-100 cm). The study authors make conflicting statements about their finding. On the one hand, they say their findings imply a stereoselective depletion of the syn- isomer in soil in comparison with the measured fanti value of the Chinese commercial product, at 0.60. On the other hand, they also state that isomer specific microbial degradation or preferential adsorption does not play a significant role in soil.

55. DP is expected to be persistent in water, soil, and sediment. Based on its binding to particles in air and available laboratory studies and modelling data DP is also considered to be persistent in air under natural conditions. Modelling studies of degradation potential and microbial metabolic pathways suggests that biodegradation of DP is likely to be very slow, and that the probability that DP will degrade any faster than analogue substances listed under the Stockholm Convention is low. Monitoring data show limited degradation in soil and sediments over time and support the conclusion that DP is persistent. The persistency of DP in soil was also recently confirmed in a controlled laboratory study."

A recent study by Cheng et al. (2020) has investigated the transformation and dissipation of DP in the rhizosphere of a soil-rice plant system. The study was carried out over 150 days and the contributions of plant uptake, microbial degradation and bound-residue formations were determined, and the overall dissipation of DP from the system were modelled and quantified. The overall half-life of DP in the soil-rice plant system was determined to be 105 days with the microbial degradation contributing 8.33 - 54.14%, bound-residue formation contributing 3.63 - 16.43% and plant uptake contributing 0.54 - 3.85% of the total dissipation seen.

In summary, there is already agreement that DP, including its anti- and syn-isomers, is very persistent and very bioaccumulating according to REACH Annex XIII criteria. DP has been listed as an SVHC-substance due to these properties (Article 57e).

B.4.2. Environmental distribution

B.4.2.1 Adsorption/desorption

Section 3.2.1 of the MSC support document (ECHA, 2017c, ECHA, 2017d) for the SVHC identification of DP has the following description of the predicted environmental distribution of DP:

"No reliable information on the organic carbon-water partition coefficient (K_{OC}) is included in the registration dossier, but a non-standard study investigating adsorption to sediment is summarised in Appendix 1 (Chou et al., 1979).

In view of the fact that Dechlorane Plus is a highly insoluble substance with a high log KOW and (relatively) high solubility in n-octanol, it is expected to have a high potential for adsorption. KOCWIN v2.00 (US EPA, 2012) can be used to predict log KOC values of 7.7 (Molecular Connectivity Index estimation method) and ≥7.8 (log KOW-based estimation method; using the log KOW value ≥9). The substance is within the domain of the method because the molecular weight is within the molecular weight range of the training set, and no fragment corrections are applied. The Registrant assumes a log K_{OC} of 8 in the registration dossier.

These predicted values indicate a high adsorption potential for Dechlorane Plus, suggesting that sediment and soil are more relevant environmental compartments than water (i.e. they are likely to be major sinks)."

The EPI Suite 4.0 estimated LogK_{OW}s of 11.3 for syn-DP and anti-DP, 10.2 for anti-Cl_{10}-DP and 10.4 for anti-Cl_{11}-DP (Zhou et al 2019).

Several studies have detected DP in sediments. In a recent study by Zhong et al. (2020), a significant positive correlation was observed between the concentration of syn-DP and total organic carbon (TOC) contents as well as grain size for surface sediment sampling sites. The authors indicate that syn-DP was likely to be adsorbed on the fine-grained particles with high TOC contents. However, in a desorption study by Zhou et al (2019), the desorption of DP was unaffected by the different TOC content of the three tested sediments.

Zhou et al. (2019) investigated the desorption behaviour of DP from laboratory spiked sediment. The sediment was sampled from three different rivers/reservoirs in China and were spiked with DP in the laboratory to obtain 500 ng DP/g dry weight sediment. Sediment 1 (S1) contained 2.1% TOC, 28.93% sand (>2000µm), 62.51% silt (2-20µm) and 8.56% clay (<2 µm). S2 contained 1.2% TOC, 33.37% sand, 58.95% silt and 7.68% clay, and S3 contained 0.3% TOC, 71.56% sand, 21.91% silt and 6.53% clay. The desorption followed a first-order, three-compartment model where a rapid decrease was followed by a transition period before the desorption became very slow. The rapid desorption was very small and the F_{rap} values ranged from 0.053-681, whereas F_{vs} was in the range of 0.268-0.904. The calculated time at which 99.9% of the DPs would be desorbed from the slow and very slow desorption compartments were 46.42 and 55.53 years for syn-DP, 44.40 and 24.49 years for anti-DP, 44.76 and 87.62 years for anti-Cl_{10}-DP and 44.01 and 86.65 years for anti-Cl_{11}-DP respectively. In summary, the study found that DPs desorb slowly from the sediment. In addition, the authors assume that anti-Cl_{10}-DP and anti-Cl_{11}-DP is bioaccumulated at a low rate due to the extremely low F_{rap} values.

Zhong et al (2020) observed an f_{anti} value in surface sediments from Liaohe Estuary (China) of 0-0.43 with an average value of 0.13 which is lower than the f_{anti} value of commercial mixtures of dechlorane plus.

In summary, the estimated and experimental data support that DP will mostly partition to sediment and soil.

B.4.2.2 Volatilisation

Section 3.2.2 of the MSC support document for the SVHC-identification of DP and its syn- and anti-isomers has the following description of the volatilisation potential of DP:

"The volatilisation potential of the substance from water can be estimated based on the available vapour pressure and water solubility data for the substance, and also by reference to QSAR-estimated values (...). Whilst there is some uncertainty in the values of water solubility and vapour pressure (...), the calculated HLC based on measured input data is $\geq 1.39\times10^{5}$ Pa.m^3/mol at 25 C, suggesting that Dechlorane Plus could be volatilised from water. However, strong adsorption to organic matter is likely to make this fate pathway less important in natural waters.

Given the very low vapour pressure and high K_{OW} of the substance (i.e. a high K_{OA}), Dechlorane Plus will be mainly adsorbed on particulates in air. This has been demonstrated by monitoring studies, with mean fractions on particulates of 97 % or more (e.g. Hoh et al. (2006), Ren et al. (2008), Wang et al. (2010b)) although Möller et al. (2010) measured it as around 80 ± 30 % and Yang et al. (2012) only detected Dechlorane Plus in the particulate phase."

The conclusion from the MSC support document is supported by a recent study by (Wang et al., 2020b)investigating halogenated flame retardants (FRs) in the atmosphere in Dalian, China, dechlorane concentration in the gas phase and particle ($PM_{2.5}$) fraction was measured. The DP concentrations were in the range of 0.02-0.74 (0.15±0.14) pg/m^3 in the gas phase and 0.03-1.06 (0.31±0.22) pg/m^3 in the $PM_{2.5}$, showing approximately 2 times higher mean concentration in the $PM_{2.5}$ fraction (0.31 ±0.22 pg/m^3) than in the gas phase (0.15±0.14 pg/m^3).

B.4.2.3 Distribution modelling and long-range transport potential

Section 3.2.3 of the MSC support document for the SVHC-identification of DP and its syn- and anti-isomers has the following description of the distribution modelling of DP:

"The CEMC Level III Fugacity Model v 2.80 (CEMC, 2004) can be used to model the distribution of Dechlorane Plus. The physico-chemical property values used in the model are those selected in Table 7: water solubility 2.0×10^{-6} mg/L; vapour pressure 4.6×10^{-4} Pa; log K_{OW} 9. The degradation half-lives used in the model environment are: air 16.8 hours; water 1.8×10^{4} hours (assuming photodegradation) or 8.4×10^{6} hours (assuming no photodegradation); soil 8.4×10^{6} hours.

If Dechlorane Plus is assumed to be released at equal rates to air, water and soil, the model predicts the following distribution: air 3.7×10^{-3} %, water 0.087 %, soil 96.5 % and sediment 3.45 % (the two half-lives in water give the same result). The substance has a very low vapour pressure. If it is released only to water (with no application to soil, including WWTP sludge), the calculated distribution is very different: air 9.0×10^{-5} %, water 2.46 %, soil 1.9×10^{-3} % and sediment 97.5 %. It should be noted that there is uncertainty in the property values used in the modelling and hence uncertainty in the results. More than 97 % of the Dechlorane Plus in the atmosphere is likely to reside in the particulate phase (see Section 3.2.1).

Using the OECD P_{ov} and LRTP Screening Tool v2.2 (Wegmann et al., 2009), the results obtained for Dechlorane Plus (see Section 3.3) suggest that it has a relatively low transfer efficiency from air to surface media[24] *of 3×10^{-4} %.*

Sverko et al. (2011) studied air-water exchange using the data measured by Möller et al. (2010) in the marine environment. The mean concentrations in air (gas phase) and seawater (dissolved phase) were 0.12 pg/m^3 and 0.009 pg/L, respectively, in the East Greenland Sea and 0.028 pg/m^3 and 0.044 pg/L, respectively, along the Atlantic transect. The resulting fugacity fraction[25] *is near unity, suggesting net gaseous deposition of Dechlorane Plus to seawater.*

Sverko et al. (2011) also compared the ratio of concentrations in air and soil reported by Wang et al. (2010b) with an estimate based on the log KOA value. The good agreement suggested that Dechlorane Plus in the gas phase originated from soil volatilization. However, they did not perform a similar analysis to compare gas phase with particulate concentrations."

DP is frequently detected in the Arctic and other remote regions which shows that the compound is transported over long distances from point sources and production facilities. The Draft POPs risk profile for DP and its syn- and anti-isomers has the following description of the long-range transport potential of DP (POPRC, 2021b):

" 44. Based on production, usage and disposal data Hansen et al. (2020) *prepared two*

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[24] Transfer efficiency in this model is defined as "the ratio of the deposition mass flux from air to surface media in a region adjacent to the region to which the chemical is released and the mass flux of the chemical emitted to air in the release region"

[25] This is used to assess equilibrium status of a chemical between two interacting phases, in this case air and water:

Fugacity fraction = $C_A / (C_A + K_{AW}C_W)$

where C_A is the air concentration (in pg/m^3), C_W is the water concentration (in pg/L)

Values equal to 0.5 indicate air–water equilibrium and no net gas exchange. Values < 0.5 indicate net volatilization from water, and values > 0.5 indicate net gaseous deposition to water.

global atmospheric emission scenarios with a detailed geographical distribution. The total DP emission to air was estimated to be 0.02 t/year and 3.2 t/year in a low and high emission scenario, respectively, reflecting the uncertainties in production volumes and emission factors. Furthermore, 0.41-21.8 tonnes year were predicted to be released to water, and 0-0.004 tonnes/year direct to soil. The validity of the emission estimates was tested by implementing them in the Danish Eulerian Hemispheric Model, an advanced chemistry-transport model, and by evaluating the predicted atmospheric concentrations with all available Arctic measurements from peer-reviewed studies. The high emission estimate was found to be the most probable as the predicted concentration range for the high emission scenario was found to be in line with the measured range, whereas the predicted concentrations for the low emission estimate was more than a factor of 100 lower than the measurements. The estimates reported in this study were based on a global annual production of 75-6,000 tonnes/year (average assumed to be 1,980 tonnes/year) and with two manufacturing plants (one in the United States and one in China).

(...)

45. The environmental distribution and fate of DP is discussed in Canada (2019) and ECHA (2017d). In the assessment by Canada (2019), level III fugacity modelling using the updated EQC model (v1.0, 2012) was applied to describe the fate of DP entering the environment from industrial sources and from commercial and consumer products. The results show that DP is expected to predominantly reside in soil and/or sediment, depending on the compartment of releases.

46. The Canadian assessment further details that the very low water solubility (2.85 x 10-7 mg/L), low vapour pressure (6.57 x 10-11 Pa at 25°C) and very high partition coefficients (log Kow of 8.78, estimated log Koc of 6.65) suggest that DP released into the environment will be less likely to partition into and/or remain in air and water, moving instead to the sediments and soil. If released to air, a small fraction (less than 1%) of DP is expected to remain in air in gas phase, with most of the substance depositing to soil and water with further partitioning to sediment. The high partition coefficients also indicate that DP released into surface water from wastewater is expected to adsorb to the organic fraction of suspended solids and sediments, with less than 4% remaining in water. However, the small mass of DP that remaining in air and in water has the potential for dispersion and some transport (e.g., particle transport). On the basis of its high log Koc, once in the sediment, DP is not expected to be mobile and may remain in this compartment with little degradation. When DP is released to soil (i.e., through biosolids application to agricultural lands), the majority of the mass fraction is expected to become adsorbed to soil (99.9%) on the basis of its high estimated log Koc and hydrophobic nature. On the basis of its low vapour pressure, DP is not expected to evaporate (volatilize) from dry soil surfaces and is therefore likely to remain in soil. In addition, low degradation is expected in soil; therefore, DP is likely to remain in this compartment, with loss processes driven by soil burial or surface runoff. The results of Level III fugacity modelling support the expectation that DP predominantly resides in soil or sediment, depending on the compartment of release.

(...)

68. Due to its high hydrophobicity and low vapour pressure (…), DP in the atmosphere *adsorbs to airborne particles (AMAP, 2017, Canada, 2019, Sverko et al., 2011). Monitoring studies have reported mean fractions of particle-bound DP in air as high as 99 % (Hoh et al., 2006). Measurements in seawater confirm the propensity of DP to adsorb to particles. In the East-Greenland Sea, particle-bound DP accounted for, on average, 97% of syn-DP and 80% of anti-DP. In Atlantic seawater, the particle bound fraction was on average 58% for syn-DP and 75% for anti-DP (Möller et al., 2010).*

69. The modelled half-life (QSAR estimate) of DP in air is 13.68 hours (Sverko et al., 2011), i.e. below the criterion of two days set in Annex D (d) (iii) of the Convention. The Canadian assessment reports estimated half-lives in air of 0.468 and 160.12 days for atmospheric oxidation and ozone reaction, respectively, using the AOPWIN 2010 model (12-hr day) (Canada, 2019). However, air modelling that is based on gas phase reactions may underestimate the half-life value because they to not take into account the particle binding which is expected for DP. Particle binding will lower the photolysis rate and result in a longer half-life in air (reviewed in Sverko et al., 2011; Canada, 2019). As shown already for other chemicals with similar physico-chemical properties such as decaBDE; (Breivik et al., 2016; UNEP/POPS/POPRC.10/10/Add.2.; POPRC-10/2), sorption to particles may slow down reaction rates, increase the actual half-life in air and facilitate long-range environmental transport (LRET) of DP on particles (Canada, 2019, Sverko et al., 2011). As described in ECHA (2017d), the LRET of substances with low vapour pressure that adsorb strongly to particulates in the air is likely to be governed by the fate of the particulates to which they bind and can undergo LRET to remote regions when atmospheric conditions permit (e.g. during dry periods).

70. Modelling studies performed with the OECD P_{OV} and LRTP Screening Tool, a software tool for screening chemicals for persistence and LRET potential (Wegmann et al., 2009), and comparing DP to DP analogues and benchmark chemicals including α-HCH, HCB, PCB-101, PCB-180, PCB-28, HBCD, atrazine, p-cresol, chlordene plus, Dec 602, Dec 603 Dec 604, suggest that DP has transport and persistence properties within the range for listed POPs (Sverko et al., 2011), and that DP may be deposited to some degree in remote regions (Canada, 2019). However, the results generated using the OECD POV and LRTP Screening Tool are associated with uncertainty, largely because most of the input parameters used in the model are estimated (ECHA, 2017d, Sverko et al., 2011).

In summary, DP is detected in the environment and biota in remote areas. LRET occurs by sorption to particles in the atmosphere and in seawater.

B.4.3 Bioaccumulation, bioavailability and transformation in biota

MSC's support document (ECHA, 2017d) for the identification of DP and its syn- and anti-isomers as substance of very high concern because of their vPvB (Article 57 e) properties, has the following conclusion on why DP should be identified as very bioaccumulative (vB):

"*Significant limitations in the available regulatory data set create uncertainty in the bioaccumulation assessment. A high level of bioaccumulation can be expected based on simple screening data related to physico-chemical properties and molecular parameters.*

There are no definitive data from fully valid studies showing that Dechlorane Plus has a fish BCF above 5 000 L/kg, a fish BMF > 1 or BSAF > 1 in the laboratory. Evidence from field studies is conflicting; whilst some suggest TMF[26]*/BMF*[27]*/BSAFs*[28]*above 1, none of the studies is considered to be particularly reliable. Nevertheless, the substance is widely dispersed in both aquatic and terrestrial food chains, including top predators. In terms of the aim of protecting organisms from unpredictable adverse effects, a long depuration half-life is a key factor since substance concentrations may take a long time to decline once emissions cease. Dechlorane Plus has a long depuration half-life in fish consistent with other substances that have a fish BCF above 5 000 L/kg (supported by a long depuration half-life in mammalian liver). Levels achieved in laboratory exposures and detected in a variety of wildlife species indicate that Dechlorane Plus can achieve a relatively high body burden in some cases, consistent with levels that may be associated with toxic effects due to baseline narcosis (see Appendix 3, 4 and 6). These are the principle reasons why the substance is concluded to meet the very bioaccumulative (vB) criteria37 in Annex XIII of REACH.*

(…)

Using a weight of evidence assessment of the data available, Dechlorane Plus meets the vB criteria in Annex XIII of REACH. This is based on:

- *the long-depuration half-life determined in fish feeding studies which is indicative of a BCF above 5 000 L/kg, by comparison with other substances (supported by a long depuration half-life in mammalian liver);*
- *numerous studies that show that the substance is widely dispersed in freshwater, marine and terrestrial food chains, including top predators; and*
- *evidence that the substance can exceed levels in biota that are of concern based on"*

The draft POPs risk profile for DP and its syn- and anti-isomers has the following updated description of DP's bioaccumulating properties (POPRC, 2021b):

"56. The log K_{ow} for DP is reported to be 9.3 (OxyChem, 2004b). The high log K_{ow} and the very low water solubility (Table 2) indicates that DP is very hydrophobic and partitions to organic matter. This is further supported by the relatively high log sediment-water partition coefficient (log K_p) of 6.65. These properties make it difficult to perform aqueous laboratory studies as it is difficult to maintain stable exposure levels in water. Therefore, aqueous exposure is expected to be of limited importance in terms of bioaccumulation potential. However, significant uptake has been shown to occur in fish in a number of field studies (Abdel Malak et al., 2018, Guo et al., 2017, Kurt-Karakus et al., 2019).

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[26] TMF = Trophic magnification factors

[27] BMF = Biomagnification factors

[28] BSAF = Biota-sediment accumulation factor

57. Although dietary exposure is expected to be more relevant for a substance with physiochemical properties as DP, one fish bioaccumulation study using aqueous exposure reported bioconcentration factor (BCF) values exceeding the bioconcentration criteria set by the Stockholm Convention (BCF < 5000 L/kg) (Wang et al., 2020a). In this study, carp were exposed continuously for 32 days to DP (range 0.14 to 0.24 ng/L) through water, followed by 32 days depuration. Dosing was carried out using four packages, each containing 1g commercial DP powder (≥ 99% purity) within filter paper enclosed in a filter screen and placed in a hollow steel ball in the bottom of the aquaria. The authors estimated that a steady state water concentration was reached within 3 days, and the equilibrium would subsequently be maintained. Maximum concentrations in muscle for syn- and anti-isomer were observed at day 32 with the concentrations of 440± 28 ng/g wet weight (ww) and 830 ± 44 ng/g ww, respectively. Equilibrium was reached and the BCF was calculated based on wet weight concentrations in muscle and ratio of uptake and elimination constants. The reported BCF values were 5700 and 9300 L/kg for syn- and anti-DP, respectively and the depuration half-life was 6.3 and 7.2 days for syn- and anti-DP, respectively (Wang et al., 2020a). The information provided by J-Check English version, on a bioaccumulation test conducted in 1974 with carp exposed to water concentrations of DP at 2.7 and 0.27 µg/L for 8 weeks shows a BCF of 87-121 L/kg (J-CHECK, 2020b). The concentrations were significantly in excess of the water solubility of the substance. As a consequence, the recorded values may be an underestimate of the true BCF values. However, as the form of exposure may have been a mix of oral and aqeous, this cannot be confirmed. No information on levels observed in fish was provided.

58. Depuration half-life is an important measure of bioaccumulation. A depuration half-life around 8-10 days is indicative of a lipid-normalised and growth-corrected BCF above 5 000 L/kg according to the analysis in Environment Agency (EA), UK (2012). In a dietary bioaccumulation laboratory test using juvenile rainbow trout, the depuration half-life (whole body minus liver) for DP was reported to be 30-40 days for the anti-isomer and 50-70 days for the syn-isomer, which is highly indicative of a very bioaccumulative substance (Tomy et al., 2008). Neither isomer reached steady state after 49 days of exposure (Tomy et al., 2008). Results from an aquatic food web study from Antarctica (Na et al., 2017) observed, in line with Tomy et al. (2008), higher bioaccumulation of the anti-DP isomer. However, a laboratory study in carp showed tissue-specific variations (Tang et al., 2018). Furthermore, a comparison of modelled studies (Larisch and Goss, 2018) and measured oral uptake in fish (Tomy et al., 2008) showed good agreement, indicating that bioaccumulation of super hydrophobic chemicals like DP via food can be reliably predicted. Uptake of DP is slow but will eventually result in substantial bioconcentration as the substance is not metabolised in fish (Larisch and Goss, 2018). Depuration half-life observed in Wang et al., (2020a) for carp muscle was slightly lower that what was observed for trout whole body minus liver in Tomy et al., (2008) and could be due to different fish species and experimental setups.

59. Bioaccumulation of anti-DP was observed in juvenile marine green macroalgae U. pertusa, following a 21-day exposure to 10-8 mol DP/L (equal to ~6.53 µg/L) and 21-day depuration (Gong et al., 2018). Accumulated DP levels were 127 and 206 ng/g ww on day 7 and 21, respectively, and half-life was 1.458 and 14.531 days for syn- and anti-DP, respectively.

60. In rats exposed to commercial DP 25 by gavage for 90 days at different doses (0,1, 10, and 100 mg/kg/d), DP pre ferentially accumulated in liver rather than muscle. At high doses (10 and 100 mg/kg/d) syn-DP was predominant isomer in tissues. The elimination half-life for syn-DP was about 179 days in liver, 44 days in muscle and 24 days in serum, and for anti-DP, 54 days in muscle and 25 days in serum. Depuration time for anti-DP for the liver was not calculated due to a non-significant increase in liver after depuration (Li et al., 2013a).

61. Several field studies report biomagnification factors (BMF) and trophic magnification factors (TMF) for DP in various food webs. Factors, such as, temperature, time of sampling, reproduction status, migration, age and tissue versus whole body calculations may affect the calculation of TMF (Borgå et al., 2012, Franklin, 2016). DP biomagnifies in various food webs, both from freshwater, marine waters and terrestric food webs, as BMFs (Tomy et al., 2007; Wu et al., 2018; Sun et al., 2015; 2017, Chen et al., 2021) and TMFs (Sun et al., 2015; Kurt-Karakus et al., 2019; Na et al., 2017) are reported to be greater than 1 in several studies, including in one out of two studies from Antarctica (Na et al., 2017; Kim et al., 2021). For prairie animals in the remote Xilingol Prairie in Inner Mongolia in China calculated BMFs for ectotherms and endotherms were in the range 0.146–88.0 and 0.866–17.2, respectively (Chen et al., 2021). Ectotherms were found to selectively enrich syn-DP, and stereoselective enrichment increased moving up the food web. The highest DP BMF was for lizards (88.0), which eat insects (Chen et al., 2021). Sample numbers were low in this study and therefore there is some uncertainty in the derived values. Bioaccumulation and maternal transfer have been observed in amphibians collected from a highly contaminated site in South China (Wu et al., 2018). Amphibians occupy an important trophic position in the food web between aquatic organisms and terrestrial biota. Based on the known predator-prey relationship between frog and insects, BMFs above 1 (1.8 – 2.7) for DP were reported in this study (Wu et al., 2018). In a study of biomagnification of DP in a freshwater reservoir in the vicinity of an electronic recycling facility in South China, the TMFs of the DP isomers were found to be 2-3 times greater than those of PBDE congeners and comparable to or lower than those of the highly recalcitrant PCB congeners in the same food web (Wu et al., 2010). In an aquatic food web study from China, TMFs were reported in the range 1.9 – 3.1. In this study, the biomagnification potential (TMF >1) weas also reported for DPMA[29], anti-Cl11-DP and anti-Cl10-DP (Wang et al., 2015), and this should also be taken into account when evaluating bioaccumulation for DP. For more information on these substances, see section 1.1 Chemical identity. Three terrestrial studies are available showing BMFs above 1 (She et al., 2013, Wu et al., 2018, Yu et al., 2013). Furthermore, in study investigating levels of DP and other flame-retardants in livers of redlisted and endangered birds in Korea, Jin et al. (2016) found a significant positive relationship (r2= 0.22 and p=0.031) between the concentrations of DP and trophic position (δ15N) in three residential and carnivorous predatory species, the Eurasian eagle owls (B. bubo), common kestrels (F. tinnunculus), and collared scops owls (O. lempiji), indicating for biomagnification of DP in these birds.

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[29] Dechlorane monoadduct (DPMA)

(…)

62. The isomer composition of DP in environmental samples can be different from the technical products because of their biota isomer-selective uptake or elimination, bioaccumulation, and stereospecific photodegradation (Wang et al., 2015; and reviewed in Wang et al., 2016). Trophic levels (Peng et al., 2014; Tomy et al., 2007; Wang et al., 2015), exposure concentrations (Li et al., 2013a,b; Mo et al., 2013; Peng et al., 2015), life cyclic stages (Klosterhaus et al., 2012; Sühring et al., 2014), the type of wildlife and tissue (Peng et al., 2014; Zhang et al., 2011; Zheng et al., 2014) and stereoselective excretion (Li et al., 2019) are the main factors for the stereoselective bioaccumulation of DP in organisms .

63. Studies in birds indicate that uptake, distribution and elimination kinetics of DP and its isomers are complex. Chickens bred in the vicinity of an e-waste recycling facility exposed to DP through the environment from sand and food showed preferential accumulation of the anti-DP isomer (Zheng et al., 2014a). Lipid content of the tissue were the main factor in the tissue distribution, although the degree of blood perfusion and the tissue function were also important factors. Furthermore, the study revealed tissue specific accumulation of anti-DP, with higher ƒanti levels in brain, fat and liver (0.65-0.64) compared to (0.54-0.59) for other tissues. The study also indicate that anti-Cl11-DP was absorbed through the diet rather than metabolised from DP in vivo based on the similar ratios for anti-Cl11-DP to anti-DP in soil and chicken (Zheng et al., 2014). This information is supported by the fact that syn-Cl11-DP and anti-Cl11-DP were detected in commercial DP-25, hence, it can be inferred that these chemicals originated from commercial products (Li et al., 2013b).

64. There are some studies on biotransformation of DP (Tomy et al., 2007; 2008; Ren et al., 2009; Sverko et al., 2010). DP has been shown not to metabolise easily in biota (Tomy et al., 2008; Xian et al., 2011) and the results from Tomy et al. suggest that enzyme-induced metabolism of DP in fish might be low, if it does occur. No hydroxylated or sulfonated metabolites of DP was observed in fish liver extracts or in human serum (Tomy et al., 2007; Ren et al., 2009). Degradation products of DP such as decachloropentacyclooctadiene (DP-Cl$_{10}$) or undecachloropentacyclooctadiene (DP-Cl$_{11}$) have been detected in bird eggs (Guerra et al., 2011; Muñoz-Arnanz et al., 2011, 2012; Zheng et al., 2014a), and rat (Li et al., 2013) but some studies suggest they are formed through biotic or abiotic processes prior to uptake or even through impurities in the commercial product (Sverko et al., 2008, 2010; Tomy et al., 2008; Zheng et al., 2010, 2014b; Li et al., 2013). Two additional dechlorination analogues were also detected in both quails and the test substance (Li et al., 2013a,b). In a study where eggs from Japanese quail were injected in the yolk sac with DP, no biotransformation of DP was shown (Briels et al., 2018). This was also observed in chicken eggs at day 18, however, at pipping the mass of syn- and anti-DP in neonate chicks (including the remaining yolks) declined significantly by 5.9% and 15%, respectively, indicating some metabolic activity during the later developmental stage (Li et al, 2019).

65. DP was first detected in archived fish (walleye) from Lake Erie sampled from 1980-2000, which suggested that DP was taken up by the fish (Hoh et al., 2006). Available monitoring studies show that DP is widely dispersed in the environment (reviewed in Canada, 2019; ECHA 2017b). Global evidence reveals that uptake of DP can occur in various biota samples such as aquatic and terrestrial food webs as well as the human body *(reviewed in Wang et al., 2016). Field monitoring data suggest that DP is bioavailable and can exceed levels in biota that are of concern based on critical body burden considerations related to baseline narcosis (ECHA 2017b).*

66. DP was detected in human milk samples collected in two Canadian cities (Siddique et al., 2012), in human serum (Brasseur et al., 2014; Yan et al., 2012: Ren et al., 2009; Chen et al., 2015) cord serum (Ben et al., 2014) and adipose tissue (Pan et al., 2020; Yin et al., 2020) as well as in human hair (Chen et al., 2015). Furthermore, very high DP concentrations in blood and hair from workers of a manufacturing facility have been reported (Zhang et al., 2013).

(…)

67. In summary, a long depuration half-life, which is indicative of a BCF above 5000 L/kg, has been reported for DP. The log K_{ow} for DP is greater than 5. Although aqueous exposure is expected to be of limited importance in terms of bioaccumulation potential of DP a BCF above 5000 L/kg have been reported for DP isomers in a fish study. In addition, BMFs and TMFs $>$ 1 have been reported for several organisms and food webs. Many studies have revealed the presence of DP in wildlife and humans. Field monitoring data suggests that DP is bioavailable and can achieve high body burdens (ECHA, 2017b). These lines of evidence support the conclusion that DP is bioaccumulative. Additionally, DP was recently identified as a very bioaccumulative (vB) substance in the EU (ECHA, 2017a)."

Recent studies have shown that DP can be taken up by plants from soil. For example, Cheng *et al*. (2020) reported that plant uptake accounted for 0.54 - 3.85% of the total dissipation of DP from soil in a soil-rice plant rhizosphere system over 150 days. The DP concentrations in roots were positively correlated with the labile fraction of DP in soil.

Fan et al. (2020) investigated the uptake and translocation of DP into corn and peanut grown on an agricultural field in an electronic waste recycling area. The plants were exposed both through the soil and ambient air. Uptake by the plants was initially by root absorption during the emergence stage but by the late seedling or early reproduction stage absorption by leaves from the air became more important. The DP isomeric composition in peanut plants were enriched with syn-DP relative to that in the rhizosphere soils and air, whereas this was not seen with corn. This suggested a more selective uptake and/or biotransformation in peanut compared with corn. The bioaccumulation factors for root-soil and stem-root were generally <1.

Sun et al. (2019) investigated the uptake of DP in vegetables. The study found that DP was taken up from soil into the roots of the vegetables and that that transport from roots into stem, leaves and fruit was also occurring. Accumulation factors for uptake from soil into roots for tomatoes and cucumber ranged from 0.089 to 0.71, and accumulation factors from resuspended soil particles into stem, leaf and fruit were in the range 0.68 - 0.78, 0.27 - 0.42 and 0.39 - 0.75 respectively. The half-life for dissipation of DP from soil was in the range 70 to 102 days.

Qiu et al. (2019) studied the accumulation of DP in natural mangrove plant species from different mangrove areas, the biota sediment accumulation factors (BSAFs) of syn-DP and anti-DP in mangrove tissues were 1.62 and 0.72, respectively. The average f_{anti} (ratio of [anti-DP]/[DP]) of DP in mangrove sediments, leaves, branches, roots and fruits were 0.47, 0.27, 0.30, 0.37 and 0.46 respectively, suggesting that syn-DP may be preferentially bio-accumulated by mangroves. Similarly Zhang et al. (2019) studied the occurrence of DP in mangrove sediments and organisms and reported that the BSAFs values in mangrove biota species ranged from 0.11–0.30 and the trophic magnification factor (TMF) value for DP was 1.23 indicating their potential of biomagnification in the studied mangrove food web.

Smythe et al. (2020) investigated the distribution and *in ovo* transfer of several flame retardants, including syn- and anti-decholarne plus. The transfer rate of syn- and anti-dechlorane plus from maternal herring gulls to their eggs *in ovo* was 2.2 and 2.6% respectively, indicating that *in ovo* depletion is not a significant depuration pathway for these compounds.

In summary, there is already agreement through the SVHC-evaluation that DP, including its anti- and syn-isomers, is a very bioaccumulative substance (vB). DP is a SVHC substance meeting the REACH Annex XIII critreria for a vB substance.

B.4.4. Environmental monitoring and trends

European monitoring results on DP are presented in Annex B.9.4.2. Environmental .

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 Section B.4.2.1 Adsorption/desorption for details. It is therefore expected to find the substance in sewage sludge rather than in the water phase, either directly from industrial activities or indirectly via wastewater treatment systems, and eventually settle in depositional sediment areas (Canada, 2019).

B.5. Human health hazard assessment

This restriction dossier is based on the established vPvB properties of DP [covering any of its individual anti- and syn-isomers or any combination thereof]. Assessment of human health effects are therefore not relevant.

The Dossier Submitter notes that potential adverse effects/toxicity of DP in humans currently are discussed under the Stockholm Convention. Information on these potential human health effects can be found in the draft POPs risk profile for DP (POPRC, 2021b).

It is also noted that more information on human toxicity is expected to become available in accordance with ECHAs compliance check descision on DP.[30]

This section on human health hazards only includes information on toxicokinetics, since this is relevant for the bioaccumulation assessment of DP (ECHA, 2017d).

B.5.1. Toxicokinetics (absorption, metabolism, distribution and elimination)

The toxicokinetic data included in this section on DP is based on the information published in the MSC support document for det SVHC identification of DP (ECHA, 2017d) as well as additional data that was published after the final literature search as described in the MSC support document.

B.5.1.1. Toxicokinetic assessment in the MSC support document for the SVHC identification of DP

Section 4.2 of the MSC support document for the SVHC identification of DP (ECHA, 2017d) has the following toxicokinetics assessment of DP:

"A toxicokinetic study conforming to OECD TG 417 is not available.

The registration dossier includes two robust study summaries for toxicokinetics assessment:

- *The first unreferenced study, considered reliable with restrictions by the Registrant (due to the small number of animals) was performed in 1983. No guideline was followed and the study was not subject to GLP. 14C-Radiolabelled Dechlorane Plus (31.5 mCi/mmol) was administered in corn oil once by oral gavage at a dose of 1 mg/kg bw (corresponding to 4.8 µCi) or 113 mg/kg bw (corresponding to 3.8 µCi) to SpragueDawley rats (Rattus norvegicus). The composition of the substance was stated to be the same as the commercial substance (the ratio of isomers was 5.4:1). The low dose group consisted of three females and two males, and the high dose group consisted of two females. Another group of two females was fed non-labelled*

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[30] https://echa.europa.eu/documents/10162/c13636b7-c6ee-569a-dd8d-75d299e0d8a8.

Dechlorane Plus at 1 % in the diet for 14 days before gavage administration. No control animals were used. Excretion via urine, faeces, and expired air and residual concentrations in organs and carcass were determined.

One rat was used for monitoring radioactivity in expired air and one rat was used for monitoring the time course of blood levels for 48 hours after administration of 1 mg/kg bw. Urine and faeces were collected from all remaining rats for 4 days, then the animals were killed and radioactivity in 17 different organs/tissues and carcass were determined.

At four days after a single oral administration of 1 mg/kg bw, the percentage of the dose excreted in faeces was 83.5 % for females and 92.7 % for males (0.07 % and 0.01 % in urine, respectively). This indicates a maximum absorption of 16.5 % in females and 7.3 % in males.

The percentage of the dose excreted in faeces in the higher dose (113 mg/kg bw) group was 96.5 % for females (0.009 % in urine). This indicates a maximum absorption of 3.5 % in females.

Four days after single oral administration of 1 mg/kg bw to rats pre-treated with the nonlabelled substance at 1 % in diet for 14 days, 102 % of the dose was excreted in faeces (0.03 % in urine) indicating almost no absorption.

Excretion in expired air amounted to 0.004 % of the administered dose within 4 days.

The concentrations in all organs and tissues investigated, besides liver and residual carcass, were below 1 ppm. At the high dose, the liver of females contained 1.66 ppm and the residual carcass contained 1.25 ppm. All organs and tissues besides liver and residual carcass contained well below 1 % of the dose. The livers of males and females at the low dose contained 1.60 and 2.29 % of the dose, respectively. The residual carcass of males and females at the low dose contained 5.09 and 5.05 % of the dose, respectively. The residual carcass of females at the high dose contained 0.90 % of the dose. The carcass of pre-treated females contained 4.44 % of the dose.

Metabolites were not investigated.

The Registrant concludes that "almost no" absorption occurs after oral administration to a single dose.

- *The second unreferenced study, considered reliable with restrictions by the Registrant (due to the small number of animals and detection of more than 100 % of the administered dose in the faeces) was performed in 1979. No guideline was followed and the study was not subject to GLP. Two groups of three Sprague-Dawley rats (R. norvegicus) each were given a single oral dose of 0.57 mg of 14C-radiolabeled Dechlorane Plus (27.6 µCi in 0.5 mL) (purity stated to be the same as the commercial substance) suspended in water with 5 % Tween 80 and 5 % gum arabic. Three rats were killed 4 hours after administration and the remainder after 24 hours, and Dechlorane Plus was determined by liquid scintillation in blood, kidneys, liver, urine, and faeces.*

Within 4 hours after oral administration, less than 0.1 % was excreted in urine. At 24 hours, less than 1 % had been excreted in urine, and a mean of 94.6 % (range: 76.1 – 104.8 %) of the administered dose was excreted in faeces, indicating a maximum absorption of around 5.4 %. The sum of total radioactivity detected in blood, kidneys, liver, and urine was at or below 6 % of the total dose.

Blood (total blood volume) contained less than 2 %, kidneys contained less than 1 %, and liver contained less than 5 % of the administered dose.

One metabolite was found in the liver but its identity and concentration was not reported.

The Registrant concludes that Dechlorane Plus is poorly absorbed after oral administration, at a maximum of 6 % of the administered dose. Highest concentrations are found in the liver.

- *A third study missing from the registration dossier is (Li et al., 2013a)), who exposed male Sprague–Dawley rats (R. norvegicus) (35 days' old with an average weight of 110 g) to commercial Dechlorane Plus mixed in corn oil by oral gavage for 90 days at different doses (0, 1, 10, and 100 mg/kg/d). Another group was exposed to 100 mg/kg/d of the substance for 45 days followed by 45 days' depuration, together with a control group that was fed uncontaminated food. Forty-two animals were used in all. Liver, muscle and serum samples were analysed using GC-MS. The LoDs for the antiand syn- isomers were 70.44 and 108.31 µg/kg lw in muscle/liver, and 0.054 and 0.20 ng/mL in serum, respectively.*

Both isomers were detected in all of the tissues measured in the control group at the end of the 90-day exposure period (average concentrations in liver were 2.8 ± 1.2 and 0.9 ± 0.4 mg/kg lw for the anti- and syn- isomer, respectively according to the paper, but the supplementary data give slightly different values), indicating a background level of exposure (e.g. from feed or air-borne dust). DP-1Cl and DP-2Cl were not detected in the control group (LoDs for anti-DP-1Cl were 0.98 µg/kg lw in muscle and liver, and 0.042 ng/mL in serum, respectively).

In the exposure groups, the highest concentrations of both isomers were detected in liver from the 100 mg/kg/d dose group, at 320 ± 49 mg/kg lw for the anti- isomer and 750 ± 120 mg/kg lw for the syn- isomer (i.e. total concentration ~1 000 mg/kg lw). These levels were 12–15 times higher than in muscle and around 5 times higher than in serum from the same group. In liver, the concentration of both isomers increased with the dose. However, in muscle, the highest concentration of the syn- isomer occurred in the 10 mg/kg/d group (~85 mg/kg lw). Some of the statements in the paper about highest concentrations of the anti- isomer and in other tissues do not seem to match the information provided in the supplementary data.

The concentration ratio of the anti- isomer to total isomers was similar to the commercial substance in the 1 mg/kg/d group, but significantly decreased in the two higher dose groups, suggesting enrichment of the syn- isomer with increasing dose. The highest average concentration of syn-DP-1Cl and anti-DP-1Cl occurred in liver in the 100 mg/kg/d group, reaching 140 ± 51 and 480 ± 170 µg/kg lw, respectively. Average concentrations *were 5-8 times lower in muscle in the same group, but whereas levels in liver increased with dose, levels in muscle remained fairly constant. Two additional unidentified substances were detected in liver as well as in the commercial substance.*

The treatment group that was exposed to 100 mg/kg/d for 45 days accumulated a lower amount of total isomers in the liver compared to the animals exposed for 90 days (achieving an average total liver concentration of ~310 mg/kg lw). This suggests that residues increase with longer exposure times. The amounts of both isomers in muscle and liver showed no statistically significant change during depuration, although levels in serum decreased significantly. The content ratio of syn- and anti- isomers in liver to those in liver plus muscle significantly increased after depuration compared with the end of the uptake phase. These data suggest that Dechlorane Plus is more prone to accumulate in liver or that the elimination rate in liver is lower than that in muscle. The content of both syn- and anti-DP-1Cl in the liver decreased significantly after depuration and neither was detected in serum after depuration. The elimination half-life of the syn- isomer was about 179 days in liver, 44 days in muscle and 24 days in serum. The elimination half-life of the anti-isomer was 54 days in muscle and 25 days in serum (the figure for liver is not provided as the concentration increased during the depuration phase, although not significantly).

In conclusion, both isomers preferentially accumulate in liver rather than muscle or blood, and have a long elimination half-life in rats. Residues appear to increase with longer exposure times – it is not known how long it would take to achieve a steady state.

Discussion

Based on the two studies summarised in the registration dossier, a single oral dose of 1 mg/kg bw in rats may lead to a maximum absorption of between 5 and 20 %. Higher doses, or dosing following 14 days' prior exposure suggest a lower level of absorption, although if the substance was present as microcrystals in the vehicle, the nominal concentrations might not reflect actual exposure to dissolved substance. About 90 % of the substance is excreted unchanged in faeces (excretion in urine and expired air is below 0.1 %). The absorbed substance is widely distributed in the body, with the highest concentration in liver. Four days after administration, between 1 % and 10 % of the administered dose was found in the carcass. Levels of around 1 – 2 ppm [mg/kg] may be reached in both liver and the residual carcass.

The main conclusion that can be drawn from the (Li et al., 2013a) study is that uptake, distribution and elimination kinetics are complex, with preferential accumulation in liver rather than muscle or blood. Dechlorane Plus achieved levels of ~1 000 mg/kg lw in rat liver when dosed at 100 mg/kg/d via oral gavage for 90 days (the paper does not provide the lipid content so a wet weight concentration cannot be estimated). Like fish, residues increased with longer exposure times and a steady state was not achieved. Also like fish, Dechlorane Plus has a long elimination half-life from rat liver, in the region of 180 days or more.

None of the studies permit firm conclusions to be drawn about the level of accumulation or tissue distribution following exposure to low concentrations over long time periods."

B.5.1.2. Other relevant toxicokinetic studies

In this section, other relevant toxicokinetic studies on DP published after the final literature search as described in the MSC support document (ECHA, 2017d) are included:

A study by Zhang et al., 2020 aimed to investigate the DP transfer in Sprague-Dawley rats during pregnancy and the effects of DP exposure on gut microbiota. In the control group - group A (n=6) the pregnant rats received corn oil (vehicle) orally through the pregnancy and until lactation day (LD) 21. In group B - the pregnancy DP exposure group (n=6) pregnant rats received 5 mg/kg bw/d DP orally in corn oil (DP purity > 98%) until embryonic day (ED) 2. In group C - pregnancy and lactation DP exposure group - (n=6) the pregnant rats received 5 mg DP/kg bw/d during the pregnancy until LD 21. The offspring was kept for 8 weeks until maturity and feces, liver and serum were collected. The females (mothers) were euthanized on lactation day 21. The genomic DNA of fecal samples was extracted. High levels of DP were found in the feces from offspring. The liver/spleen ratio indicated liver-specific accumulation of DP. The results demonstrated that the excretion by feces was a very important pathway for DP exposure. Transfer to offspring probably mainly took place via lactation in this study based on the higher concentrations in liver and serum of offspring in group C. Milk samples was not collected. Transfer of DP from mother to the foetus through the placenta seemed limited. Based on gut microbiota analysis it was proposed that DP exposure may alter the structure and function of the gut microbiota in the offspring and influenced the short-chain fatty acids metabolites (SCFAs, a kind of metabolite of gut microbiota produced in the colon primarily absorbed into the intestinal mucosa (90% - 95%) (the rest are excreted in the feces).

Fredriksen et al., 2016, investigated dermal uptake and percutaneous penetration of ten flame retardants, including the syn- and anti-DP, in an ex vivo human skin model. The dermal uptake was studied using Franz diffusion cells as described in OECD TG 428 (Skin Absorption: *in vitro* Method). Concentrations varied between the different flame retardants, for DP the concentration used was 50 ng per cell in a duration of 72 h. Two different types of receptor fluids were used, either physiological relevant fluid (n=3) or worst-case fluid (n=7), the worst-case fluid contained 50% ethanol to increase skin permeability. The amount of the given flame retardant was analysed in epidermis, dermis and in the receptor fluid. The amount of syn- and anti- DP in the different compartments were in the same range as the other flame retardants. When using the physiological receptor fluid, 8.4 and 7.9% of total syn- and anti-DP was detected in epidermis. A lower level was detected in the dermis, 0.5 and 0.8% of the total syn- and anti-DP, respectively. When using worst-case receptor fluid the amount detected was higher, 13 and 12% of total syn- and anti-DP was detected in epidermis and 2.2 and 2.7% of the total syn- and anti-DP were detected in the dermis. A permeability coefficient was calculated as the flux over the entire experimental period, this was calculated for the lower bound (absorbed levels of substance in the dermis and in the receptor fluid) or upper bound (also includes the levels of the substance in epidermis). The results showed that the upper bound permeability coefficient was higher than the lower bound permeability coefficient and that the worst-case receptor fluid resulted in a higher permeability coefficient compared to the physiological receptor fluid.

The study shows that there is dermal uptake of the syn- and anti-DP, but there is little or no percutaneous penetration and the dermis may povide a significant barrier for DP penetration. The study investigated dermal uptake and percutanous penetration only at a single timepoint and did not study the effects of long exposure period. However, the authors suggest that when considering the continuous exposure of flame retardants to the skin surface, this may lead to dermal uptake and possibly eventually percutaneous penetration over time.

B.5.2. Acute toxicity

Not relevant for this dossier.

B.5.3. Irritation

Not relevant for this dossier.

B.5.4. Corrosivity

Not relevant for this dossier.

B.5.5. Sensitisation

Not relevant for this dossier.

B.5.6. Repeated dosed toxicity

Not relevant for this dossier.

B.5.7. Mutagenicity

Not relevant for this dossier.

B.5.8. Carcinogenicity

Not relevant for this dossier.

B.5.9. Toxicity for reproduction

Not relevant for this dossier.

B.5.10. Other effects

Not relevant for this dossier.

B.5.11. Derivation of DNEL(s)/DMEL(s)

No DNEL/DMEL values are derived in this dossier as the proposed restriction of DP (covering any of its individual anti- and syn-isomers or any combination thereof) is based on the substance's vPvB-properties. Due to the uncertainties regarding long-term exposure and effects, the risks of vPvB substances, such as DP, to the environment or to humans cannot be adequately addressed in a quantitative way. Therefore, no health hazard assessment and no DNELs has been established.

B.6. Human health hazard assessment of physicochemical properties

Not relevant for this dossier.

B.7. Environmental hazard assessment

This topic has not been assessed as DP [covering any of its individual anti- and syn-isomers or any combination thereof] is a vPvB substance.

The Dossier Submitter notes that the potential adverse effects/toxicity of DP in the environment currently are discussed under the Stockholm Convention. Information on the environmental hazardous properties can be found in the draft POPs risk profile for DP (POPRC, 2021b).

B.8. PBT and vPvB assessment

B.8.1. Assessment of PBT/vPvB Properties – Comparison with the Criteria of Annex XIII

DP is a very persistent and very bioaccumulative (vPvB) substance according to article 57 (e) of Regulation (EC) No 1907/2006 (REACH). The ECHA Member States Committee included DP on the list of substances of very high concern in 2017 (ECHA, 2017a). See Annex B.4.1. Degradation and B.4.3 Bioaccumulation, bioavailability and transformation in biota for more details.

B.9. Exposure assessment

The exposure assessment of DP comprises both estimated and monitoring data from humans and the environment. 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). Indirect exposure for humans via the environment and environmental exposure (PECs) for different environmental compartments have been estimated using EUSES (Section B.9.3. Estimated releases and exposure from the use of Dechlorane Plus). Human biomonitoring and environmental monitoring data are described in a separate section (B.9.4. Biomonitoring and environmental monitoring data).

According to the registration information, DP is used at industrial sites as a flame retardant in adhesives/sealants and polymers (ECHA, 2018b; 2020b). Furthermore, the substance is used in articles in volumes >10 t/y, e.g. computers, electronic and optical products, vehicle textiles (ECHA, 2017b), automobiles, aerospace and defence engines (ComRef, 2019).

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 or volatisation to air during wastewater treatment plants, and atmospheric deposition of the airborne dust to soil from dismantling, result in exposure of air, water, sediment, soil and organisms. Currently, there is one active registration in the EU (see Annex A: Manufacture and uses). Monitoring information shows that DP is found in remote areas (e.g. Arctic). It is also found in high concentrations in house dust, WWTP effluent and other (ECHA, 2017c, ComRef, 2019), indicating the use of substance in articles with potential for releases.

Acknowledging the very persistent and bioaccumulating nature of DP (see Annex B.4.1. Degradation), emissions will lead to increasing exposure of DP to humans and the environment over time. Measures to reduce the ongoing emissions of DP are therefore necessary.

The stakeholder consultation and publicly available literature (see Annex A: Manufacture and uses) indicated that there is one current manufacturer of DP globally, located in China, and that DP is currently used in the following applications, both in the EU and globally:

- Use in sealants and adhesives.
- Use in polymers.
- Use in greases.

The exposure assessment considers these three main areas of use generically, giving worst case release estimates from all relevant lifecycle stages including (where relevant):

- Manufacture.
- Formulation.
- Industrial use.
- Releases over the service life of articles containing DP.

- Releases from waste.

It is important to note that there may be different uses of DP within some of these main areas of use, for example polymers could cover uses such as use in plastic articles, electronic components and polymeric coatings used for cables and textiles. The available information on use (see Section A.2. Uses) 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.

DP has been registered in the EU under the REACH Regulation. Only limited information on releases to the environment is available from the publicly available dissemination dossier available on the ECHA website (ECHA, 2020b). The ECHA Substance Infocard (accessed in March 2021) summarises potential sources of emissions.

- Manufacture. No public information is available on the routes of release to the environment.
- Formulation or re-packing. Releases to the environment can occur from formulation in materials and formulation of mixtures.
- Uses at industrial sites. Releases to the environment can occur from the production/formulation of adhesives and sealants, polymers and semiconductors and in the production of articles from these products.
- Widespread uses by professional workers. No public information is available on the products in which the substances might be used or on the routes of release of the substance to the environment.
- Consumer uses. No public information is available on the products in which the substances might be used or on the routes of release of the substance to the environment.
- Article service life. Releases to the environment are likely to occur from long-life materials with low release rate such as metal, wooden, and plastic construction and building materials, flooring, furniture, toys, curtains, footwear, leather products, paper and cardboard products and electronics. Releases could occur during both indoor and outdoor use of such articles.

The REACH registered substance factsheet contains the following descriptors for the lifecycle of DP relevant for releases to the environment. The Environmental Release Categories (ERCs) describe the processes from which releases to the environment could occur and the Process Categories (PROCs) describe the processes from which occupational exposure could occur.

Formulation of DP in adhesives:

- ERC 2: Formulation into mixture.
- ERC 3: Formulation into solid matrix.
- PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions.

- PROC 2: Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions.
- PROC 3: Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment conditions.
- PROC 8b: Transfer of substance or mixture (charging and discharging) at dedicated facilities.
- PROC 9: Transfer of substance or mixture into small containers (dedicated filling line, including weighing).
- PROC 15: Use as laboratory reagent.

Formulation of polymer preparations and compounds:

- ERC 2: Formulation into mixture.
- ERC 3: Formulation into solid matrix.
- PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions.
- PROC 2: Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions.
- PROC 3: Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment conditions.
- PROC 4: Chemical production where opportunity for exposure arises.
- PROC 5: Mixing or blending in batch processes.
- PROC 6: Calendering operations.
- PROC 8a: Transfer of substance or mixture (charging and discharging) at non-dedicated facilities.
- PROC 8b: Transfer of substance or mixture (charging and discharging) at dedicated facilities.
- PROC 9: Transfer of substance or mixture into small containers (dedicated filling line, including weighing).
- PROC 14: Tabletting, compression, extrusion, pelletisation, granulation.
- PROC 15: Use as laboratory reagent.
- PROC 21: Low energy manipulation of substances bound in materials and/or articles.
- PROC 28: Manual maintenance (cleaning and repair) of machinery.

Using DP at Industrial Sites to Manufacture Polymer Products and Articles

- ERC 5: Use at industrial site leading to inclusion into/onto article.
- PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions.
- PROC 2: Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions.
- PROC 3: Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment

conditions.
- PROC 4: Chemical production where opportunity for exposure arises.
- PROC 5: Mixing or blending in batch processes.
- PROC 6: Calendering operations.
- PROC 8a: Transfer of substance or mixture (charging and discharging) at non-dedicated facilities.
- PROC 8b: Transfer of substance or mixture (charging and discharging) at dedicated facilities.
- PROC 9: Transfer of substance or mixture into small containers (dedicated filling line, including weighing).
- PROC 14: Tabletting, compression, extrusion, pelletisation, granulation.
- PROC 15: Use as laboratory reagent.
- PROC 21: Low energy manipulation of substances bound in materials and/or articles.
- PROC 28: Manual maintenance (cleaning and repair) of machinery.

Industrial use of DP in adhesives

- ERC 5: Use at industrial site leading to inclusion into/onto article.
- PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions.
- PROC 2: Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions.
- PROC 3: Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition.
- PROC 7: Industrial spraying.
- PROC 8b: Transfer of substance or mixture (charging and discharging) at dedicated facilities.
- PROC 9: Transfer of substance or mixture into small containers (dedicated filling line, including weighing).
- PROC 10: Roller application or brushing.
- PROC 13: Treatment of articles by dipping and pouring.
- PROC 15: Use as laboratory reagent.
- PROC 21: Low energy manipulation of substances bound in materials and/or articles.
- PROC 28: Manual maintenance (cleaning and repair) of machinery.

Article service life

- Service life of glued articles (aircraft parts) in industrial settings.
    - ERC 12c: Use of articles at industrial sites with low release.
    - PROC 21: Low energy manipulation of substances bound in materials and/or articles.

- Service life of glued articles (aircraft parts) in professional settings.
    - ERC 10a: Widespread use of articles with low release (outdoor).

  - ERC 11a: Widespread use of articles with low release (indoor).
  - PROC 21: Low energy manipulation of substances bound in materials and/or articles.

- Service life of electric cables in industrial settings.
  - ERC 12c: Use of articles at industrial sites with low release.
  - PROC 21: Low energy manipulation of substances bound in materials and/or articles.

- Service life of electric cables in professional settings.
  - ERC 10a: Widespread use of articles with low release (outdoor).
  - ERC 11a: Widespread use of articles with low release (indoor).
  - PROC 21: Low energy manipulation of substances bound in materials and/or articles.

- Service life of electric cables by consumers.
  - ERC 10a: Widespread use of articles with low release (outdoor).
  - ERC 11a: Widespread use of articles with low release (indoor).

- Service life of electronic articles and components thereof.
  - ERC 10a: Widespread use of articles with low release (outdoor).
  - ERC 11a: Widespread use of articles with low release (indoor).

This exposure assessment is based on the default approaches according to REACH (Guidance R. 16). Other sources of generic exposure information are also available, including OECD Emission Scenario Documents and Specific Environmental Release Categories (SPERCs). Where these 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.

In terms of release to the environment, the default release factors for the 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 13 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 18: 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%
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 estimates are based on information found in publicly available sources and information provided during the stakeholder consultation – Section A.2.4 Summary and conclusions and Annex H for more details. It is important to note that the information on the amounts of articles containing DP both imported into the EU and exported from the EU is not known with any certainty and therefore the EU release estimates are based on the estimated amounts of DP itself supplied into the EU market.

The generic approach taken uses a likely range of the tonnages for each lifecycle stage in order to reflect the uncertainty in these data. For certain scenarios, a range of emission factors or other assumptions are also given that are considered to be applicable to DP. These are detailed in each exposure scenario. In this way a range (lower and upper) of estimates for the emissions are reported. This is similar to the approach used in the Annex XV report for decaBDE (ECHA, 2015b) except that for decaBDE emission factors based on measured data were available for some scenarios whereas actual emission information for DP is generally lacking and so use is made of more generic approaches.

An exposure assessment has been carried out in the EU registrant’s CSR. This exposure assessment is confidential and has not been directly taken into account here. The use tonnages and release estimates obtained in the registrant’s CSR may differ from those presented here. Any such differences have not been investigated in detail but may result from, for example, differences in the current usage data obtained in the stakeholder consultation carried out for this Annex XV report and the registered tonnage data, release factors and use pattern, assumed in the registrant’s CSR (see Confidential Annex H.2. Exposure assessment for more information).

The properties of DP that have been assumed in the exposure assessment in the present Annex XV report were taken from ECHA (2017c) and are summarised in Table 19.

Table 19: Properties of Dechlorane Plus assumed in the exposure assessment (taken from ECHA, 2017c)

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	$\leq 1.67 \times 10^{-3}$ µg l^{-1}at 20°C
Henry's law constant	$\geq 1.39 \times 10^{5}$ Pa m^{3} mol^{-1}at 25°C
Log Kow	9
Log Koc	8
Biodegradation	Not biodegradable
Half-life in air	17 hours
Bioaccumulation parameters	ECHA (2017a) concludes that the substance is very bioaccumulative but the actual bioaccumulation parameters are uncertain. For the exposure assessment the relevant bioaccumulation parameters have been estimated from the log Kow using the default methods in the EUSES 2.2.0 programme (ECHA, 2019d).

The exposure assessment is given in two parts for each relevant lifecycle stage. Firstly, the initial releases to air, wastewater and industrial soil[31] are estimated using generic exposure methods. This is carried out at the local (site), regional (highly industrialised area) and continental (approximates to the whole EU) scale.

The second part of the exposure assessment considers the distribution of the initial releases to wastewater in sewage treatment plants, direct releases to air and the resulting predicted environmental concentrations (PECs). 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. The predicted distribution of DP in a sewage treatment plant has been estimated using the EUSES 2.2.0 and is summarised in Table 20.

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[31] 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.

Table 20: Estimated distribution in a sewage treatment plant (STP) for Dechlorane Plus

Distribution	**%**
Percentage to air	0.092
Percentage to water	7.272
Percentage to sludge	92.63
Percentage degraded	0
Total	**100**

Uncertainties associated with the approach and assumptions are further discussed in Appendix F.

B.9.1. General discussion on releases and exposure

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 from Europe and other parts of the world 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. See Annex B.4.4. Environmental monitoring and trends.

The draft POPs risk profile for DP describes the following releases to the environment (POPRC, 2021b):

"5. DP is released to the environment during production, processing and use, as well as from waste disposal and recycling activities. Releases from use include industrial and professional uses as well as releases from consumer products. DP entering the enviroment is expected to predominantly reside in soil and/or sediment, depending on the compartment of release, but DP remaining in air and in water has the potential for dispersion and may undergo environmental transport by particle binding. DP has been detected globally in many locations, ranging from production and recycling sites to urban, rural and remote areas. It has been detected in air, water, sediment, ice, soil, wastewater, sludge, biosolids, landfill leachate, indoor and outdoor dust, wildlife and humans.

6. On a global scale, the high DP concentrations were detected close to known production sites or electronic waste (e-waste) treatment facilities. Monitoring studies document the long-range transport of DP to remote regions via the atmosphere, ocean currents and possibly also via migratory birds. Modelling studies suggests DP has transport and persistence properties similar to listed POPs. DP has been detected in different environmental matrices and biota in the Arctic, Antarctic, the Tibetan Plateau, a mountain region in Asia and in the remote Xilingol Prairie in Inner Mongolia, China. The atmospheric half-life of DP is in one study calculated to ~14 hours, i.e. below the criterion of two days set in Annex D (d) (iii) of the Convention. Another study report estimated half-lives in air of 0.468 and 160.12 days for atmospheric oxidation and ozone reaction, respectively, using the AOPWIN 2010 model (12-hr day). However, modelled half-lives in air are largely based on gas phase reactions and do not consider possibly longer half-lives following sorption to particles, which is presumed to be the primary mode of transport for DP due to its low vapour pressure and a high log octanol-air partitioning coefficient. Available monitoring *data confirms this assumption and shows that DP is found predominantly in the particulate phase both in air and water. Long-range transport of DP is thus likely mediated by particle binding. Sorption to particles may slow down reaction rates, increase the actual half-lives in air and facilitate the long-range transport of DP.*

(…)

10. Exposure of the general population to DP takes place by consumption of food and drinking water, inhalation of indoor and ambient air, as well as respiratory and oral uptake of dust containing DP. DP has been detected in human blood and breast milk in many regions of the word. Moreover, the human foetus may be exposed to DP via the umbilical cord blood, and breast milk may be an important source of exposure for infants. The highest DP levels have been observed in occupationally exposed workers and residents living near production facilities and e-waste recycling sites in China.

(…)

12. DP is widely detected in the global environment, including in remote regions. It is transported to locations far from production sites and places of use. Available scientific data show that DP is persistent and bioaccumulative. Although data are limited and chronic toxicity studies are lacking, there are studies showing that DP may have adverse effects on the environment and that it can be potentially toxic to mammals and humans. Based on evidence for persistence, bioaccumulation and adverse effects of DP observed in some organisms and its widespread occurrence in the global environment including at remote regions, [it is concluded that DP is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted]."

B.9.1.1. Summary of the existing legal requirements

REACH

DP was identified as a Substance of Very High Concern (SVHC) according to Article 57(e) as it meets the criteria of a vPvB substance and was therefore included in the Candidate List for authorisation on 15 January 2018, following ECHA's decision ED/01/2018.

Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants was adopted on 22nd May 2001 and entered into force on 17th May 2004. The main objective of the Convention is to protect human health and the environment from the threats presented by persistent organic pollutants (POPs). Regulation (EU) 2019/1021 (the POPs regulation) implements the Stockholm Convention on POPs in the EU. In May 2019, Norway submitted a proposal to list DP as a POP under the Stockholm Convention (UNEP, 2019). The risk profile (Annex E criteria under the Stockholm Convention) is still under scrutiny with further discussions on the adverse effects of DP tentatively scheduled for the 17th meeting of POPRC in September 2021 (UNEP/POPS/POPRC.16/9, Annex I, Decision POPRC-16/1) (POPRC, 2021a). If there are no delays in the further regulatory process under the Stockholm Convention, the Conference of the Parties (COP) could decide on the listing of DP in 2023. If a substance is listed in the Stockholm Convention on POPs the practice is to implement this in EU law by amending the POPs regulation and by removing the corresponding restriction from Annex XVII of REACH.

Ecodesign Directive

From 1 March 2021, the use of halogenated flame retardants is not allowed in the enclosure and stand of electronic displays (halogenated flame retardant means a flame retardant that contains any halogen). The legal basis for the ban is to be found in the Commission regulation (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to the Ecodesign Directive (2009/125/EC of the European Parliament and of the Council). The ban is questioned by The International Bromine Council (BSEF) which has filed a legal challenge against the European Commission. It is not known to the Dossier Submitter when and if this will evolve into a court case. At the same time, under the Sustainable Products Initiative, the Commission has proposed to widen the scope of the Ecodesign directive beyond energy related products and make it applicable to the broadest possible range of products.

Waste legislation

Companies supplying articles containing DP in a concentration above 0.1% weight by weight (w/w) on the EU market must submit information on these articles to the ECHA SCIP database, as from 5 January 2021 [Waste Framework Directive (WFD), 2008/98/EC]. The information in the SCIP database may help waste operators in sorting and recycling articles that contain DP and inform consumers on the presence of DP in an article.

Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste from electrical and electronic equipment. The Directive aims to ensure separate collection of WEEE and promotes that all separately collected WEEE shall undergo proper treatment. Furthermore, collection and recovery targets for WEEE are set (see A.2.5. Recycling). The WEEE Directive prescribes selective treatment for certain materials and components, as a minimum it requires separate removal of certain articles and substances, this applies to e.g. plastics containing brominated flame retardants and PCB containing capacitors.

Directive 2000/53/EC on end-of life vehicles (ELV) lays down measures which aim at the prevention of waste from vehicles and sets targets for their reuse, recycling and recovery (see also A.2.5.1. End-of-Life Vehicles (ELVs)). Furthermore, the objective is to limit the use of hazardous substances when manufacturing new vehicles. The use of lead, mercury, cadmium and hexavalent chromium is prohibited in materials and components in new vehicles put on the market after 1 July 2003, except in defined exemptions. A Commission's proposal for the Review of the ELV Directive is expected in the second quarter of 2022 (EC, 2020b).[32]

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[32] https://ec.europa.eu/environment/topics/waste-and-recycling/end-life-vehicles_en

A restriction on the manufacture and placing on the market of DP would contribute to the fulfilment of the aims of the WFD, WEEE and ELV directives.

B.9.1.2. Summary of the effectiveness of the implemented operational conditions and risk management measures

In terms of articles, and the release to the environment over their service lifetimes and the waste stage, there are no currently implemented risk management measures for DP that are effective in reducing the potential for release to the environment.

B.9.2. Manufacture of Dechlorane Plus

B.9.2.1. General information

DP is not currently manufactured in the EU. The sole REACH registrant, ADAMA, who recently acquired the Chinese company Jiangsu Anpon Electrochemical Company Ltd (ADAMA, 2019), has an active registration of DP. There is also one inactive registration by Occidental Chemical Belgium BVBA, which is an 'only representative' for the US-based company OxyChem. OxyChem registered DP in 2013 but ceased their supply to the EU market in 2017. The current volumes of DP used in the EU are estimated to be between 90 t/y (low volume scenario) and 230 t/year (high volume scenario). See Annex A for further details.

Several downstream users confirmed in the stakeholder consultation that ADAMA is currently the only manufacturer of DP globally with a plant in China. No information is available on the releases to the environment from this plant. The best estimates for the current volume of DP manufactured globally (300 tonnes/year – 1 000 tonnes/year) and the estimated EU supply (90 tonnes/year – 230 tonnes/year) shown in Table 11, along with the estimated use pattern for DP presented in Table 12, have been used as the starting point of the environmental release estimation.

B.9.2.2. Environmental releases

DP itself is not manufactured in the EU and all of the DP used is imported. The only current manufacturing site for DP is located in China, therefore there are no releases to the environment in the EU from manufacture of DP as a substance.

DP has been detected in the environment (sediment and soil) in the vicinity of manufacturing plants outside of the EU. The available data are summarised in the in draft POPs risk profile (POPRC, 2021b) and include studies by Wang et al. (2010a) and Sverko et al. (2008) amongst others.

B.9.3. Estimated releases and exposure from the use of Dechlorane Plus

B.9.3.1. Use 1: Formulation of sealants and adhesives

B.9.3.1.1. General information

According to the registration information, detailed in A.2.1. REACH Registration data, DP is used at industrial sites as a flame retardant in adhesives/sealants (ECHA, 2020b), which was also confirmed in the stakeholder consultation. This section considers the release of DP from formulation of sealants containing DP.

B.9.3.1.2. Release and exposure estimation

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, 2017d, FEICA, 2017c). The details of the approach and assumptions made are documented in Table 21.

Table 21: Estimated EU release to the environment for Dechlorane Plus from formulation of sealants and adhesives

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12
Share of total volume - sealants and adhesives	5%		See Table 12
Total tonnage in sealants and adhesives	5 - 12	tonnes/year	
Number of days of formulation	225	days/year	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Daily amount of DP formulated at a site (local scenario)	0.022 - 0.053	tonnes/day	Estimate – assumes all of the tonnage is formulated at one site as a worst case
Fraction released to air	0.0008 – solvent-borne 0.000097 – water-borne		Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to wastewater	0.0002 – solvent-borne 0.00505 – water-borne		Default from FEICA SPERC 2.1a.v3 and 2.2b.v3

Input factor / Assumption	**Value**	**Unit**	**Comment**
Fraction release 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)
Estimated release to air	0.49 - 9.6	kg/year	
Estimate release to wastewater	1 - 60.6	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal	125 - 300	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 22. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 22: Estimated EU release to the environment for Dechlorane Plus from formulation of sealants and adhesives following redistribution in a STP

Total EU releases following redistribution in STP	**Lower estimate (kg/year)**	**Upper estimate (kg/year)**
Air	0.5	9.6
Water	0.3	15.6
Agricultural soil	0.7	44.9
Industrial soil	0	0
Total	**1.5**	**70.2**

B.9.3.1.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 23.

Table 23: Estimated indirect local exposure of human via the environment for Dechlorane Plus from formulation of sealants and adhesives in the EU

Route of exposure of humans via the environment	Lower estimate	Upper estimate	Unit
Daily dose through intake of drinking water	1.19E-09	7.18E-08	mg/kg/d
Fraction of total dose through intake of drinking water	1.02E-06	1.02E-06	
Daily dose through intake of fish	6.16E-07	3.61E-05	mg/kg/d
Fraction of total dose through intake of fish	5.29E-04	5.13E-04	
Daily dose through intake of leaf crops	1.17E-06	2.23E-05	mg/kg/d
Fraction of total dose through intake of leaf crops	0.00101	3.17E-04	
Daily dose through intake of root crops	0.00115	0.0699	mg/kg/d
Fraction of total dose through intake of root crops	0.990	0.992	
Daily dose through intake of meat	6.19E-06	3.08E-04	mg/kg/d
Fraction of total dose through intake of meat	0.00531	0.00438	
Daily dose through intake of milk	3.65E-06	1.82E-04	mg/kg/d
Fraction of total dose through intake of milk	0.00313	0.00258	
Daily dose through intake of air	1.11E-07	2.10E-06	mg/kg/d
Fraction of total dose through intake of air	9.49E-05	2.99E-05	
Local total daily intake for humans	0.00117	0.0704	mg/kg/d

B.9.3.1.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 24.

Table 24: Estimated environmental local exposure for Dechlorane Plus from formulation of sealants and adhesives in the EU

Compartment	Lower estimate	Upper estimate	Unit
Annual average local PEC in air (total)	3.91E-07	7.39E-06	mg/m^3
Local PEC in surface water during emission episode (dissolved)	1.09E-07	6.48E-06	mg/l
Annual average local PEC in surface water (dissolved)	6.82E-08	4.00E-06	mg/l

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Local PEC in freshwater sediment during emission episode	0.237	14.1	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	1.13E-08	6.49E-07	mg/l
Annual average local PEC in seawater (dissolved)	7.16E-09	4.01E-07	mg/l
Local PEC in marine sediment during emission episode	0.025	1.41	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	0.073	4.44	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	0.073	4.43	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	0.029	1.75	mg/kg ww
Local PEC in pore water of agricultural soil	4.15E-08	2.51E-06	mg/l
Local PEC in pore water of grassland	1.64E-08	9.92E-07	mg/l
Local PEC in groundwater under agricultural soil	4.15E-08	2.51E-06	mg/l
Concentration in fish for secondary poisoning (freshwater)	5.81E-04	0.033	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg
Concentration in fish for secondary poisoning (marine)	6.38E-05	0.00332	mg/kg ww
Concentration in fish-eating marine top-predators	6.09E-05	0.00206	mg/kg ww

B.9.3.2. Use 2: Industrial use of sealants and adhesives

B.9.3.2.1. General information

According to the registration information, outlined in A.2.1. REACH Registration data, DP is used at industrial sites as a flame retardant in adhesives/sealants (ECHA, 2020b) and the use of adhesives was confirmed in the stakeholder consultation. This section considers the industrial use of adhesives/sealants containing DP.

B.9.3.2.2. Release and exposure estimation

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

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[33] The log Kow value for DP is outside the range over which EUSES 2.2.0 calculates the concentration in earthworms. Therefore, no estimate is possible.

FEICA SPERC 5.1c (for industrial use of water-borne products) (FEICA, 2017b, FEICA, 2017a). The details of the approach and assumptions made are documented in Table 25.

Table 25: Estimated EU release to the environment for Dechlorane Plus from industrial use of sealants and adhesives

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12
Share of total volume - sealants and adhesives	5%		See Table 12
Total tonnage in sealants and adhesives	5 - 12	tonnes/year	
Number of days of use	225	days/year	Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Daily amount used (local scenario)	0.0022 - 0.0053	tonnes/day	Estimate– assumes 10% of the total use occurs at a large site
Fraction released to air	0.017		Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction released to wastewater	0 – solvent-borne 0.003 – water-borne		Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction release 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)
Estimated release to air	85 - 204	kg/year	
Estimate release to wastewater	0 - 36	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal	250 - 600	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 26. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 26: Estimated EU release to the environment for Dechlorane Plus from industrial use of sealants and adhesives following redistribution in a STP

Total EU releases following redistribution in STP	**Lower estimate (kg/year)**	**Upper estimate (kg/year)**
Air	85.0	204.0
Water	0	9.3
Agricultural soil	0	26.7
Industrial soil	0	0
Total	**85.0**	**240.0**

B.9.3.2.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 27.

Table 27: Estimated indirect local exposure of humans via the environment for Dechlorane Plus from industrial use of sealants and adhesives in the EU

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of drinking water	8.27E-12	5.34E-09	mg/kg/d
Fraction of total dose through intake of drinking water	1.19E-07	9.92E-07	
Daily dose through intake of fish	2.09E-08	2.74E-06	mg/kg/d
Fraction of total dose through intake of fish	3.02E-04	5.09E-04	
Daily dose through intake of leaf crops	2.08E-05	4.69E-05	mg/kg/d
Fraction of total dose through intake of leaf crops	0.301	0.00872	
Daily dose through intake of root crops	1.29E-06	0.0052	mg/kg/d
Fraction of total dose through intake of root crops	0.019	0.965	
Daily dose through intake of meat	2.84E-05	8.46E-05	mg/kg/d
Fraction of total dose through intake of meat	0.410	0.016	
Daily dose through intake of milk	1.67E-05	4.99E-05	mg/kg/d
Fraction of total dose through intake of milk	0.242	0.00926	
Daily dose through intake of air	1.96E-06	4.43E-06	mg/kg/d
Fraction of total dose through intake of air	0.028	8.22E-04	
Local total daily intake for humans	6.92E-05	0.00539	mg/kg/d

B.9.3.2.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 28.

Table 28: Estimated environmental local exposure for Dechlorane Plus from industrial use of sealants and adhesives in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	6.88E-06	1.55E-05	mg/m^3
Local PEC in surface water during emission episode (dissolved)	2.32E-09	4.88E-07	mg/l
Annual average local PEC in surface water (dissolved)	2.32E-09	3.04E-07	mg/l
Local PEC in freshwater sediment during emission episode	0.00503	1.06	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	5.73E-10	4.98E-08	mg/l
Annual average local PEC in seawater (dissolved)	5.73E-10	3.14E-08	mg/l
Local PEC in marine sediment during emission episode	0.00125	0.108	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	8.01E-05	0.330	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	8.17E-05	0.330	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	1.60E-04	0.131	mg/kg ww
Local PEC in pore water of agricultural soil	4.63E-11	1.87E-07	mg/l
Local PEC in pore water of grassland	9.05E-11	7.40E-08	mg/l
Local PEC in groundwater under agricultural soil	4.63E-11	1.87E-07	mg/l
Concentration in fish for secondary poisoning (freshwater)	3.82E-05	0.00256	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	9.45E-06	2.72E-04	mg/kg ww
Concentration in fish-eating marine top-predators	2.83E-05	2.30E-04	mg/kg ww

B.9.3.3. Use 3: Industrial use in polymers

B.9.3.3.1. General information

According to the registration information, detailed in A.2.1. REACH Registration data, DP is used at industrial sites as a flame retardant in polymers (ECHA, 2020e), which was also confirmed in the stakeholder consultation. This section considers release of DP from compounding and conversion of polymers containing DP.

B.9.3.3.2. Release and exposure estimation

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)[34]. The details of the approach and assumptions made are documented in Table 29.

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, 2020b) and the OxyChem Manual reports three grades with average particle size below this value (OxyChem, 2007)).

Table 29: Estimated EU release to the environment for Dechlorane Plus from industrial use in polymers

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12
Share of volume used in polymers	93%		See Table 12
Total tonnage in polymers	84 - 214	tonnes/year	
Number of days of use	20	days/year	Default from ECHA (2016a)
Daily amount of used (local scenario)	0.42 - 1.07	tonnes/day	Estimate – assumes 10% of the total use occurs at a large site

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[34] 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.

Input factor / Assumption	Value	Unit	Comment
Fraction released to air	0.00002 – closed processes 0.00004 – partially open processes 0.00006 – open processes		For powders <40 µm - OECD (2009)
Fraction released to wastewater	0.00652 – closed processes 0.00654 – partially open processes 0.00656 – open processes		For powders <40 µm - OECD (2009)
Fraction release to industrial soil	0		OECD (2009)
Fraction to solid waste	0.01		For powders <40 µm - OECD (2009)
Estimated release to air	1.68 - 12.8	kg/year	
Estimate release to wastewater	548 – 1 400	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal	840 – 2 140	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 30. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 30: Estimated EU release to the environment for Dechlorane Plus from industrial use in polymers following redistribution in a STP

Total EU releases following redistribution in STP	Lower estimate (kg/year)	Upper estimate (kg/year)
Air	2.1	13.9
Water	141.4	362.4
Agricultural soil	405.9	1 040.3
Industrial soil	0	0
Total	**549.3**	**1 416.6**

B.9.3.3.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 31.

Table 31: Estimated indirect local exposure of human via the environment for Dechlorane Plus from industrial use in polymers in the EU

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of drinking water	7.31E-07	1.87E-06	mg/kg/d
Fraction of total dose through intake of drinking water	1.02E-06	1.02E-06	
Daily dose through intake of fish	3.27E-05	8.37E-05	mg/kg/d
Fraction of total dose through intake of fish	4.56E-05	4.56E-05	
Daily dose through intake of leaf crops	4.58E-07	3.19E-06	mg/kg/d
Fraction of total dose through intake of leaf crops	6.39E-07	1.74E-06	
Daily dose through intake of root crops	0.712	1.82	mg/kg/d
Fraction of total dose through intake of root crops	0.994	0.994	
Daily dose through intake of meat	0.00283	0.00726	mg/kg/d
Fraction of total dose through intake of meat	0.00395	0.00396	
Daily dose through intake of milk	0.00167	0.00428	mg/kg/d
Fraction of total dose through intake of milk	0.00233	0.00233	
Daily dose through intake of air	4.25E-08	2.99E-07	mg/kg/d
Fraction of total dose through intake of air	5.94E-08	1.63E-07	
Local total daily intake for humans	0.716	1.84	mg/kg/d

It should be noted that the total daily intake figure estimate is of the order to 1-2 mg/kg/d for this scenario. The largest proportion of this figure arises from ingestion of root crops. As discussed in Appendix F, there are uncertainties associated with these estimates.

B.9.3.3.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 32.

Table 32: Estimated environmental local exposure for Dechlorane Plus from industrial use in polymers in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	1.49E-07	1.05E-06	mg/m^3
Local PEC in surface water during emission episode (dissolved)	6.60E-05	1.69E-04	mg/l
Annual average local PEC in surface water (dissolved)	3.62E-06	9.27E-06	mg/l
Local PEC in freshwater sediment during emission episode	143	367	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	6.60E-06	1.69E-05	mg/l
Annual average local PEC in seawater (dissolved)	3.62E-07	9.28E-07	mg/l
Local PEC in marine sediment during emission episode	14.3	36.7	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	45.2	116	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	45.2	116	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	17.8	45.7	mg/kg ww
Local PEC in pore water of agricultural soil	2.56E-05	6.56E-05	mg/l
Local PEC in pore water of grassland	1.01E-05	2.59E-05	mg/l
Local PEC in groundwater under agricultural soil	2.56E-05	6.56E-05	mg/l
Concentration in fish for secondary poisoning (freshwater)	0.030	0.077	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg
Concentration in fish for secondary poisoning (marine)	0.00299	0.00766	mg/kg ww
Concentration in fish-eating marine top-predators	0.00182	0.00466	mg/kg ww

B.9.3.4. Use 4: Formulation of greases

B.9.3.4.1. General information

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 release during formulation.

B.9.3.4.2. Release and exposure estimation

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. Details of the assumptions made are summarised in

Table *33*. 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.

Table 33: Estimated EU release to the environment for Dechlorane Plus from formulation of greases

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of total volume - greases	2%		See Table 12.
Total tonnage in greases	2 - 5	tonnes/year	
Number of days of formulation	10	days/year	Default from ECHA (2016a)
Daily amount of formulated (local scenario)	0.2 - 0.5	tonnes/day	Estimate – assumes that all of the formulation occurs at one site as a worst case
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 release to industrial soil	0		Losses to soil expected to be low.
Fraction to solid waste	0.015		Based on OECD (2004)
Estimated release to air	0	kg/year	
Estimate release to wastewater	5 - 12.5	kg/year	

Input factor / Assumption	Value	Unit	Comment
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal	30 - 75	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 34. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 34: Estimated EU release to the environment for Dechlorane Plus from formulation of greases following redistribution in a STP

Total EU releases following redistribution in STP	Lower estimate (kg/year)	Upper estimate (kg/year)
Air	0.004	0.009
Water	1.3	3.2
Agricultural soil	3.7	9.3
Industrial soil	0	0
Total	**5.0**	**12.5**

B.9.3.4.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 35.

Table 35: Estimated indirect local exposure of human via the environment for Dechlorane Plus from formulation of greases in the EU

Route of exposure of humans via the environment	Lower estimate	Upper estimate	Unit
Daily dose through intake of drinking water	1.33E-07	3.34E-07	mg/kg/d
Fraction of total dose through intake of drinking water	1.02E-06	1.02E-06	
Daily dose through intake of fish	3.00E-06	7.51E-06	mg/kg/d
Fraction of total dose through intake of fish	2.29E-05	2.30E-05	
Daily dose through intake of leaf crops	7.52E-08	2.37E-07	mg/kg/d
Fraction of total dose through intake of leaf crops	5.76E-07	7.25E-07	
Daily dose through intake of root crops	0.130	0.325	mg/kg/d
Fraction of total dose through intake of root crops	0.994	0.994	

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of meat	5.17E-04	0.00129	mg/kg/d
Fraction of total dose through intake of meat	0.00395	0.00395	
Daily dose through intake of milk	3.05E-04	7.61E-04	mg/kg/d
Fraction of total dose through intake of milk	0.00233	0.00233	
Daily dose through intake of air	6.98E-09	2.20E-08	mg/kg/d
Fraction of total dose through intake of air	5.34E-08	6.74E-08	
Local total daily intake for humans	0.131	0.327	mg/kg/d

It should be noted that the total daily intake figure estimate is of the order to 1-2 mg/kg/d for this scenario. The largest proportion of this figure arises from ingestion of root crops. As discussed in Appendix F, there are uncertainties associated with these estimates.

B.9.3.4.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 36.

Table 36: Estimated environmental local exposure for Dechlorane Plus from formulation of greases in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	2.44E-08	7.71E-08	mg/m^3
Local PEC in surface water during emission episode (dissolved)	1.20E-05	3.01E-05	mg/l
Annual average local PEC in surface water (dissolved)	3.32E-07	8.31E-07	mg/l
Local PEC in freshwater sediment during emission episode	26.2	65.4	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	1.20E-06	3.01E-06	mg/l
Annual average local PEC in seawater (dissolved)	3.36E-08	8.41E-08	mg/l
Local PEC in marine sediment during emission episode	2.62	6.55	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	8.25	20.6	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	8.24	20.6	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	3.25	8.14	mg/kg ww
Local PEC in pore water of agricultural soil	4.67E-06	1.17E-05	mg/l

Compartment	Lower estimate	Upper estimate	Unit
Local PEC in pore water of grassland	1.84E-06	4.61E-06	mg/l
Local PEC in groundwater under agricultural soil	4.67E-06	1.17E-05	mg/l
Concentration in fish for secondary poisoning (freshwater)	0.00276	0.00691	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	2.81E-04	7.07E-04	mg/kg ww
Concentration in fish-eating marine top-predators	1.91E-04	4.91E-04	mg/kg ww

B.9.3.5. Use 5: Indoor use of articles containing Dechlorane Plus over their service life

B.9.3.5.1. General information

As described in Section A.2. Uses , 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 release to the environment over the articles' service lives. ECHA (2016a) provides a generic method of estimating the releases from such articles. This section considers release of DP from indoor use of such articles.

B.9.3.5.2. Release and exposure estimation

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 estimated EU release to the environment for DP from indoor use of articles over their service life is summarised in Table 37.

Table 37: Estimated EU release to the environment for Dechlorane Plus from indoor use of articles over their service life

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12
Share of volume used in articles	98%		Sum of volume used for polymers and sealants. See Table 12
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume used in articles that are used indoors	90%		Assumption
Total tonnage - indoor use of articles	79.2 - 203	tonnes/year	
Number of days of use	365	days/year	Default from ECHA (2016a)
Daily amount used (local scenario)	4.34E-05- 1.11E-04	tonnes/day	Estimated using ECHA (2016a)
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 release 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).
Estimated release to air	39.6 - 101	kg/year	
Estimate release to wastewater	39.6 - 101	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal/recycling	79 200 – 203 000	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 38. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 38: Estimated EU release to the environment for Dechlorane Plus from indoor use of articles over their service life following redistribution in a STP

Total EU releases following redistribution in STP	**Lower estimate (kg/year)**	**Upper estimate (kg/year)**
Air	39.6	101.3
Water	10.2	26.1
Agricultural soil	29.3	75.0
Industrial soil	0	0
Total	**79.2**	**202.5**

B.9.3.5.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 39.

Table 39: Estimated indirect exposure of human via the environment for Dechlorane Plus from indoor use of articles over their service life in the EU

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of drinking water	1.01E-11	2.89E-11	mg/kg/d
Fraction of total dose through intake of drinking water	1.69E-06	1.87E-06	
Daily dose through intake of fish	2.56E-08	7.31E-08	mg/kg/d
Fraction of total dose through intake of fish	0.00428	0.00472	
Daily dose through intake of leaf crops	8.17E-08	2.54E-07	mg/kg/d
Fraction of total dose through intake of leaf crops	0.014	0.016	
Daily dose through intake of root crops	5.66E-06	1.45E-05	mg/kg/d
Fraction of total dose through intake of root crops	0.945	0.936	
Daily dose through intake of meat	1.34E-07	4.04E-07	mg/kg/d
Fraction of total dose through intake of meat	0.022	0.026	
Daily dose through intake of milk	7.89E-08	2.38E-07	mg/kg/d
Fraction of total dose through intake of milk	0.013	0.015	

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of air	7.70E-09	2.39E-08	mg/kg/d
Fraction of total dose through intake of air	0.00129	0.00155	
Local total daily intake for humans	5.99E-06	1.55E-05	mg/kg/d

B.9.3.5.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 40.

Table 40: Estimated environmental exposure for Dechlorane Plus from indoor use of articles over their service life in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	2.70E-08	8.38E-08	mg/m^3
Local PEC in surface water during emission episode (dissolved)	2.84E-09	8.10E-09	mg/l
Annual average local PEC in surface water (dissolved)	2.84E-09	8.10E-09	mg/l
Local PEC in freshwater sediment during emission episode	0.00617	0.018	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	6.25E-10	1.81E-09	mg/l
Annual average local PEC in seawater (dissolved)	6.25E-10	1.81E-09	mg/l
Local PEC in marine sediment during emission episode	0.00136	0.00393	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	3.59E-04	9.20E-04	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	3.59E-04	9.19E-04	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	1.43E-04	3.66E-04	mg/kg ww
Local PEC in pore water of agricultural soil	2.03E-10	5.21E-10	mg/l
Local PEC in pore water of grassland	8.09E-11	2.07E-10	mg/l
Local PEC in groundwater under agricultural soil	2.03E-10	5.21E-10	mg/l
Concentration in fish for secondary poisoning (freshwater)	4.25E-05	1.22E-04	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[3333]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	9.88E-06	2.87E-05	mg/kg ww
Concentration in fish-eating marine top-predators	2.86E-05	8.34E-05	mg/kg ww

B.9.3.6. Use 6: Outdoor use of articles containing Dechlorane Plus over their service life

B.9.3.6.1. General information

As described in Section A.2. Uses , 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 release to the environment over the articles' service lives. ECHA (2016a) provides a generic method for estimating the releases from such articles. This section considers release of DP from outdoor use of such articles.

B.9.3.6.2. Release and exposure estimation

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 estimated EU release to the environment for DP from outdoor use of articles over their service life is summarised in Table 41.

Table 41: Estimated EU release to the environment for Dechlorane Plus from outdoor use of articles over their service life

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12
Share of volume used in articles	98%		Sum of volume used for polymers and sealants. See Table 12
Total volume used in articles	88 - 225	tonnes/year	
Share of volume used outdoors	10%		Assumption
Total tonnage - outdoor use of articles	8.8 - 22.5	tonnes/year	
Number of days of use	365	days/year	Default from ECHA (2016a)

Input factor / Assumption	**Value**	**Unit**	**Comment**
Daily amount used	4.82E-6 - 1.23E-5	tonnes/day	Estimated using ECHA (2016a)
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 release to industrial soil	0		Default for ERC 10a (ECHA, 2016a) and OECD (2009)
Fraction to solid waste/recycling	1		Default from ECHA (2012).
Estimated release to air	4.4 - 11.3	kg/year	
Estimate release to wastewater	282 - 720	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal/recycling	8 800 – 22 500	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 42. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 42: Estimated EU release to the environment for Dechlorane Plus from outdoor use of articles over their service life following redistribution in a STP

Total EU releases following redistribution in STP	**Lower estimate (kg/year)**	**Upper estimate (kg/year)**
Air	4.6	11.8
Water	72.7	185.9
Agricultural soil	208.7	533.5
Industrial soil	0	0
Total	**286.0**	**731.2**

B.9.3.6.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 43.

Table 43: Estimated indirect exposure of human via the environment for Dechlorane Plus from outdoor use of articles over their service life in the EU

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of drinking water	4.11E-11	1.05E-10	mg/kg/d
Fraction of total dose through intake of drinking water	1.01E-06	1.01E-06	
Daily dose through intake of fish	5.44E-08	1.47E-07	mg/kg/d
Fraction of total dose through intake of fish	0.00134	0.00141	
Daily dose through intake of leaf crops	6.54E-08	2.12E-07	mg/kg/d
Fraction of total dose through intake of leaf crops	0.00161	0.00204	
Daily dose through intake of root crops	4.00E-05	1.03E-04	mg/kg/d
Fraction of total dose through intake of root crops	0.987	0.986	
Daily dose through intake of meat	2.48E-07	6.98E-07	mg/kg/d
Fraction of total dose through intake of meat	0.00613	0.00670	
Daily dose through intake of milk	1.46E-07	4.11E-07	mg/kg/d
Fraction of total dose through intake of milk	0.00361	0.00395	
Daily dose through intake of air	6.17E-09	2.00E-08	mg/kg/d
Fraction of total dose through intake of air	1.52E-04	1.92E-04	
Local total daily intake for humans	4.05E-05	1.04E-04	mg/kg/d

B.9.3.6.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 44.

Table 44: Estimated environmental exposure for Dechlorane Plus from outdoor use of articles over their service life in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	2.16E-08	7.01E-08	mg/m^3
Local PEC in surface water during emission episode (dissolved)	6.02E-09	1.63E-08	mg/l
Annual average local PEC in surface water (dissolved)	6.02E-09	1.63E-08	mg/l
Local PEC in freshwater sediment during emission episode	0.013	0.035	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	9.44E-10	2.62E-09	mg/l
Annual average local PEC in seawater (dissolved)	9.44E-10	2.62E-09	mg/l
Local PEC in marine sediment during emission episode	0.00205	0.00570	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	0.00254	0.00652	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	0.00254	0.00651	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	0.00100	0.00258	mg/kg ww
Local PEC in pore water of agricultural soil	1.44E-09	3.69E-09	mg/l
Local PEC in pore water of grassland	5.69E-10	1.46E-09	mg/l
Local PEC in groundwater under agricultural soil	1.44E-09	3.69E-09	mg/l
Concentration in fish for secondary poisoning (freshwater)	6.87E-05	1.90E-04	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	1.25E-05	3.54E-05	mg/kg ww
Concentration in fish-eating marine top-predators	3.02E-05	8.74E-05	mg/kg ww

B.9.3.7. Use 7: Dismantling and recycling of waste/articles containing Dechlorane Plus

B.9.3.7.1. General information

As described in Section A.2. Uses , 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 A.2.5. Recycling).

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 release 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. Gravel et al. (2019), Wang et al. (2016), Yu et al. (2010), and other references in the draft POPs risk profile for DP (POPRC, 2021b).

B.9.3.7.2. Release and exposure estimation

Environmental exposure is estimated in line with the ECHA (2016a) and ECHA (2012) guidance.

It is assumed that articles containing DP may undergo dismantling and/or shredding before recycling or final disposal. This is likely to be the case with vehicles, aircrafts and electrical and electronic equipment. As noted in Section B.9.3.4. Use 4: Formulation of greases, the potential for release of DP from automotive uses of greases during dismantling is low.

(ECHA, 2012) provides a generic method for assessing the releases to the environment from shredding and mechanical size reduction of wastes prior to recycling. Such processes may result in the formation of dusts containing DP which may be released to the air.

ECHA (2012) indicates that there are 210 installations in the EU carrying out shredding operations and these typically operate for 330 days per year. The default release factor to air from the process is 10%. No contact with water occurs during the process and so the release factor to water is zero and the process does not give risk to direct releases to soil (ECHA, 2012). Although direct releases to soil are not likely to occur, indirect release to soil may occur by subsequent atmospheric deposition of the airborne dust. This is taken into account in the later PEC calculations.

The estimated EU releases to the environment for DP from shredding/dismantling of waste articles is summarised in Table 45.

The actual fraction of articles containing DP that undergo recycling or shredding operations is not known precisely. As noted in Section A.2.5.1. End-of-Life Vehicles (ELVs), around 87.9% and 93.7% of ELVs (by vehicle weight) are recycled and recovered respectively in the EU. Each car is estimated to contain between 2 g and 35 g of DP. The recycling rate for electrical and electronic equipment is lower. As noted in Section A.2.5.2. 39.4% of WEEE was recycled in the EU in 2017. Plastics, which are likely to contain DP, constitute around 20% of this waste. WEEE recycling rates are however expected to increase as a result of Directive 2012/19/EU increasing the WEEE target collection rate as a share of total EEE from 45% in 2016 to 65% in 2019 (Eurostat, 2020b).

For the assessment it is necessary to make an assumption about the fraction of articles containing DP that will undergo shredding. The exact figure is not known but, as noted in A.2.5 Recycling, recycling involving shredding is widely used as part of ELV treatment (e.g. Krinke et al., 2006; Plastics Market Watch, 2016) and is increasingly used as part of the recycling of WEEE (e.g. Maisel et al. (2020)). The Plastics Europe website indicates that mechanical recycling is currently the main form of plastics recycling in Europe[35], representing more than 99% of the recycled quantities.

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.

Following dismantling, polymers containing DP may be subjected to recycling. The potential for release 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).

Table 45: Estimated EU release to the environment from dismantling/shredding of waste articles containing Dechlorane Plus

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume of articles undergoing shredding	65% - 85%		Assumption
Total tonnage undergoing shredding	57 – 191	tonnes/year	
Number of days of use	330	days/year	Default from ECHA (2012)
Daily amount used (local scenario)	0.00321 - 0.0107	tonnes/day	Estimated using ECHA (2012)
Fraction released to air	0.1		Default from ECHA (2012)
Fraction released to wastewater	0		Default from ECHA (2012)
Fraction release to industrial soil	0		Default from ECHA (2012)
Fraction to solid waste/recycling	0		Default from ECHA (2012)
Estimated release to air	5 720 – 19 100	kg/year	

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[35] https://www.plasticseurope.org/en/focus-areas/circular-economy/zero-plastics-landfill/recycling-and-energy-recovery

Input factor / Assumption	**Value**	**Unit**	**Comment**
Estimate release to wastewater	0	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal/recycling	0	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 46. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 46: Estimated EU release to the environment for Dechlorane Plus from dismantling/shredding of waste articles following redistribution in a STP

Total EU releases following redistribution in STP	**Lower estimate (kg/year)**	**Upper estimate (kg/year)**
Air	5 720	19 125
Water	0	0
Agricultural soil	0	0
Industrial soil	0	0
Total	**5 720**	**19 125**

B.9.3.7.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 47.

Table 47: Estimated indirect exposure of human via the environment for Dechlorane Plus from dismantling/shredding of waste articles in the EU

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of drinking water	1.53E-11	5.11E-11	mg/kg/d
Fraction of total dose through intake of drinking water	1.89E-08	1.89E-08	
Daily dose through intake of fish	2.09E-08	6.10E-08	mg/kg/d
Fraction of total dose through intake of fish	2.57E-05	2.26E-05	
Daily dose through intake of leaf crops	2.45E-04	8.15E-04	mg/kg/d
Fraction of total dose through intake of leaf crops	0.301	0.301	

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of root crops	1.49E-05	4.97E-05	mg/kg/d
Fraction of total dose through intake of root crops	0.018	0.018	
Daily dose through intake of meat	3.33E-04	0.00111	mg/kg/d
Fraction of total dose through intake of meat	0.410	0.410	
Daily dose through intake of milk	1.96E-04	6.54E-04	mg/kg/d
Fraction of total dose through intake of milk	0.242	0.242	
Daily dose through intake of air	2.31E-05	7.69E-05	mg/kg/d
Fraction of total dose through intake of air	0.028	0.028	
Local total daily intake for humans	8.12E-04	0.00271	mg/kg/d

B.9.3.7.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 48.

Table 48: Estimated environmental exposure for Dechlorane Plus from dismantling/shredding of waste articles in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	8.07E-05	2.69E-04	mg/m^3
Local PEC in surface water during emission episode (dissolved)	2.32E-09	6.76E-09	mg/l
Annual average local PEC in surface water (dissolved)	2.32E-09	6.76E-09	mg/l
Local PEC in freshwater sediment during emission episode	0.00503	0.015	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	5.73E-10	1.67E-09	mg/l
Annual average local PEC in seawater (dissolved)	5.73E-10	1.67E-09	mg/l
Local PEC in marine sediment during emission episode	0.00125	0.00364	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	9.28E-04	0.00309	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	9.47E-04	0.00316	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	0.00187	0.00622	mg/kg ww
Local PEC in pore water of agricultural soil	5.37E-10	1.79E-09	mg/l

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Local PEC in pore water of grassland	1.06E-09	3.53E-09	mg/l
Local PEC in groundwater under agricultural soil	5.37E-10	1.79E-09	mg/l
Concentration in fish for secondary poisoning (freshwater)	3.82E-05	1.11E-04	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	9.45E-06	2.76E-05	mg/kg ww
Concentration in fish-eating marine top-predators	2.83E-05	8.27E-05	mg/kg ww

B.9.3.8. Use 8: Disposal of waste/articles containing Dechlorane Plus by incineration

B.9.3.8.1. General information

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

B.9.3.8.2. Release and exposure estimation

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 by landfill. The estimated release to the environment of DP from incineration of waste/articles in the EU is summarised in Table 49.

Table 49: Estimated release to the environment from incineration of waste/artcles containing Dechlorane Plus

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume in articles ending up being incinerated	50%		Assumption
Total tonnage incinerated	45 - 115	tonnes/year	

Input factor / Assumption	**Value**	**Unit**	**Comment**
Number of days of use	330	days/year	Default from ECHA (2012)
Daily amount used (local scenario)	0.00109 - 0.00279	tonnes/day	Estimated using ECHA (2012)
Fraction released to air	0.0001		Default from ECHA (2012)
Fraction released to wastewater	0.0001		Default from ECHA (2012)
Fraction release to industrial soil	0		Default from ECHA (2012)
Fraction to solid waste/recycling	0		Default from ECHA (2012)
Estimated release to air	4.5 - 11.5	kg/year	
Estimate release to wastewater	4.5 - 11.5	kg/year	
Estimated release to industrial soil	0	kg/year	
Estimated amount to solid waste for disposal/recycling	0	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 50. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 50: Estimated EU release to the environment for Dechlorane Plus from incineration of waste/articles following redistribution in a STP

Total EU releases following redistribution in STP	Lower estimate (kg/year)	Upper estimate (kg/year)
Air	4.5	11.5
Water	1.2	3.0
Agricultural soil	3.3	8.5
Industrial soil	0	0
Total	**9.0**	**23.0**

B.9.3.8.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 51.

Table 51: Estimated indirect exposure of humans via the environment for Dechlorane Plus from incineration of waste/articles in the EU

Route of exposure of humans via the environment	Lower estimate	Upper estimate	Unit
Daily dose through intake of drinking water	1.25E-10	3.22E-10	mg/kg/d
Fraction of total dose through intake of drinking water	1.52E-04	1.42E-04	
Daily dose through intake of fish	3.16E-07	8.15E-07	mg/kg/d
Fraction of total dose through intake of fish	0.385	0.356	
Daily dose through intake of leaf crops	1.46E-07	4.20E-07	mg/kg/d
Fraction of total dose through intake of leaf crops	0.179	0.185	
Daily dose through intake of root crops	2.57E-08	8.05E-08	mg/kg/d
Fraction of total dose through intake of root crops	0.031	0.036	
Daily dose through intake of meat	2.00E-07	5.72E-07	mg/kg/d
Fraction of total dose through intake of meat	0.244	0.253	
Daily dose through intake of milk	1.18E-07	3.37E-07	mg/kg/d
Fraction of total dose through intake of milk	0.144	0.149	

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of air	1.38E-08	3.96E-08	mg/kg/d
Fraction of total dose through intake of air	0.017	0.018	
Local total daily intake for humans	8.19E-07	2.26E-06	mg/kg/d

B.9.3.8.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 52.

Table 52: Estimated environmental exposure for Dechlorane Plus from incineration of waste/articles in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Annual average local PEC in air (total)	4.83E-08	1.38E-07	mg/m^3
Local PEC in surface water during emission episode (dissolved)	3.84E-08	9.91E-08	mg/l
Annual average local PEC in surface water (dissolved)	3.49E-08	9.03E-08	mg/l
Local PEC in freshwater sediment during emission episode	0.084	0.216	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	4.18E-09	1.09E-08	mg/l
Annual average local PEC in seawater (dissolved)	3.84E-09	1.00E-08	mg/l
Local PEC in marine sediment during emission episode	0.00909	0.024	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	1.63E-06	5.09E-06	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	1.63E-06	5.11E-06	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	1.95E-06	5.91E-06	mg/kg ww
Local PEC in pore water of agricultural soil	9.26E-13	2.90E-12	mg/l
Local PEC in pore water of grassland	1.10E-12	3.35E-12	mg/l
Local PEC in groundwater under agricultural soil	9.26E-13	2.90E-12	mg/l
Concentration in fish for secondary poisoning (freshwater)	3.07E-04	8.00E-04	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	3.63E-05	9.64E-05	mg/kg ww
Concentration in fish-eating marine top-predators	4.45E-05	1.24E-04	mg/kg ww

B.9.3.9. Use 9: Disposal of waste/articles containing Dechlorane Plus by landfill

B.9.3.9.1. General information

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

B.9.3.9.2. Release and exposure estimation

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 by landfill. The estimated release to the environment of DP from incineration of waste/articles in the EU is summarised in Table 53.

Table 53: Estimated EU release to the environment from disposal of waste/articles containing Dechlorane Plus by landfill

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume in articles ending up in landfill	50%		Assumption
Total tonnage landfilled	45 - 115	tonnes/year	
Number of days of formulation	365	days/year	Default from ECHA (2012)
Daily amount of formulated	5.87E-05 – 1.50E-04	tonnes/day	Estimated using ECHA (2012)
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, 20-year lifetime of the landfill, removal fraction of 0.5 for on-site treatment.
Fraction release to industrial soil	0.0016		Default from ECHA (2012)
Fraction to solid waste	0		Default from ECHA (2012)
Estimated release to air	0	kg/year	

Input factor / Assumption	Value	Unit	Comment
Estimate release to wastewater	720 – 1 840	kg/year	
Estimated release to industrial soil	72 - 184	kg/year	
Estimated amount to solid waste for disposal	0	kg/year	

The estimated total EU releases following redistribution in a STP are summarised in Table 54. These include any direct release to air and surface water and take account of the redistribution in the STP for emissions to wastewater.

Table 54: Estimated EU release to the environment for Dechlorane Plus from disposal of waste/articles by landfill following redistribution in a STP

Total EU releases following redistribution in STP	**Lower estimate (kg/year)**	**Upper estimate (kg/year)**
Air	0.5	1.4
Water	185.9	475
Agricultural soil	533.5	1 363.5
Industrial soil	72	184
Total	**792.0**	**2 023.9**

B.9.3.9.2.1. Indirect exposure of humans via the environment

The indirect exposure of human via the environment has been estimated using EUSES 2.2.0. The exposure predicted for the EU situation is summarised in Table 55.

Table 55: Estimated indirect exposure of human via the environment for Dechlorane Plus from disposal of waste/articles by landfill in the EU

Route of exposure of humans via the environment	**Lower estimate**	**Upper estimate**	**Unit**
Daily dose through intake of drinking water	2.51E-10	6.41E-10	mg/kg/d
Fraction of total dose through intake of drinking water	1.02E-06	1.02E-06	
Daily dose through intake of fish	2.25E-07	5.83E-07	mg/kg/d
Fraction of total dose through intake of fish	9.15E-04	9.27E-04	
Daily dose through intake of leaf crops	6.41E-08	2.09E-07	mg/kg/d
Fraction of total dose through intake of leaf crops	2.61E-04	3.33E-04	

Route of exposure of humans via the environment	Lower estimate	Upper estimate	Unit
Daily dose through intake of root crops	2.44E-04	6.23E-04	mg/kg/d
Fraction of total dose through intake of root crops	0.992	0.992	
Daily dose through intake of meat	1.06E-06	2.76E-06	mg/kg/d
Fraction of total dose through intake of meat	0.00430	0.00440	
Daily dose through intake of milk	6.23E-07	1.63E-06	mg/kg/d
Fraction of total dose through intake of milk	0.00254	0.00259	
Daily dose through intake of air	6.05E-09	1.97E-08	mg/kg/d
Fraction of total dose through intake of air	2.46E-05	3.13E-05	
Local total daily intake for humans	2.46E-04	6.29E-04	mg/kg/d

B.9.3.9.2.2. Environmental exposure

The environmental exposure assessment has been carried out using EUSES 2.2.0. The PECs estimated for the EU situation are summarised in Table 56.

Table 56: Estimated environmental exposure for Dechlorane Plus from disposal of waste/articles by landfill in the EU

Compartment	Lower estimate	Upper estimate	Unit
Annual average local PEC in air (total)	2.12E-08	6.90E-08	mg/m^3
Local PEC in surface water during emission episode (dissolved)	2.49E-08	6.45E-08	mg/l
Annual average local PEC in surface water (dissolved)	2.49E-08	6.45E-08	mg/l
Local PEC in freshwater sediment during emission episode	0.054	0.140	mg/kg ww
Local PEC in seawater during emission episode (dissolved)	2.83E-09	7.45E-09	mg/l
Annual average local PEC in seawater (dissolved)	2.83E-09	7.45E-09	mg/l
Local PEC in marine sediment during emission episode	0.00616	0.016	mg/kg ww
Local PEC in agric. soil (total) averaged over 30 days	0.016	0.040	mg/kg ww
Local PEC in agric. soil (total) averaged over 180 days	0.016	0.040	mg/kg ww
Local PEC in grassland (total) averaged over 180 days	0.00611	0.016	mg/kg ww
Local PEC in pore water of agricultural soil	8.77E-09	2.24E-08	mg/l

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Local PEC in pore water of grassland	3.46E-09	8.85E-09	mg/l
Local PEC in groundwater under agricultural soil	8.77E-09	2.24E-08	mg/l
Concentration in fish for secondary poisoning (freshwater)	2.25E-04	5.88E-04	mg/kg ww
Concentration in earthworms from agricultural soil	no estimate possible[33]	no estimate possible	mg/kg ww
Concentration in fish for secondary poisoning (marine)	2.81E-05	7.52E-05	mg/kg ww
Concentration in fish-eating marine top-predators	3.95E-05	1.11E-04	mg/kg ww

B.9.3.10. Other sources (for example natural sources, unintentional releases)

There are no known natural sources of DP.

B.9.3.11. Summary of overall releases and environmental exposure

The exposure assessment shows that the largest source of emission of DP to the environment in the EU is dismantling and recycling, which is responsible for 76% - 80% of total emissions. Furthermore, it can be seen that the second largest emission source is landfill (10.5% – 8.5%), which means that 86% - 89% of the releases of DP to the environment are attributable to the waste stages. A number of environmental monitoring studies points at e-waste recycling sites as a source of release of DP to the environment, see section B.9.4.2. for details. Table 57 summarises and details all of the emission sources and their high and low share of total emissions.

Table 57: Emission sources of DP

Scenario	**Share of total – Low emission scenario**	**Share of total – High emission scenario**
Manufacture of substance	0%	0%
Formulation of sealants/ adhesives	0.02%	0.3%
Industrial use of sealants/ adhesives	1.1%	1.0%
Polymer raw materials handling, compounding and conversion	7.3%	5.9%
Formulation of greases	0.1%	0.1%
Widespread use of articles over their service life - indoor use	1.1%	0.8%

Scenario	**Share of total – Low emission scenario**	**Share of total – High emission scenario**
Widespread use of articles over their service life - outdoor use	3.8%	3.1%
Waste dismantling and recycling	76.0%	80.2%
Waste incineration	0.1%	0.1%
Landfill	10.5%	8.5%

Note: There is no manufacture of DP in the EU

The overall release estimates for DP for the EU are summarised in Table 58. The 'Total' DP refers to the sum of estimate releases to the air, water, agricultural soil and industrial soil. These include any direct releases and take account of the redistribution in the STP for emissions to wastewater. The table shows that emissions to air far exceed the estimates of the other routes, comprising around 78 - 82% of the total DP released to the environment.

Table 58: Estimated total EU releases for DP following redistribution in STP

Environmental compartment	**Estimated EU emissions in 2020 (kg/year)**		
	Low	**High**	**Share of total**
Air	5 857	19 479	78 - 82%
Water	413	1 081	4.5 - 5.5%
Agricultural soil	1 185	3 102	13 - 16%
Industrial soil	72	184	0.8 - 1.0%
All / Total	**7 527**	**23 845**	**100%**

Note: Sums may not add up due to rounding.

Estimates of DP releases to the environment were also included in the UK Environment Agency's analysis of the most appropriate risk management option (RMOA) for DP (EA, 2018b). A description of these releases is reported in the Confidential Annex (see Section H.2. Exposure assessment for more details). Estimates of DP releases to the environment were also included in the UK Environment Agency's analysis of the most appropriate risk management option (RMOA) for DP (EA, 2018a). A description of these releases is reported in the Confidential Annex (see Section H.2. Exposure assessment for more details).

The estimated regional and continental PECs for DP in the EU are summarised in Table 59 and Table 60.

Table 59: Estimated regional PECs for Dechlorane Plus in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Regional PEC in surface water (total)	3.50E-07	1.02E-06	mg/l
Regional PEC in seawater (total)	2.92E-08	8.53E-08	mg/l
Regional PEC in surface water (dissolved)	2.32E-09	6.76E-09	mg/l
Regional PEC in seawater (dissolved)	5.73E-10	1.67E-09	mg/l
Regional PEC in air (total)	2.09E-08	6.84E-08	mg/m^3
Regional PEC in agricultural soil (total)	0.00475	0.014	mg/kg ww
Regional PEC in pore water of agricultural soils	2.69E-09	7.90E-09	mg/l
Regional PEC in natural soil (total)	1.31E-06	4.29E-06	mg/kg ww
Regional PEC in industrial soil (total)	0.00179	0.00457	mg/kg ww
Regional PEC in sediment (total)	0.010	0.029	mg/kg ww
Regional PEC in seawater sediment (total)	0.00249	0.00727	mg/kg ww

Table 60: Estimated continental PECs for Dechlorane Plus in the EU

Compartment	**Lower estimate**	**Upper estimate**	**Unit**
Continental PEC in surface water (total)	4.15E-08	1.07E-07	mg/l
Continental PEC in seawater (total)	1.11E-10	2.97E-10	mg/l
Continental PEC in surface water (dissolved)	2.75E-10	7.08E-10	mg/l
Continental PEC in seawater (dissolved)	2.18E-12	5.82E-12	mg/l
Continental PEC in air (total)	2.39E-09	7.69E-09	mg/l
Continental PEC in agricultural soil (total)	4.72E-04	0.00122	mg/l
Continental PEC in pore water of agricultural soils	2.67E-10	6.90E-10	mg/m^3
Continental PEC in natural soil (total)	1.50E-07	4.83E-07	mg/kg ww
Continental PEC in industrial soil (total)	1.85E-04	4.71E-04	mg/l
Continental PEC in sediment (total)	0.00119	0.00308	mg/kg ww
Continental PEC in seawater sediment (total)	9.47E-06	2.53E-05	mg/kg ww

B.9.3.11.1. Temporal trends in use and emissions

Significant differences in information provided by stakeholders on supply and use of DP (see Annex A: Manufacture and uses) 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 Annex D: Baseline.

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[36]. 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.

B.9.4. Biomonitoring and environmental monitoring data

B.9.4.1. Human exposure

B.9.4.1.1 General

Exposure to dechlorane plus (DP) and its *syn*- and *anti*-isomers (*syn*-DP and *anti*-DP) can occur through 1) workers exposure, 2) consumer exposure and 3) indirect exposure of humans via the environment (ECHA, 2016a) . Further, the foetus is exposed to DP due to transfer through the placenta, and breast-fed children are exposed through intake of breast milk (see section B.9.4.1.5.3. Levels in children and toddlers for details).

Exposure can be estimated in two ways; 1) calculating the external dose by multiplying measured or modelled concentrations of DP from different sources (e.g. food, air and drinking water) with exposure factors (e.g. inhalation rate or volume/amount consumed), or 2) assessing the internal dose which is based on measuring concentrations of DP in a suitable biological matrix (e.g. blood or breast milk), which further can be used to calculate the body burden based on knowledge on distribution in the human body.

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[36] 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

This section focuses on exposure characterised by the internal dose, which reflects an integrated exposure over time comprising various sources and pathways and will take individual differences, for example age and gender, into consideration.

B.9.4.1.2 Occupational exposure

Workers can be occupationally exposed to DP either directly or indirectly. Examples on direct exposures are workers exposed during production processes (Zhang et al., 2013) and indirect when handling e-waste (Yan et al., 2012). Biomonitoring data from workers was only available from China. In Table 61 biomonitoring data from Chinese workers which have been exposed to DP are presented. For information on selection of suitable biomarkers and matrices please see section B.9.4.1. Human exposure.

For serum samples (see Table 61), the central estimates (means or medians) vary from around 50 to 400 ng/g serum lipid for *syn*-DP and from around 100 to 500 ng/g serum lipid for *anti*-DP. In single samples, concentrations up to 1242 and 1716 ng/g serum lipids were reported for *syn*-DP and *anti*-DP, respectively. Based on results from analyses of hair samples, the central estimates for *syn*-DP were around 10 to 300 ng/g hair while they were around 10 to 150 ng/g hair for *anti*-DP. The maximum concentrations in the single hair samples were 799 and 1360 ng/g hair for *syn*-DP and *anti*-DP, respectively.

In a study by Yan et al. (2012) DP were measured in occupationally exposed workers in e-waste recycling workshops in Longtang Town, Qingyuan County in China and compared to serum concentrations from persons with no occupational exposure living in Guangzhou City in China. The concentrations in workers were significantly higher (median of 52.7 ng/g serum lipid for *syn*-DP and 103.6 ng/g serum lipid for *anti*-DP) as compared to the urban residents (median of <LOD for *syn*-DP and 4.63 ng/g serum lipid for *anti*-DP). This demonstrates that occupational exposure to DP results in elevated internal doses of *syn*-DP and *anti*-DP.

Furthermore, Zhang et al. (2013) found significant associations between the number of years working in a DP manufacturing plant and the measured DP concentrations in hair or serum, strongly indicating bioaccumulation of DP in humans.

In another study from China, Zheng et al. (2010) measured DP in samples of hair and indoor dust. The study included e-waste dismantling workers, non-occupational residents in the e-waste area, residents living a rural area, and residents in the largest urban center in South China. Strong positive correlations between human hair and dust samples were observed for both *syn*-DP and *anti*-DP, indicating that dust could be one of the major pathways for DP exposure.

To summarise, elevated internal doses of *syn*-DP and *anti*-DP are observed in occupational exposed workers, and dust could be one of the major pathways for DP exposure in such settings.

Table 61: Examples of studies presenting concentrations of syn-DP and anti-DP in serum (in ng/g serum lipids) and hair (ng/g hair) from adult workers experiencing occupational exposure to DP.

Location	Subjects	Matrix	Collection year	Detection frequency, %	Median	Mean	Minimum	Maximum	Reference
***syn*-DP**									
China	Workers in DP manufacturing plant directly engaged in manufacturing, N=23	serum	2011	100	NR	386	80.4	1242	Zhang et al., (2013)
China	Workers in DP manufacturing plant not directly engaged in manufacturing of DP, N=12	serum	2011	100	NR	143	69.4	302	Zhang et al., (2013)
China	Occupationally exposed workers in e-waste recycling workshops in Longtang Town, Qingyuan County. N=70 (33 males and 37 females), age 20-59 years	serum	2011	100	52.7	NR	7.44	578	Yan et al., (2012)
China	E-waste recycling workers in Longtang, Qingyuan city in Guangdong province, N=34 (19 males and 15 females)	serum	NR	100	77	NR	7.4	420	Chen et al., (2015)
China	Workers in DP manufacturing plant directly engaged in manufacturing, N=22	hair	2011	100	NR	279	89.1	799	Zhang et al., (2013)
China	Workers in DP manufacturing plant not directly engaged in manufacturing of DP, N=11	hair	2011	100	NR	102	13.0	379	Zhang et al., (2013)
China	E-waste recycling workers in Longtang, Qingyuan city in Guangdong province, N=34 (19 males and 15 females)	hair	NR	100	23	NR	3.5	860	Chen et al., (2015)

Location	Subjects	Matrix	Collection year	Detection frequency, %	Median	Mean	Minimum	Maximum	Reference
China	E-waste dismantling workers, N=30	hair	NR	NR	NR	6.86	0.66	19.7	Zheng et al., (2010)
China	E-waste dismantling workers from an e-waste recycling site in South China, N=31, female, 20 to 50 years	hair	2015	100	10.6	31.0	0.47	203	Qiao et al., (2019)
***anti*-DP**									
China	Workers in DP manufacturing plant directly engaged in manufacturing, N=24	serum	2011	100	NR	471	90.6	1716	Zhang et al., (2013)
China	Workers in DP manufacturing plant not directly engaged in manufacturing of DP, N=12	serum	2011	100	NR	207	95.8	385	Zhang et al., (2013)
China	Occupationally exposed workers in e-waste recycling workshops in Longtang Town, Qingyuan County. N=70 (33 males and 37 females), age 20-59 years	serum	2011	100	103.6	NR	14.2	1640	Yan et al., (2012)
China	E-waste recycling workers in Longtang, Qingyuan city in Guangdong province, N=34 (19 males and 15 females)	serum	NR	100	120	NR	14	990	Chen et al., (2015)
China	Workers in DP manufacturing plant directly engaged in manufacturing, N=22	hair	2011	100	NR	158	82.3	1360	Zhang et al., (2013)
China	Workers in DP manufacturing plant not directly engaged in manufacturing of DP, N=11	hair	2011	100	NR	158	14.7	545	Zhang et al., (2013)

China	E-waste recycling workers in Longtang, Qingyuan city in Guangdong province, N=34 (19 males and 15 females)	hair	NR	100	24	NR	2.8	240	Chen et al., (2015)
China	E-waste dismantling workers, N=30	hair	NR	NR	NR	8.52	0.8	43.6	Zheng et al., (2010)
China	E-waste dismantling workers from an e-waste recycling site in South China, N=31, female, 20 to 50 years	hair	2015	100	12.1	30.2	1.17	157	Qiao et al. (2019)

B.9.4.1.3 Consumer exposure

In this section, exposure to DP have primarily been described as internal doses, which comprise all sources of exposure and exposure pathways. However, consumer exposure includes exposure from house dust and indoor air as well as dermal or oral contact with consumer products.

DP may leach from consumer products into house dust as well as both indoor and outdoor air. This means that ingestion of house dust and inhalation of air may be potential sources of exposure to DP. Furthermore, exposure can also occur through direct contact with consumer products such as electronics.

DP have been detected in dust from a wide range of microenvironments, including homes, offices, classrooms, kindergartens, cars and airplanes (Allen et al., 2013, Cao et al., 2014, Hassan and Shoeib, 2015, Lee et al., 2020, Shoeib et al., 2012). This demonstrates that exposure to DP from ingestion of dust is likely to occur. Both *syn*- and *anti*- DP were also detected in Norwegian house dust from homes (Cequier et al., 2014, Norwegian Environment Agency, 2021a, Norwegian Environmental Agency, 2017) and classrooms (Cequier et al., 2014).

Exposure to DP from inhalation of indoor air is also likely to occur, as DP have been found in indoor air in several countries (Cequier et al., 2014, Tao et al., 2016, Tay et al., 2017, Yadav et al., 2020).

Dermal exposure to DP may occur through direct contact with both consumer products and house dust. DP have been detected in hand-wipe samples, indicating possible dermal exposure (Liu et al., 2017, Tang et al., 2019). For more information on dermal uptake see B.5.1. Toxicokinetics (absorption, metabolism, distribution and elimination)

To summarise, DP are found in both house dust, indoor air and hand wipes, demonstrating that consumer exposure is likely to occur, but the relative importance of each exposure pathway is not yet clear.

B.9.4.1.4. Indirect exposure of humans via the environment

Indirect exposure via the environment includes exposure from food and beverages, drinking water and inhalation of outdoor air. As described above, exposure to DP have primarily been described as internal doses. Nevertheless, DP have been detected in food and beverages from several countries, such as for example Belgium, South Korea, Lebanon, Japan and Vietnam (Kakimoto et al., 2014, Kim et al., 2014, Malak et al., 2019, Poma et al., 2018, Tao et al., 2016). DP are also found in outdoor air, primarily bound to particles, and in water (AMAP, 2017).

In a review by Ma et al. (2021) it was concluded that diet was the dominant pathway of exposure to novel halogenated flame retardants, including DP, when considering both inhalation exposure, ingestion exposure and dermal exposure.

To summarise, DP are found in both food and beverages, outdoor air and water, demonstrating that indirect exposure of humans via the environment is likely to occur. There is limited knowledge on the relative importance of each exposure pathway, but there are indications that diet is the major exposure pathway, when taking into account both consumer exposure and indirect exposure of humans via the environment.

B.9.4.1.5. Combined human exposure assessment

B.9.4.1.5.1. General

The combined human exposure assessment considers exposure from all sources. This includes both sources of consumer exposure and indirect exposure of humans via the environment as described in section B.9.4.1.3 Consumer exposure. and B.9.4.1.4. Indirect exposure of humans via the environment., respectively.

In this section, exposure to DP have primarily been described as internal doses, which reflects an integrated exposure over time comprising various sources and pathways and may be assessed e.g. using biomonitoring data.

Dechlorane plus is categorised within REACH as very persistent in the environment and very bioaccumulative (ECHA, 2017a, ECHA, 2017d), and studies in human matrices (described in detail below) have demonstrated that DP can be measured unchanged in human matrices.

The technical DP mixture contains two stereoisomers, *syn*-DP and *anti*-DP of which approximately 25% is *syn*-DP and approx. 75% is *anti*-DP (Sverko et al., 2011). The two stereoisomers can be measured individually in human matrices (Ren et al., 2009). The relative fraction of the two isomers is commonly reported as fraction of *anti*-DP (*f-anti*). This corresponds to the fraction of *anti*-DP relative to the sum of *syn*-DP and *anti*- DP. The fraction of *anti*-DP in human samples can be compared to the fraction of *anti*-DP of the technical mixture, and this may give valuable information on potential selective bioaccumulation of one of the stereoisomers (see below for further information).

Some degradation products of DP such as decachloropentacyclooctadiene (DP-Cl_{10}) and undecachloropentacyclooctadiene (DP-Cl_{11}) have been detected in both wildlife (Guerra et al., 2011) and human samples (Ren et al., 2009). However, some studies suggest that these degradation products are formed through biotic or abiotic processes prior to uptake in both animals and humans, or that impurities in the commercial product exists (Sverko et al., 2010, Sverko et al., 2008, Tomy et al., 2008, Zheng et al., 2010, Zheng et al., 2014). Therefore, detection of DP-Cl_{10} and DP-Cl_{11} demonstrate presence of DP in the environment, but presently these degradation products cannot be used as exposure biomarkers of dechlorane plus.

Internal doses of persistent environmental contaminants are usually assessed by measuring levels in blood, breast milk or hair. As described in more detail below, all these matrices are suitable for assessing exposure to DP, but blood and in particular blood serum is the matrix which up to now have been most frequently used. As DP are lipophilic it is common practise to measure the lipid content in the samples and report DP concentrations in ng/g serum lipid in the samples.

B.9.4.1.5.2. Levels detected in different matrices

DP in human blood

In Table 62 below, an overview of studies presenting blood concentrations of DP in non-occupationally exposed adults and children worldwide are given. All the studies have investigated blood serum, except one study on plasma. Most studies are from China, but single studies from South Korea and Canada and some studies from Europe have been identified. In most studies DP were detected in more than 75% of the samples (see Table 62 below). However, the detection frequencies were in general lower in Europe and Canada as compared to China and South Korea, but detection frequencies can be highly impacted by detection limits in the various studies. For instance, in the study by (Kim et al., 2016) where the LOQ was 0.02 ng/g serum lipid the detection frequency was 91.8% while in the study by Tay et al. (2019) where the LOQ was 0.8 ng/g serum lipid the detection frequency was 3%.

As can be seen from Table 62, measured concentrations of DP in non-occupationally exposed individuals vary a lot among the available studies, with concentrations ranging from <LOQ to 1000 and 1450 ng/g serum lipid for *syn*-DP and *anti*-DP, respectively. The highest max concentrations were reported in serum samples from men and women in China living in a town with e-waste dismantling activities (n=54). Note that the studies did not report whether the women were involved in e-waste activities. The highest central estimates (mean/median concentration) were observed in the study by Guo et al. (2019) and a study by Zhang et al 2013 with mean concentrations of 124 and 207 ng/g serum lipid for *syn*-DP and *anti*-DP, respectively. Central estimates above 10 ng/g serum lipid were also reported in studies by Ben et al. (2013), Ben et al. (2014), Guo et al. (2020), Ren et al. (2009). In all these studies, the participants were living in e-waste dismantling regions or close to a production facility in China. In the remaining studies both from China, South Korea, Canada and Europe the central estimates were below 9 ng/g serum lipid for both *syn*-DP and *anti*-DP.

Summarised, this demonstrates ubiquitous exposure to DP world-wide, despite the fact that no production of DP occurs in most countries. Furthermore, elevated concentrations of DP are observed in non-occupationally exposed individuals, in particular when residing in areas where DP are manufactured or where e-waste is handled.

Time trends

To explore potential changes in exposure to DP over time, a 180 samples of archived blood plasma samples from the German Environmental Specimen Bank, collected at six time points between 1995 and 2017, were assessed, but no clear time trends were observed (Fromme et al., 2020), Similar results were also observed in serum samples from the Shandong Province, China collected during 2011-2015 (Ma et al., 2017) and from South Korea collected during 2006-2013 (Kim et al., 2016)

Thus, available studies indicate a relatively similar exposure to DP during the last two decades.

Age and gender differences

Most studies so far comprise adults, however a study by Guo et al. (2018) assessed fifth grade students (average age= 10 years) from two schools near a petrochemical complex in South China. DP were detected in almost all samples and in concentrations similar to other studies from China where participants were not living in e-waste dismantling regions or close to a production facility in China. In contrast, in a study comprising toddlers (age 15 months) from Sweden, only one sample had DP concentrations above LOQ (Sahlström et al., 2014). However, also only one of the samples of mothers of these toddlers had DP concentrations above LOQ. This implies that the low detection frequency in the toddlers in the Swedish is not necessarily in contrast to high detection frequencies in older age groups in other studies. In a study by He et al. (2013), ten pooled samples based on 305 samples collected from volunteers at a hospital from the south coast of Laizhou Bay, China, with participants in the range 20–84 years were analysed. No consistent age trend was observed between DP concentrations in the serum samples and age of the participants. Similarly, no relationships between age of participants and DP concentrations were observed in a study by (Ma et al., 2017), where 20 pools comprising 942 adults were assessed. As DP have been shown to bioaccumulate in humans occupationally exposed to DP, it can be expected that DP concentrations increase with increasing age. However, as age trends so far have been assessed in adults which likely have experienced exposure to DP for an equal amount of time, the findings from the abovementioned studies are not very well suited to assess age trends. In the aforementioned studies by He et al. (2013) and (Ma et al., 2017) no differences between genders were observed. Also, in a study on German healthy blood donors no gender differences were reported (Fromme et al., 2015). In contrast, in a study on Chinese e-waste recycling workers, significantly higher concentrations of both *syn*-DP and *anti*-DP were observed in females as compared to males (Yan et al 2012).

Thus, at present there is too little knowledge to conclude on the relationships between DP concentrations in blood and gender or age of participants.

Correlations and ratios between DP stereoisomers

As expected, high correlations between concentrations of the two stereoisomers *syn*-DP and *anti*-DP have been observed in both background exposed individuals (Brasseur et al., 2014, Cequier et al., 2015, Kim et al., 2016, Zhou et al., 2014) and in occupationally exposed populations (Ren et al., 2009).

Thus, high correlations between *syn*-DP and *anti*-DP strongly indicate co-exposure to both isomers.

DP are present in adipose tissue

In a study by Yin et al. (2020) paired samples (n=64) of abdominal subcutaneous adipose tissue and serum samples from the same pregnant women living in Wenling, China were collected in 2011. Both *syn*-DP and *anti*- DP were detected in 100% of the adipose tissue samples, and in 95% and 100% of the serum samples, respectively. On wet weight basis, the concentrations in adipose tissues were around 30-times higher than the ones in serum, while on a lipid weight basis the concentrations in adipose tissue were around one third of the ones in serum. High correlations between concentrations in serum and adipose tissue were observed both on a lipid weight basis and on a wet weight basis. The authors furthermore included data on paired samples of serum and breast milk from Ben et al 2013 Ben et al. (2013) and paired samples of maternal serum, placenta and cord serum from (Ben et al., 2014) and found a high correlation between tissue concentrations and lipid contents in the tissues.

To summarise, DP are present in adipose tissue, and both the tissue lipid content and type of organ have an influence on the DP tissue distribution.

DP can be measured in hair

Zhang et al. (2013) assessed DP in matched samples of serum and hair from both workers directly involved in DP manufacturing, workers not directly involved in DP manufacturing and from persons not working in a manufacturing plant and living approx. 3 km from manufacturing plant. Significant and relatively strong correlations between serum and hair concentrations were observed.

Similarly, Chen et al. (2015) measured DP in 34 matched human hair and serum samples (19 males and 15 females) collected from e-waste recycling workers in China. A moderate positive correlation between hair and serum was observed for the sum of *syn*-DP and *anti*-DP ($r = 0.42$, $p = 0.01$), with a stronger correlation for *syn*-DP ($r = 0.48$, $p < 0.01$) compared to *anti*-DP ($r = 0.36$, $p = 0.03$. However, the correlation was only significant for men. This indicates that concentrations in hair cannot necessarily be extrapolated to serum concentrations. A sharp gender difference was found in the levels of DP in hair, with more than 10 times higher DP levels in hair from females than in hair from males. The authors speculate if this in part may be due to the much longer external exposure time for female hair than for male hair as male hair in general was cut closer to the the scalp than female hair.

In Table 63 studies reporting concentrations of *syn*-DP and *anti*-DP in samples of hair from occupationally exposed and non-occupationally exposed adults are presented.

Taken together, data on human hair support data on other human samples including blood, and clearly demonstrate human exposure to DP. However, more information is needed to extrapolate data from hair to blood.

B.9.4.1.5.3. Levels in children and toddlers

Children are exposed to DP in utero through transplacental transfer

The foetus may be exposed to DP through trans-placental transfer. In a study from Taizhou, Zhejiang Province, China, (Ben et al., 2014) collected paired samples of maternal blood, placenta and cord blood from 72 women. The samples were collected in 2010-2011. Two groups of women were recruited; 1) women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations (n= 48) and 2) women that have been living in the same region for less than three years, did not live in an area with recycling villages and did participate in any e-waste recycling activities (n=24). The maternal blood samples were partly the same as in (Ben et al., 2013). Both *syn*-DP and *anti*-DP were observed in all cord blood samples, demonstrating prenatal exposure DP. The median cord serum: maternal serum concentrations -were estimated to be 0.45 for *syn*-DP and 0.35 for *anti*-DP, while the ratio median placenta: maternal serum concentrations were 0.27 and 0.30 for *syn*-DP and *anti*-DP, respectively. These ratios demonstrate that DP are partially retained in the placenta and partially transferred to the foetus. The findings indicate that *anti*-DP *is* retained to a somewhat larger extent in the placenta than *syn-DP, while syn*-DP is transferred more efficiently to the foetus than *anti*-DP. Furthermore, for *syn*-DP the extent of placental transfer was relatively larger than the extent of placental retention, whereas for *anti*-DP both were more similar. The authors found strong correlations between DP concentrations in maternal serum, placenta, and cord serum, demonstrating that children of women with high exposure to DP will experience high prenatal exposure to DP.

To summarise, both *syn*-DP and *anti*-DP were observed in all cord blood samples, demonstrating prenatal exposure to DP. DP are partially retained in the placenta and partially transferred to the foetus. Further, strong correlations between DP concentrations in maternal serum, placenta, and cord serum demonstrate that children of women with high exposure to DP will experience high prenatal exposure to DP.

Newborns and toddlers are exposed to DP through breast milk

Breast milk is an easy to obtain, non-invasive medium for biomonitoring and any contamination of this medium is of great concern as this contamination is directly passed on to the next generation.

In a study from Taizhou, Zhejiang Province, China, (Ben et al., 2013) measured concentrations of DP in paired samples of serum and breast milk from the same women (breast milk; n=44, serum; n= 45; paired samples; n=40). Serum samples were collected at delivery while breast milk samples were collected 2-7 days after birth. The samples were collected in 2010-2011.Two groups of women were recruited; 1) women that had been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations (n= 33) and 2) women that have been living in the same region for less than three years, did not live in an area with recycling villages and did not participate in any e-waste recycling activities (n=16). The authors found that both *syn*-DP and *anti*-DP were present in all samples of serum and breast milk, demonstrating human exposure and postnatal transfer through breast milk for breast fed infants. The serum and breast milk concentrations were 2-3 fold higher in samples from women living for a long period of time in the area heavily involved in e-waste recycling as compared to the women not living close to such facilities**.** This demonstrates that e-waste recycling activities can contribute to elevated exposure to DP. Furthermore, the median breast milk/serum ratios on a lipid weight basis were 0.41 (range 0.07-2.25) for *syn*-DP and 0.44 (range 0.09-2.22) for *anti*-DP.

Zhou et al. (2014) analysed DP in 102 human serum and 105 breast milk samples (100 serum samples were paired with milk samples) collected between 2007 and 2009 in Québec, Canada. The serum samples were collected at delivery while breast milk was collected and frozen by the mothers at home. Unfortunately, the date of the breast milk collection was not recorded, but the samples were brought to the laboratory between 3 and 5 months after delivery. The detection frequency in serum was 77% and 87% for *syn*-DP and *anti*-DP, respectively. In breast milk *syn*-DP was detected in 40% of the samples and *anti*-DP in 50% of the samples. The authors found no correlation between DP in breastmilk and serum, which they explain may be due to the potential long time between serum and breast milk collection. Due to the lack of correlation, the authors concluded that they were not able to assess breast milk/serum ratios.

In a study including 54 women from Wenling, China matched breast milk and adipose tissue samples were assessed (Pan et al., 2020). Statistically significant associations between DP levels (lipid adjusted) in adipose tissue and breast milk were observed. The milk/adipose tissue ratio was 1.4 and 1.3 for *syn*-DP and *anti*-DP, respectively, pointing to a preferable distribution to milk lipids.

In Table 64 studies reporting concentrations of *syn*-DP and *anti*-DP in samples of breast milk from non-occupationally exposed adults are presented. The mean DP concentrations in breast milk from Chinese women that have been living >20 years in villages heavily involved in e-waste recycling (*syn*-DP: 10.4 ng/g serum lipid and *anti*-DP: 27.4 ng/g serum lipid) were considerably higher than those in samples from Chinese women that did not live in an area with recycling villages (*syn*-DP: 0.62 ng/g serum lipid and *anti*-DP: 2.06 ng/g serum lipid) and from women from Canada (*syn*-DP: 0.26-0.28 ng/g serum lipid and *anti*-DP: 0.66-0.78 ng/g serum lipid) and Europe (*syn*-DP: 0.111-0.355 ng/g serum lipid and *anti*-DP: 0.055-0.155 ng/g serum lipid).

Taken together, data on breast milk support data on blood, and clearly demonstrate postnatal exposure to DP through breastfeeding. Furthermore, similarly as for blood, elevated concentrations of DP in breast milk are observed in non-occupationally exposed individuals, in particular when residing in areas where DP are manufactured or where e-waste is handled. More information is needed on the ratio between breast milk and blood concentrations in order to be able to extrapolate data on blood to breast milk and vice versa.

B.9.4.1.5.4. Relative fraction of the two DP isomers in human samples

As mentioned above, several studies have assessed the relative fraction of the two isomers in human samples. In blood serum, Zhang et al., 2013, He et al. (2013) and Yan et al., 2012 reported fractions of *anti*-DP that in general were lower than those of the technical mixtures, while for instance (Brasseur et al., 2014) and Zhou et al., 2014 observed fractions in serum within the range of what has been reported for the technical mixtures. Thus, it is not entirely clear whether the fraction of *anti*-DP in serum deviates from that of the technical mixtures. Yin et al., 2020 reported fractions of *anti*-DP in adipose similar to those in commercial DP products, indicating no steroselective accumulation in adipose tissue. In a study on paired samples of human hair and serum, Chen et al., 2015 reported fractions of *anti*-DP that were significantly lower in human hair than in serum, indicating possible stereoselective accumulation in hair. (Ben et al., 2014), reported fractions of *anti*-DP in placenta and cord serum samples which were significantly different from those in the maternal serum, suggesting that DP are retained stereoselectively in the placenta and transferred stereoselectively to the foetus. (Ben et al., 2013) and Zhou et al (2014) measured concentrations of DP in breast milk, and the fractions of *anti*-DP in were similar to those in commercial DP products, indicating no stereoselective accumulation in breast milk. Furthermore, (Pan et al., 2020) found that the fraction of *anti*-DP in breast milk and adipose tissue was not significantly different, pointing to a non-stereoselective transfer between milk lipids and adipose tissue lipids.

Taken together, to little data is available to conclude on whether or not stereoselective accumulation of DP isomers occur in human samples.

Table 62 Overview of studies presenting blood concentrations of DP-syn and DP-anti in adults and children worldwide (ng/g serum lipids) (no known occupational exposure

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
***Syn*-DP**									
France	Volunteers living in the area of a municipal solid waste incinerator in Besançon, N=48, (24 males and 24 females) Mean age 57 years (range 28-86)	serum	2003-2005	75	0.22	0.34	<LOD (0.08)	2.30	Brasseur et al. (2014)
Germany	Healthy blood donors living in Munich and the surrounding areas. N= 42 (21 females and 21 males), median: 46 years	plasma	2013-2014	79	0.77	2.33	<LOQ (NR)	29.8	Fromme et al. (2015)
Norway	Women from a Norwegian mother–child cohort, N=48	serum	2012	78	0.45	0.77	<LOQ (NR)	6.7	Cequier et al (2015)
Norway	Adults living in the Oslo area, N=61 (16 males and 45 females), age: 20–66	serum	2013-2014	3	<LOD (0.80)	2.1*	<LOD (0.80)	15	Tay et al (2019)
Sweden	Samples from mothers in the Uppsala county, N=24, mean age 29.9 years	serum	2010-2012	4.2	<LOD (NR)	NR	<LOD (NR)	39	Sahlström et al. (2014)
Sweden	Samples from toddlers in the Uppsala county, N=24, age 15 months	serum	2010-2012	4.2	<LOD (NR)	NR	<LOD (NR)	63	Sahlström et al. (2014)
Canada	Pregnant women from Québec, N=102, average age 29.5 years	serum	2007-2009	77	0.49	NR	<LOD (0.04)	15	Zhou et al (2014)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
South Korea	Volunteers that participated in the Health Assessment Study of Seoul Citizen Seoul, N=61 (7 males and 54 females), mean age=54.2 years	serum	2013	91.8	0.21	0.21	<LOQ (0.02)	0.86	Kim et al. (2016)
China	residents from an e-waste dismantling region, Guiyu town, Shantou City, Guangdong Province, where 80% of families are active in e-waste dismantling, N=20	serum	2005	100	17.1	16.2	2.7	236	Ren et al. (2009)
China	residents of Haojiang district, Shantou City, Guangdong Province, N=20, 23-67 years, 27% females	serum	2005	100	5.1	4.3	0.35	17.6	Ren et al. (2009)
China	Pregnant women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations, N= 33, 64% < 30 years	serum	2010-2011	100	2.79	25.4	0.56	278	Ben et al. (2013)
China	Pregnant women that did not live in an area with recycling villages and did not participate in any e-waste recycling activities, N=16 , 40% < 30 years	serum	2010-2011	100	0.96	1.29	0.37	3.18	Ben et al. (2013)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
China	Pregnant women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations, N= 48, mean age 27.2 years	serum	2010-2011	100	2.40	18.5	0.395	278	Ben et al. (2014)
China	Pregnant women that did not live in an area with recycling villages and did not participate in any e-waste recycling activities, N=24, mean age 26.9 years	serum	2010-2011	100	0.82	1.07	0.350	3.18	Ben et al. (2014)
China	Not working in a manufacturing plant and living approx. 3 km from manufacturing plant, N=12	serum	2011	100	NR	106	47.6	252	Zhang et al (2013)
China	No occupational exposure. living in Guangzhou City, N=13 (7 males and 6 females), age 24-46 years	serum	2011	23	<LOQ (3.08)	NR	<LOQ (3.08)	36.3	Yan et al (2012)
China	Ten pooled samples based on 305 samples collected from volunteers at a hospital from the south coast of Laizhou Bay, 20–84 years	serum	2011	100	NR	2.5	0.75	9.2	He et al. (2013)
China	Healthy pregnant women residing in Wenling for more than 5 years, without	serum	2011	95	1.00	5.42	<LOQ (NR)	167	Yin et al (2020)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
	professional history on e-waste recycling operation, N=64,								
China	Volunteer participants in Sun Yat-sen University located in Guangzhou. The participants included 26 males and 17 females (21–25 years old)	serum	2014	0	< LOQ (5.14)	NR	NR	NR	Qiao et al. (2018)
China	Ten pooled samples based on 490 samples from residents of Weifang City, Shandong Province	serum	2014	100	NR	0.65	0.41	1.0	Ma et al. (2017)
China	Ten pooled samples based on 452samples from residents of Weifang City, Shandong Province	serum	2015	100	NR	0.86	0.38	1.4	Ma et al. (2017)
China	Fifth grade students from two schools near a petrochemical complex in South China. N=174, average age= 10 years	serum	2015	95	4.9	5.8	<LOQ (0.66-2.1)	40	Guo et al. (2018)
China	town with e-waste dismantling activities, N=54 (26 male, 28 female), 25-75 years	serum	2016	100	57	124	12	1000	Guo et al. (2019)
China	town without e-waste dismantling activities, N=58 (25 male, 33 female), 25-75 years	serum	2016	100	3.2	4.2	0.36	12	Guo et al. (2019)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
China	town with e-waste dismantling activities, sixth grade students, N=57 (27 male, 30 female)	serum	2016	100	19	38	2.6	230	Guo et al. (2020)
China	town without e-waste dismantling activities, sixth grade students, N=57 (18 male, 39 female)	serum	2016	100	6.1	8.9	0.90	54	Guo et al. (2020)
***Anti*-DP**									
France	Volunteers living in the area of a municipal solid waste incinerator in Besançon, N=48, (24 males and 24 females) Mean age 57 years (range 28-86),	serum	2003-2005	94	0.89	1.2	<LOD (0.16)	5.09	Brasseur et al. (2014)
Germany	Healthy blood donors living in Munich and the surrounding areas. N= 42 (21 females and 21 males), median: 46 years	plasma	2013-2014	93	1.23	2.11	<LOQ (NR)	21.2	Fromme et al. (2015)
Norway	Women from a Norwegian mother–child cohort, N=48	serum	2012	89	0,85	1.8	<LOQ (NR)	25	Cequier et al (2015)
Norway	Adults living in the Oslo area, N=61 (16 males and 45 females), age: 20–66	serum	2013-2014	3	<LOD (2.1)	5.3*	<LOD (2.1)	41	Tay et al (2019)
Sweden	Samples from mothers in the Uppsala county, N=24, mean age 29.9 years	serum	2010-2012	4.2	<LOD (NR)	NR	<LOD (NR)	49	Sahlström et al. (2014)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
Sweden	Samples from toddlers in the Uppsala county, N=24, age 15 months	serum	2010-2012	4.2	<LOD (NR)	NR	<LOD (NR)	85	Sahlström et al. (2014)
Canada	Pregnant women from Québec, N=102, average age 29.5 years	serum	2007-2009	87	1.9	NR	<LOD (0.12)	67	Zhou et al (2014)
South Korea	Volunteers that participated in the Health Assessment Study of Seoul Citizen Seoul, N=61 (7 males and 54 females), mean age=54.2 years	serum	2013	91.8	0.58	0.52	0.10	1.31	Kim et al. (2016)
China	residents from an e-waste dismantling region, Guiyu town, Shantou City, Guangdong Province, where 80% of families are active in e-waste dismantling, N=20	serum	2005	100	21.2	22.5	5.1	229	Ren et al (2009)
China	residents of Haojiang district, Shantou City, Guangdong Province, N=20, 23-67 years, 27% females	serum	2005	100	8.6	7.5	0.54	32.9	Ren et al (2009)
China	Pregnant women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations, N= 33, 64% < 30 years	serum	2010-2011	100	5.95	46.1	1.24	656	Ben et al. (2013)

Location	Subjects	Matrix	Collection year	Detection frequency, %	Median	Mean*	Minimum	Maximum	Reference
China	Pregnant women that did not live in an area with recycling villages and did not participate in any e-waste recycling activities, N=16, 40% < 30 years	serum	2010-2011	100	2.71	3.55	1.44	8.54	Ben et al. (2013)
China	Pregnant women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations, N= 48, mean age 27.2 years	serum	2010-2011	100	6.16	35.4	0.861	655	Ben et al. (2014)
China	Pregnant women that did not live in an area with recycling villages and did not participate in any e-waste recycling activities, N=24, mean age 26.9 years	serum	2010-2011	100	2.83	3.12	1.26	8.54	Ben et al. (2014)
China	Not working in a manufacturing plant and living approx. 3 km from manufacturing plant, N=12	serum	2011	100	NR	207	42.2	339	Zhang et al (2013)
China	No occupational exposure, living in Guangzhou City, N=13 (7s male and 6 females), age 24-46 years	serum	2011	100	4.63	NR	2.66	54.9	Yan et al (2012)
China	Tenpooled samples based on 305 serum samples collected from volunteers at	serum	2011	100	NR	1.0	0.62	2.0	He et al. (2013)

Location	Subjects	Matrix	Collection year	Detection frequency, %	Median	Mean*	Minimum	Maximum	Reference
	a hospital from the south coast of Laizhou Bay, 20–84 years								
China	Healthy pregnant women residing in Wenling for more than 5 years, without professional history on e-waste recycling operation, N=64,	serum	2011	100	2.96	8.48	0.410	82.4	Yin et al (2020)
China	Volunteer participants in Sun Yat-sen University located in Guangzhou. The participants included 26 males and 17 females (21–25 years old)	serum	2014	23.3	< LOQ (0.37)	NR	NR	NR	Qiao et al., (2018)
China	Ten pooled samples based on 490 samples from residents of Weifang City, Shandong Province	serum	2014	100	NR	1.5	1.1	2.2	Ma et al. (2017)
China	Ten pooled samples based on 452 samples from residents of Weifang City, Shandong Province	serum	2015	100	NR	2.2	1.4	3.5	Ma et al. (2017)
China	Fifth grade students from two schools near a petrochemical complex in South China. N=174, average age= 10 years	serum	2015	100	7.4	8.7	1.2	7.4	Guo et al. (2018)
China	town with e-waste dismantling activities, N=54	serum	2016	100	58	131	11	1450	Guo et al. (2019)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
	(26 male, 28 female), 25-75 years								
China	town without e-waste dismantling activities, N=58 (25 male, 33 female), 25-75 years	serum	2016	100	5.9	7.2	0.67	38	Guo et al. (2019)
China	town with e-waste dismantling activities, sixth grade students, N=57 (27 male, 30 female)	serum	2016	100	27	48	2.7	270	Guo et al. (2020)
China	town without e-waste dismantling activities, sixth grade students, N=57 (18 male, 39 female)	serum	2016	100	5.6	7.7	0.72	49	Guo et al., (2019)

** Geometric mean*

NR: not reported

Table 63: Overview of studies presenting hair concentrations of DP-syn and DP-anti in adults and children worldwide (ng/g dry weight) (no known occupational exposure)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
***syn*-DP**									
China	Not working in a manufacturing plant and living approx. 3 km from manufacturing plant, N=12,	hair	2011	100	NR	28.5	1.88	142	Zhang et al (2013)
China	Non-occupationally exposed residents in an e-waste area, N=82	hair	NR	NR	NR	2.48	0.06	11.4	Zheng et al (2010)
China	Residents living Yuangtan Town, a rural area, N=32	hair	NR	NR	NR	0.19	0.02	1.1	Zheng et al (2010)
China	Residents in Guangzhou City, the largest urban center in South China, N=29	hair	NR	NR	NR	0.24	0.002	1.1	Zheng et al (2010)
China	Students of the Minzu University of China, Beijing, N=24 females	hair	NR	91.7	NR	0.181	<LOD (NR)	0.966	Chen et al. (2019)
China	Students of the Minzu University of China, Beijing, N=24 males	hair	NR	70.8	NR	0.0783	<LOD (NR)	0.360	Chen et al (2019)
***anti*-DP**									
China	Not working in a manufacturing plant and living approx. 3 km from manufacturing plant, N=12	hair	2011	100	NR	53.3	2.20	213	Zhang et al (2013)
China	Non-occupationally exposed residents in an e-waste area, N=82	hair	NR	NR	NR	3.6	0.13	25.4	Zheng et al (2010)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean***	**Minimum**	**Maximum**	**Reference**
China	Residents living Yuangtan Town, a rural area, N=32	hair	NR	NR	NR	0.84	0.07	7.28	Zheng et al (2010)
China	Residents in Guangzhou City, the largest urban center in South China, N=29	hair	NR	NR	NR	0.65	0.01	3.91	Zheng et al (2010)
China	Students of the Minzu University of China, Beijing, N=24 females	hair	NR	91.7	NR	0.604	<LOD (NR)	3.33	Chen et al (2019)
China	Students of the Minzu University of China, Beijing, N=24 males	hair	NR	75	NR	0.220	<LOD (NR)	1.11	Chen et al (2019)

Table 64: Overview of studies presenting breast milk concentrations of DP-syn and DP-anti in women worldwide (ng/g breast milk lipids) (no known occupational exposure)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean**	**Minimum**	**Maximum**	**Reference**
***syn*-DP**									
Norway	Women, N=305	Breast milk	2003-2006	7	<LOQ	0.355	<LOQ	0.560 (95 percentile)	Čechova et al (2017)
The Netherlands	Women, N=116	Breast milk	2011-2014	9	<LOQ	0.278	<LOQ	0.848 (95 percentile)	Čechova et al (2017)
Slovakia	Women, N=37	Breast milk	2011-2012	3	<LOQ	0.111	<LOQ	NR	Čechova et al (2017)
Canada	Women from Kingston, N=39	Breast milk	2003–2004	74	0.23	0.26	<LOQ (NR)	1.6	Siddique et al (2012)
Canada	Women from Québec, N=105, average age 29.5 years	Breast milk	2007-2009	40	<LOQ (NR)	NR	<LOQ (NR)	3.0	Zhou et al (2014)

Location	**Subjects**	**Matrix**	**Collection year**	**Detection frequency, %**	**Median**	**Mean**	**Minimum**	**Maximum**	**Reference**
Canada	Women from Sherbrooke, N=48	Breast milk	2008–2009	77	0.17	0.28	<LOQ (NR)	3.0	Siddique et al (2012)
China	Pregnant women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations, N= 33, 64% < 30 years	Breast milk	2010-2011	100	1.33	10.4	0.290	139.2	Ben et al. (2013)
China	Pregnant women that did not live in an area with recycling villages and did not participate in any e-waste recycling activities, N=15, 40% < 30 years	Breast milk	2010-2011	100	0.500	0.620	0.150	1.68	Ben et al. (2013)
***anti*-DP**									
Norway	Women, N=305	Breast milk	2003-2006	26	<LOQ	0.055	<LOQ	0.180 (95 percentile)	Čechova et al (2017)
The Netherlands	Women, N=116	Breast milk	2011-2014	20	<LOQ	0.155	<LOQ	0.491 (95 percentile)	Čechova et al (2017)
Slovakia	Women, N=37	Breast milk	2011-2012	24	<LOQ	0.057	<LOQ	0.128 (95 percentile)	Čechova et al (2017)
Canada	Women from Kingston, N=39	Breast milk	2003–2004	85	0.49	0.78	<LOQ (NR)	6.3	Siddique et al (2012)
Canada	Pregnant women from Québec, N=105, average age 29.5 years	Breast milk	2007-2009	50	0.02	NR	<LOQ (NR)	12	Zhou et al (2014)
Canada	Women from Sherbrooke, N=48	Breast milk	2008–2009	96	0.41	0.66	<LOQ (NR)	7.1	Siddique et al (2012)

Location	Subjects	Matrix	Collection year	Detection frequency, %	Median	Mean	Minimum	Maximum	Reference
China	Pregnant women that have been living >20 years in villages heavily involved in e-waste recycling but did not directly participate in e-waste recycling operations, N= 33, 64% < 30 years	Breast milk	2010-2011	100	3.32	27.4	0.710	451	Ben et al. (2013)
China	Pregnant women that did not live in an area with recycling villages and did not participate in any e-waste recycling activities, N=15, 40% < 30 years	Breast milk	2010-2011	100	1.58	2.06	0.640	6.81	Ben et al. (2013)

B.9.4.2. Environmental monitoring data

Monitoring results from Europe and the rest of the world 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, see Table 119 to Table 124 in Appendix 1 for details.

The draft POPs risk profile for DP has the following description of environmental monitoring results POPRC (2021b):

"84. DP is globally distributed and is detected worldwide in many different environmental matrices and biota, and at different types of locations spanning from production sites and recycling facilities to urban, rural and remote areas (de la Torre et al., 2010; Sverko et al., 2011; Wang et al., 2016; Saini et al., 2020; Zafar et al., 2020; Schuster et al, 2021). Elevated DP levels are reported in source areas (e.g. Saini et al., 2020; Schuster et al, 2021,) and are higher in urban centres compared to rural, agricultural and remote sites (Syed et al., 2020; Schuster et al. 2021) and also differ between cities globally (Saini et al., 2020). As described also in section 2.2.3 above, Schuster et al. (2021) report that the median value at urban sites (~0.9 pg/m3) was approximately 10 times greater than at background, rural, and agricultural sites. Similar findings were reported by de la Torre et al. (2009) who found that DP levels from urban locations in Spain were 15 times higher than those found at remote sites, suggesting urban zones as important sources of DP to the environment.

(...)

154. DP is emitted into the environment from human activities, e.g. from manufacturing, use and disposal and management of waste. DP is persistent, bioaccumulative and undergoes LRET, making emissions and releases of this substance a transboundary pollution problem. Globally, DP is detected in humans, wildlife and environmental samples in all global regions, including in the Arctic and Antarctic."

B.9.4.2.1. Biota

Several recent studies have shown DP and its analogues in terrestrial and marine biota, including birds, reindeer, seals, cetaceans and polar bears. The draft POPs risk profile has the following description of findings of DP in biota (POPRC, 2021b):

"80. DP has been detected in muscle, guano, eggs, plasma, preen oil and feathers in different species of birds around the world (Gauthier and Letcher 2009; Guerra et al., 2011; Munoz-Arnanz et al., 2011; 2012; Baron et al., 2014b; 2015; Jin et al. 2016; Vorkamp et al., 2018; Løseth et al., 2019; Briels et al., 2019; Mo et al., 2019; Desjardins et al., 2019; Zhu et al., 2020), including in migratory birds and eggs of migratory birds (e.g. Zhu et al., 2020 Vorkamp et al., 2018;). Vorkamp et al. (2018) detected DP in eggs of Greenland peregrine falcons which migrate from the Caribbean and South America to the Arctic for the summer. The DP detected in these eggs could reflect exposure experienced at the wintering and breeding grounds, as well as during migration.

81. Birds have previously been identified as biovectors for the transport and deposition of POPs to ecosystems in remote regions through deposition of guano, feather loss and decaying carcasses (Evenset et al., 2007; Blais et al., 2005) and may represent an additional transport *pathway for DP to remote regions. In Ellasjøen at Svalbard, seabird guano was, based on measurements of PCB, found to account for approximately 14% of the contaminant inventory of the lake catchment area, approximately 80% of the contaminant inventory of the lake itself and was suggested to be approximately thirty times more efficient as a contaminant transport pathway compared to atmospheric LRET (Evenset et al., 2007).*

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90. In a study of halogenated FRs in eels from five Latvian lakes, nine dechlorane-related compounds (i.e. mirex, syn-DP, anti-DP, Dec 602, Dec 603, Dec 604, hexachlorocyclopentadienyldibromocyclooctane, Cl10DP and Cl11DP) were analyzed. The mean total concentration of dechlorane-related compounds was 0.62 ng/g lw and the geographical distribution was nearly uniform among the five lakes (Zacs et al. 2018). The concentrations of syn- and anti-DP ranged from non-detect to 0.45 ng/g lw, and from non-detect to 0.89 ng/g lw, respectively, with average concentrations of 0.14 ng/g lw, and 0.24 ng/g lw, respectively. The contribution of anti-DP to the total concentration of dechlorane-related compounds was approximately 33%, while syn-DP accounted for approximately 10% on average. The composition of mixtures containing syn- and anti- DP showed an fanti value that was close to the composition of the OxyChem® DP commercial product, indicating the release of DP from disposal of consumer products as the probable source. In another study from Baltic region, de Wit et al. (2020) widely detected DP in Baltic biota, with high levels in some birds (particularly eider). In this study a suite of chemicals of emerging concern, including DP, were analysed in blue mussel, viviparous eelpout, Atlantic herring, grey seal, harbor seal, harbor porpoise, common eider, common guillemot and white-tailed eagle from the Baltic Proper, sampled between 2006 and 2016. Both DP isomers were found in all species. Mean reported syn- and anti-DP levels were highest in common eider liver (16 and 52 ng/g lw, respectively). Mean reported syn- and anti-DP levels were also high in grey seal blubber (6.0 and 26 ng/g lw, respectively) and white-tailed eagle (3.7 and 7.8 ng/g lw, respectively). Lower means were found in herring muscle (0.035 and 0.070 ng/g lw for syn- and anti-DP), harbor seal blubber (046 and 0.092 ng/g lw for syn- and anti-DP), harbor porpoise (0.04 and 0.074 ng/g lw for syn- and anti-DP), eider eggs (0.10 and 0.21 ng/g lw for syn- and anti-DP) and guillemot eggs (0.13 and 0.40 ng/g lw for syn- and anti-DP). The lowest levels were found in blue mussel and viviparous eelpout with reported syn- and anti-DP means of <0.18-<0.21 and <0.14 and 0.16 ng/g lw.

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93. In a Norwegian screening assessment of emerging Arctic contaminants, DP was detected in all species monitored. The detection frequency within the species tested was 100%, except in common eiders where it was 80% (Norwegian Environment Agency, 2018a). Syn- and anti-DP concentrations in organisms from Svalbard were in the range from non-detect to 6.9 ng/g ww with reported average values of 0.04 and 0.07 ng/g ww for common eider (eggs), 0.01 and 0.03 ng/g ww for kittiwakes (eggs), 0.24 and 1.8 ng/g ww for glaucous gull (eggs), 0.63 and 4.5 ng/g ww for polar bear (blood). Moreover, DP was also detected in European shag (eggs) from Røst, in mink (liver) from Sommarøy and in common gulls from Tromsø. Reported syn-and anti-DP levels in these species were 0.22 and 1.4 ng/g ww in European shag, 0.21 and 1.2 ng/g ww in mink, and 0.1 and 0.63 ng/g ww in common gulls, respectively. In another study conducted for the Norwegian Environment Agency, DP levels were below the limit of *quantification in cod livers from Arctic sites at Svalbard and Kjøfjord in the Outer Varangerfjord and the Tromsø harbour area (Green et al., 2019). In contrast, reported syn- and anti-DP in cod livers from the Bergen harbour area, a non-Arctic site on the west coast of Norway, were 0.178 and 0.203 µg/kg ww. Syn- and anti-DP levels in cod livers from the Inner-Oslofjord in Southern Norway were 0.135 and 0.231 µg/kg ww, respectively.*

94. In the previously mentioned report by Vorkamp et al. (2019a) on DP in air and biota from Greenland, anti-DP isomer was detected in 92% of all air samples from 2014 to 2016 and in 46% of the air samples collected in 2014. As already indicated above in section 2.2.3, the mean reported concentrations in air in this study were 4.2 pg/m3 and 0.64 pg/m3 for the period 2014 to 2016 and for 2014, respectively. Except for glaucous gull, DP levels were close to or below limits of quantification in biota samples. Neither of the two DP isomers were found in ringed seal samples from Thule. In ringed seals from East-Greenland, Arctic char and narwhals, only the anti-DP isomer was present. Syn- and anti-DP were both detected in 100% of all glaucous gull samples from Thule at mean concentrations of 0.22 and 0.89 ng/g lw (0.012 and 0.049 ng/g ww), respectively. Detection frequencies for syn- and anti-DP in glaucous gull samples from East-Greenland were 87.5 and 100%, with mean concentrations of 0.24 and 0.93 ng/g lw for syn- and anti-DP. A geographical comparison based on samples of glaucous gull and ringed seal showed relatively uniform DP levels. The DP levels measured in this study were generally comparable to concentrations reported for some of the same species (e.g. ringed seals, glaucous gull and Arctic char) from other locations in the Arctic. However, DP concentrations in glaucous gull liver samples from Greenland reported in this study were a factor of 5-10 lower than in corresponding samples from the Canadian Arctic (Verreault et al., 2018). In the study from the Canadian Arctic, syn- and anti-DP were detected in 65% and 59% of male liver samples from 2012, respectively (Verreault et al., 2018). In females, the detection frequency of both isomers was 21%. Mean concentrations were only calculated for male birds and were 0.18 and 0.16 ng/g ww for syn- and anti-DP, respectively.

95. DP was also previously detected in air and biota samples from Greenland along with other FRs (Vorkamp et al., 2015). Mean syn- and anti-DP concentrations in air were 2.3 and 5.2 pg/m3. While the detection frequency of both isomers in air was 46%, anti- and syn-DP was detected in 95% and 100% of biota samples, respectively. In biota, ringed seals from East-Greenland had the highest DP concentrations with reported mean blubber concentrations of 0.096 and 0.42 ng/g ww for syn- and anti-DP, respectively, but were not statistically different from West-Greenland ringed seal samples. Reported mean concentrations for syn- and anti-DP in other species were; 0.14 and 0.67 ng/g ww in black guillemot eggs, 0.023 and 0.11 ng/g ww in glaucous gull liver, 0.019 and 0.071 ng/g ww in ringed seal blubber from West-Greenland and 0.021 and 0.055 ng/g ww in polar bear adipose tissue.

96. In another study, covering multiple locations in the Canadian Arctic, DP was only detected sporadically in ringed seals (Houde et al., 2017). Detectable levels of syn- and anti-DP ranged between 0.04 and 0.41 ng/g lw and 0.04-6.3 ng/g lw, respectively.

97. Minke whales and beluga whales from the St. Lawrence Estuary as well as beluga from the Canadian Arctic have also been studied (Simond et al., 2017). In 2013, the mean DP concentration for these three populations was 0.31 (minke whales, St. Lawrence Estuary), 0.44 (beluga, St. Lawrence Estuary) and 1.28 ng/g lw (beluga, Arctic). The highest *concentration of 1.28 ng/g lw in the Arctic beluga population was different from the generally observed contaminant distribution, which usually showed higher concentrations at more southern locations, and could not be explained. Concentrations in beluga from St. Lawrence estuary and the Canadian Arctic were roughly the same order of magnitude as observed in two killer whales from Greenland with quantifiable levels of anti-DP (Vorkamp et al., 2019a).*

98. Research on four avian species on King George Island showed that DP was present in Gentoo penguin, Adelie penguin, South Polar skua and Brown skua (Kim et al., 2015). Reported concentrations of DP were 0.250−0.329 ng/g lw in the penguin tissues and 2.12−11.1 ng/g-lw in the skua tissues. Dec 603 and 604 were not detected, whereas Dec 602 was detected in the highest concentrations in all samples, followed by anti-DP and syn-DP. In another Antarctic study, Gao et al. (2018), reported mean DP concentrations of 0.233 ± 0.089, 0.201 ± 0.086 and 0.15 ± 0.147 ng/g dw in soil from three different locations (i.e. a coastal area, an inland area and Ardely Island) on the Fildes Peninsula. Reported levels in lichen from the same locations were 0.449 ± 0.213, 0.337 ± 0.172 and 1.513 ± 1.376 pg/g dw, respectively. DP was detected in all samples. Kim et al. (2018) reported the presence of DP in lichen and mosses sampled from 16 different sampling sites spread across the South-Shetland Islands, King George Island and Anvers Island in Antarctica. Similar to Gao et al. (2018) and based on geographical differences in DP levels and fanti values, the authors propose that LRET, human activities, melting glacier water and biological activities, e.g. from penguins, are possible sources of DP in the area (Kim et al., 2018). In yet another study by Kim et al, DP was detected in limpet (0.398–11.1 ng/g lw), antarctic cods (0.0–0.548 ng/g lw), amphipods (0.227–8.71 ng/g lw), antarctic icefish (2.50 ng/g lw), gentoo penguins (0.009–11.8 ng/g lw), chinstrap penguins (0.0–3.00 ng/g lw), south polar skua (0.731 ng/g lipid), and kelp gull (0.028 ng/g lw) collected from the Barton Peninsula and Maxwell Bay, King George Island (Kim et al., 2021). Compared with the results from King George Island in 2008/09 (Kim et al., 2015), the DP levels in the penguin samples had slightly increased, although the sample size of the previous study was small. Aznar-Alemany et al. (2019) investigated DP and other dechloranes in dead seals from the South Shetland Islands on the Antarctic Peninsula. Only Dec 602 and anti-DP were found. Anti-DP was detected in adipose tissue from southern elephant seals and in Antarctic fur seals at average concentrations of 0.60 ng/g lw and 0.16±0.16 ng/g lw, respectively, but were below the limit of quantification in muscle, brain and fur. Dec 602 appeared in higher concentrations than anti-DP, especially in adipose tissue (Aznar-Alemany et al., 2019). Syn- and anti-DP has also been detected in integuement biopsies (epidermis, dermis and blubber) of killer whales from the Ross Sea, Antarctica (0.0068-0.0741 ng/g lw; with mean and median concentraions of 0.0192 and 0.0119 ng/g lw) (Muñoz-Arnanz et al., 2016).

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104. There is also some information on timetrends in biota. A recent study by Vorkamp et al. (2018), the only study available on temporal trends of DP in the Arctic, reported DP concentrations in the range 0.984 to 37.9 ng/g lw during the period 1986−2014 in peregrine falcon eggs from South Greenland. A non-significant increasing trend (annual change 3.3%) was observed (Vorkamp et al., 2018). In belugas from the St. Lawrence Estuary, DP increased from 1997 to about 2000 and decreased subsequently, possibly with a second peak around 2010 Barón et al. (2014), (De la Torre et al., 2011), Ji et al. (2018), Norwegian Environment Agency (2018b), Norwegian Environment Agency (2019a). In contrast, no significant change *in DP concentrations was found in eggs of white storks or black kites collected in 1999, 2003, 2011 and 2013 from the Doñana Natural Space in Spain; however, the authors highlight that underlying timetrends may have been oscured by large intraspecies variation in concentration levels (Barón et al., 2015). No differences were found in white stork. In the same study the authors also report a higher BDE-209/ DP ratio in black kites in 1999 than in 2011. Although the difference was not significant, it suggests a decrease in BDE-209 levels relative to DP possibly reflecting a shift in the use of these flame retardants. In a study on Indo-Pacific humpback dolphins and finless porpoises from the South China Sea, Zhu et al. (2014) found a positive temporal trend in the ratio of DP to BDE-209 between 2003. The finding was assumed to indicate a shift in the use of flame retarndants from PBDEs to other alternatives such as DP in China. A study reporting levels and trends of different flame retardants in the German and polar environments from 2005 to 2015/16 found declining trends for DP in some of the investigated biological matrices (i.e. tree leaves, tree shoots, herring gull eggs) and increasing trends in bream filet and blue mussel soft body (Dreyer et al., 2019). In the same period, a small declining trend was also observed in riverine suspended matter; however, the standard deviation in this sample set was quite large. As noted by the authors herring gulls feed in the marine environment, e.g. on blue mussels, but may also have a terrestrial diet. Although it is not clear to which extent the herring gulls investigated in this study feed in the terrestrial environment, transmitter-tracked female North Sea herring gulls have been shown to spend of 70% of their time in such costal terrestrial and urban habitats (e.g. harbors, food disposal facilities, recycling facilities and industrial parks), prior to the breeding season (Schwemmer et al., 2019). Thus, one possibility is that the time trends reported by Dreyer et al. (2019) reflect differences in DP emission and deposition between terrestrial and aquatic environments."*

Furthermore, three other monitoring studies that were not included in the draft risk profile are summarised below.

Dechloranes were measured in catfish, *Silurus spp.,* samples (n= 102) from different rivers in 22 areas in France (Abdel Malak et al., 2018). The concentrations of anti-DP were higher than those of syn-DP in about 85% of the quantified samples, results exhibiting a pronounced domination of anti-DP. These observations are similar to those reported by other authors (Barón et al., 2012, De La Torre et al., 2012). Detection frequencies were 34% and 47% for the syn- and anti-isomer, respectively. The concentration levels of DP in the fish ranged from <3.0 (limit of reporting (LOR)) to 73.8 pg/g ww (LOR to 6.01 ng/g lipid weight (lw)) with an average value comprised between 8.05 (0.56) and 11.63 (1.14) pg/g ww (ng/g lw). The highest concentration of DP was detected in a *Silurus spp.* from the Jonage channel (a branch of the Rhone River, upstream from Lyon), close to a hydroelectric plant. Similar concentrations have been reported in a study on Baltic salmon (n= 25) from Latvian rivers, with a mean syn-DP concentration of 0.086 ng/g lw and anti-DP of 0.16 ng/g lw) (Rjabova et al., 2016).

In a Norwegian screening assessment of environmental pollutants in the terrestrial and urban environment, dechloranes were analysed in earthworm, fieldfare, sparrow hawk and red fox (Heimstad et al., 2019). The highest median sum concentration of dechloranes was detected in sparrow hawk eggs followed by fieldfare eggs and was 72 ng/g lw (2.9 ng/g ww) and 33 ng/g lw (1.6 ng/g ww), respectively. Similar values were reported in the following year within the same biomonitoring program (Heimstad et al., 2020). In fox liver, the anti-isomer had the highest concentration of 0.19 ng/g ww (LOD-0.6 ng/g ww) of the DPs but was only detected in 50% of the samples in 2019 (Heimstad et al., 2019). Only Dechlorane 602 was detected at low concentrations in fox liver the following year (Heimstad et al., 2020).

B.9.4.2.2 Urban sources/areas

The draft POPs risk profile for DP has the following description of environmental monitoring results in urban areas:

"40. DP has been detected in sludge (e.g. de la Torre et al., 2011; Barón et al., 2014a; Norwegian Environment Agency, 2018b; 2019a; Ji et al., 2018) and biosolids (Davis et al., 2012) from wastewater treatment plants (WWTPs). In addition, sludge from WWTPs contaminated with DP can be used as soil enrichment (Wu et al., 2017) or fertilizer (Dai, 2011 reviewed in Ji et al., 2018). Furthermore, syn- and anti-DP was detected in the particulate fraction of storm water in Oslo, Norway (Norwegian Environment Agency, 2018b; 2019a).

41. In samples from Canadian WWTPs investigated for chlorinated FRs the detection frequency of DP was greater than 90% in both wastewater and biosolids samples, while median removal efficiencies were between 51% and 66% for total DP (Shanmuganathan et al., 2018). In a conventional WWTP in Shanghai DP levels were detected in wastewater with a mean concentration of 0.46 ng/L (range: 0.05 to 1.40 ng/L). Sludge contained DP in the range of 1.1 to 2.0 ng/g. The fraction of anti-DP (fanti) was consistently higher than that of syn-DP (fsyn). Average fsyn values ranged from 0.16 to 0.33 and was in the range of two commercial DP mixtures. The annual release of DP via sewage sludge from all WWTPs in Shanghai were estimated to be 164.8 g (Xiang et al., 2014).

42. DP is used as a FR in electrical and electronic equipment and recycling of e-waste is reported to be a source of DP release to the environment (Wang et al., 2016). Very high levels of DP in soil (3327 ng/g) were detected at a recycling site in China suggesting that e-waste recycling activities serve as an important source of DP emissions in China (Yu et al., 2010). In a Swiss study, the overall DP concentration in e-waste was 33±11 mg/kg. This translates into an annual DP mass flow of 2.3±0.9 tonnes/year in all Swiss e-waste generated in 2011 (Taverna et al., 2017)."

B.9.4.2.2.1. Sludge, WWTP, e-waste, production sites

Elevated levels of DP are associated with human activity. Studies from around the world indicate that, in addition to production sites where DP is produced or used, high levels of DP are found in urban areas in the world (reviewed by (Wang et al., 2016); Schuster et al., 2020).

Norwegian monitoring data (Norwegian Environment Agency, 2019a) of sediments from the Oslo fjord reported DP levels in the same range as sediments of the North American Great Lakes, and 1 - 2 orders of magnitude lower than in sediments of Lake Ontario, close to a DP manufacturing plant in the city of Niagara Falls (Sverko et al., 2011). There is no production of DP in Norway and (Norwegian Environment Agency, 2019a) propose the contamination to be due to imported plastic products. A study by Möller et al. (2010) of DP in the Atlantic atmosphere, reported that the highest concentrations were observed in the English Channel originating from continental air passing Western Europe. The authors indicate that Western Europe is a source region of DP to the Atlantic marine environment.

B.9.4.2.2.2. Sewage sludge

DP has a high adsorption potential, see chapter B.4.2.1 Adsorption/desorptionfor details. It is therefore expected to find the substance in sewage sludge rather than in the water phase at wastewater treatment plants. Most environmental monitoring studies report the presence of DP in sludge and do not report whether the analysis of the water phase has been performed. However, the Norwegian Environment Agency reports that DP was found in the sewage sludge but not in the sewage water of a wastewater treatment plant near Oslo (Norwegian Environment Agency, 2018b, Norwegian Environment Agency, 2019a). The mean concentration (sum of syn- and anti-isomers) of DP in the sludge was 9.5 ng/g dw (n= 2) in 2017 and 14.2 ng/g dw (n= 2) in 2018, where anti-isomers constituted 78% and 83% of the total DP detected (Norwegian Environment Agency, 2018b, Norwegian Environment Agency, 2019a).The mean concentration (sum of syn- and anti-isomers) of DP in the sludge was 9.5 ng/g dw (n= 2) in 2017 and 14.2 ng/g dw (n= 2) in 2018, where anti-isomers constituted 78% and 83% of the total DP detected (Norwegian Environment Agency, 2018b, Norwegian Environment Agency, 2019a).

De la Torre et al. (2011) sampled 31 differently sized urban wastewater treatment plants located across Spain from April to June 2006. The concentrations of DP *syn*- and *anti*- in sewage sludge, ranged between 0.903 – 19.2 and 1.55 – 75.1 ng/g dw respectively. The authors report elevated levels of DP in sewage sludge from areas of industrial activities potentially involving flame retardant use, such as printed circuits, textiles, surface treatments, galvanic processes and others. However, the authors also do not dismiss that the DP levels also could be explained by emissions of DP from the use and disposal of articles. No information on the levels of DP in the water phase was reported.

Barón et al. (2012) reported that the levels of DP in sewage sludge from six wastewater treatment plants in along the Ebro river basin in Spain ranged between 2.58 – 18.8 ng/g dw. A subsequent study by Barón et al. (2014) including six wastewater treatment plants along the Ebro river basin, and one sludge site from the Llobregat river reports that both isomers of DP (*syn*- and *anti*-) were detected in all the sewage sludge samples, with values ranging from 0.85 to 11.2 and from nq to 11.9 ng/g dw respectively.

B.9.4.2.2.3. River sediments

DP has been detected in river sediments around Europe. Barón et al. (2012) reported that the total levels of DP in the two Spanish rivers Llobregat and Ebro ranged from nd to 1.39 ng/g dw and nq to 1.64 ng/g dw, respectively. The same study reports that the isomeric ratio of the two DP isomers in the sediment samples were similar to those found in commercial mixtures. A study of three European river basins by Giulivo et al. (2017) of sediment samples from the Evrotas river basin (Greece), the Adige river basin (Italy) and the Sava river basin (Slovenia) reported DP levels ranging from nd – 2.30, nd – 3.67 and nd – 2.80 ng/g dw, respectively. A recent study by of River Thames sediments (United Kingdom) reported levels between 0.04 – 66 ng/g dw of syn-/anti- DP. DP in 11% of the samples.

B.9.4.2.2.4. Point sources

A number of recent studies have confirmed e-waste recycling sites as a source of release of DP to the environment. The draft POPs risk profile for DP has the following description of environmental monitoring results at point sources (POPRC, 2021b):

" 86. Several DP monitoring studies have been carried out in the vicinity of DP manufacturers and e-waste recycling sites, including in the US, China and Pakistan (Sverko et al., 2011; Ji et al., 2018; Iqbal et al., 2017). High DP levels have been reported in various matrices from these areas (Wang et al., 2016), with reported concentrations up to several ng/m3 close to known production or e-waste recycling sites (Sverko et al., 2011). The soil concentration of DP near the Anpon Electrochemical Co. production facility in China was found to be 0.83-1200 ng/g dw but decreased by an order of magnitude within 7.5 km (Wang et al., 2010a). Other studies have reported average soil concentrations of 1490 ng/g and 35.6 ng/g for this site (Wang et al., 2010c; Zhang et al., 2015). Atmospheric DP concentrations near the DP production plant in, China were found to be as high as 7737 to 26,734 pg/m3 (Wang et al., 2010a). DP has also been detected in air and precipitation at Sturgeon Point and in Niagara River suspended sediment samples, near the OxyChem manufacturing facility in the US (Shen et al., 2011; Olukunle et al., 2018). Total DP levels in air at Sturgeon Point were reported to be 2.70 pg/m3 by Olukunle et al. (2018) and 3.1 pg/m3 by (Liu et al., 2016), while Hoh et al. (2006) in one instance measured concentrations up tp 490 pg/m3. Total DP levels in precipitation from the same site were 323 pg/m3 and 890 pg/m3, as reported by Olukunle et al. (2018) and by Salamova and Hites (2011), respectively. Examination of sediments collected in this area between 1980 and 2006 showed a declining concentration trend for DP (Shen et al., 2011). A declining concentration trend for DP was also reported previously for Niagara River suspended sediments (Sverko et al., 2008) and are consistent with declines observed in a sediment core collected near the river mouth on the Niagara River bar (Sverko et al., 2010). The suspended sediment trends observed by Shen et al. (2011) were also reflected in open lake sediment cores, which generally showed a decline in DP concentrations since 1980 in the Niagara basin. Similar findings were reported for the Mississauga basin (Shen et al., 2010). It is not clear if the decline in DP in Niagara River suspended sediment samples represent changes in production volumes at the Oxychem manufacturing site or whether it reflects emission controls adopted over the past 20 years at the site. Reported DP levels in surface sediments in Lake Ontario (2.230×103 -5.860×105 pg/g dw) and Lake Erie (61.00– 8.620×103 pg/g dw) in North-America, down-stream of the Oxychem manufacturing plant, are at the high end of reported concentrations globally along with levels in surface sediments from some locations in China including the Huai'an area where there is also a DP manufacturing plant (1.860 × 103–8.000×103 pg/g dw), the Dongjiang River (80.00–1.940 × 104 pg/g dw) Qiantang River (<9000-1.100x103 pg/g dw) and mangrove sediments of the Pearl River Estuary (13.00-1.504 × 103 pg/g dw) (Sverko et al., 2008; Wang et al., 2010; He et al., 2014; Sun et al., 2013; 2016, as cited in Niu et al. 2020). Surface sediments in source areas are likely important reservoirs of DP in the environment (Niu et al. 2020), but monitoring data also provide evidence for uptake in biota and elevated levels in aquatic species in these areas (reviewed in Zafar et al. 2020 (…)). For example, DP levels in muscle tissues of commercial fish species from one of Chinas most polluted rivers, the Liaohe River, ranged from below detection limit to 470 pg/g lw (Ren et al. 2013).

87. A very high DP concentration (3327 ng/g) was found in soil at an e-waste recycling site in Qingyuan, China. DP levels fell dramatically with increasing distance away from the recycling site (Yu et al., 2010). High levels (average 3398 ng/g) of DP were also reported in soil samples from areas with informal e-waste recycling activities in Karachi, Pakistan (Iqbal et al. (2017). The high DP levels in soil reported at recycling sites by Iqbal et al. (2017) and Yu et al. (2010) are comparable with levels reported from other e-waste recycling sites in Asia (South/ Southeast China) (Li et al., 2018; Ge et al., 2020) and much higher than the DP levels in soil collected in close vicinity to the DP manufacturing facility in Huai'an City, China (Wang et al., 2010a,c; Zhang et al. 2015). In the recycling town Guiyu, in southeastern China total DP levels in soil were 3.8-2100 ng/g, and DP was also found in sediment (1100 - 7200 ng/g dw), road dust (14 – 1100 ng/g dw) and PM2.5 particles (180 pg/m3 syn- DP and 170 pg/m3 anti-DP) (Li et al., 2018). Elevated DP levels in air (15 – 85 ng/m3) were also reported in the e-waste area of Karachi, and are higher than reported levels found in air close to the DP manufacturing site (7.7 – 26.7 ng/m3) in China (Iqbal et al., 2017; Wang et al., 2010a; see also review by Zafar et al., 2020). Elevated levels have also been reported in biota near e-waste sites. DP concentrations from 19 to 9630 ng/g lw have been reported in aquatic species including water snake and mud carp from an e-waste recycling workshop of South China (Wu et al., 2010). In another study from e-waste recycling site at South Longtang Town China, two species, northern snakehead and Crucian carp were studied for maternal transfer and sex-related accumulation of DP. The concentrations of hepatic DP for northern snakehead and Crucian carp were 260–1920 ng/g lw and 340 to 1670 ng/g lw, respectively (Wu et al. 2013).

88. According to Iqbal et al. (2017) elevated levels of DP at informal recycling sites may originate from emission associated open-air burning-, acid stripping-, manual dismantling-, and shredding of cables, televisions, plastic roofing and connectors Iqbal et al. (2017). Iqbal et al. (2017) furthermore suggest that sites with informal e-waste recycling may have higher environmental impact than manufacturing sites and urban environments, stressing the importance of chemical management strategies across the entire life cycle of electronics (Iqbal et al., 2017). However, Ge et al. (2020) found elevated concentration levels of DP (range of total DP was 21.8 – 18 000 ng/g and the median levels of syn- and anti-isomers was 211 ng/g and 504 ng/g, respectively) in soil samples from within a newly (2015) established recycling facility that uses modern technology. The study compared soil samples from the recycling facility with samples from the surrounding area (range of total DP was 1.76 – 4 050 ng/g and the median levels of syn- and anti-isomers was 2.81 ng/g and 8.52 ng/g respectively) which had lower levels of DP in soil. DP has also been detected wildlife living at or in close vicinity of e-waste sites (e.g. Li et al., 2014; Wu et al., 2013; 2018, Peng et al. 2019). Peng et al. (2019) found that birds (kingfishers) feeding close to e-waste recycling sites in South China had 10- to 1 000- times higher levels of total DP concentrations than kingfishers from non-e-waste sites.

(…)

105. Rauert et al. (2018) report air monitoring data from 48 global sites across all five UN regions that were collected using polyurethane foam passive air samplers. The study generally showed low detection for all FRs at background sites. PBDEs showed higher mean concentrations and detection frequencies than novel FRs (Rauert et al., 2018). Syn-DP was below the detection limit at all 48 sites and anti-DP at all sites except Paris, France, where *high levels of DP were reported in 2014 (19 pg/m3 in the first and fourth of the year, 7.5 pg/m3 in the second quarter two and 116 pg/m3 in third quarter). When compared to monitoring data from 2005 and 2008 to 2009, respectively, Paris had elevated concentrations of novel FRs and reduced PBDE levels. Anti-DP and the FRs β-tetrabromoethylcyclohexane and bis(2-ethyl-1-hexyl) tetrabromophthalate were the dominating novel FRs. Rauert et al. (2018) propose that "the increasing concentrations of the replacement FRs and the reduced levels of the PBDEs may be indicating the shift away from the use of PBDEs to alternative FRs in this urban area".*

Furthermore, in a study of 31 Spanish wastewater treatment plants, De la Torre et al. (2011) found significant positive correlation ($r = 0.619$, $p < 0.05$) between the total DP concentrations and the contribution of industrial input to wastewater.

B.9.4.2.3. Arctic/ remote regions

DP is detected in the Arctic. The draft POPs risk profile for DP has this description of the levels of DP in the Arctic and the Antarctic (POPRC, 2021b).

"71. DP has been detected in many different environmental matrices and biota in remote regions; in Arctic air, snow, soil, sediment, water and biota (reviewed in AMAP, 2017; Vorkamp et al., 2019a,b; Canada, 2019a); in Antarctic air, soil, lichens, mosses, limpet, amphipods, cod, icefish, kelp gulls, penguins, skuas, giant petrels, killer whales, southern elephant seals and Antarctic fur seals (Möller et al., 2010; Muñoz-Arnanz et al., 2016; Gao et al., 2018; Kim et al., 2015; 2018; 2021; Aznar-Alemany et al., 2019; Roscales et al., 2021); in air, soil and lichen at the Tibetan Plateau, a remote mountain region in Asia (Yang et al., 2016a; Liu et al., 2018); and in air, water, soil, plant and animal muscle and hair in the remote Xilingol Prairie in Inner Mongolia, China (Chen et al., 2021).

72. In Arctic biota, most detections have been made in species in the marine food web (polar bear, ringed seal, harp seal, hooded seal, beluga whale, killer whale, narwhal, glaucous gull, common gull, black guillemot eggs, common eider, European shag, kittiwake, mink, and cod (anti-DP only)). Detections also include terrestrial and freshwater species, i.e. reindeer dung, peregrine falcon eggs and landlocked Arctic char (reviewed in AMAP 2017; Canada, 2019; see also Norwegian Environment Agency, 2018a; Dreyer et al., 2019; Letcher et al., 2018; Green 2019; Verrault et al., 2018; Vorkamp et al., 2015; 2018; 2019a; Houde et al., 2017; Simond et al., 2017; Schlabach et al., 2011).

73.(...) while concentrations in remote regions are generally low, they are not always lower than DP levels in source regions (…). Reported detection frequencies vary from non-detect to 100% detection. Collectively, the available monitoring data suggests that DP can be transported over large geographical distances to remote areas where it deposits, transfers to the receiving environment and is taken up in biota (reviewed in Sverko et al., 2011; AMAP 2017 and Canada 2019a; see also Möller et al., 2010; 2011; 2012; Na et al., 2015; Yang et al., 2013; Wang et al., 2010b).

(…)

77. As discussed by Vorkamp et al. (2019b), the highest DP levels in Arctic air to date were detected on Greenland in 2012. Reported mean DP concentrations in Greenland air in 2012, 2014 and the period 2014-2016 were 6.7, 0.64 and 4.2 pg/m3, respectively (Vorkamp et al., *2015; 2019a). DP was also positively detected in atmospheric samples from other Arctic sites: Alert in the Canadian Arctic (Xiao et al., 2012), Longyearbyen in the Norwegian Arctic (Salamova et al., 2014), and Little Fox Lake in the Canadian Sub-Arctic (Yu et al. 2015). Mean DP concentrations reported for these sites were ~0.75, ~1.2 and ~0.25 pg/m3, respectively. DP was also detected in air from Pallas in Northern-Finland at a mean concentration of 0.039 pg/m3 (Haglund et al., 2016).*

(…)

92. In Antarctic soil, lichen and moss samples, DP was detected in all samples (100%) (Gao et al., 2018; Kim et al., 2018). The DP concentrations in Antarctic soil were between one and several orders of magnitude lower than the levels reported in surface soil samples collected from an industrial region (0.0336–4.65 ng/g) and an e-waste recycling area (nd–47.4 ng/g) in South China (Yu et al., 2010). On the other hand, DP levels in both lichen and moss from Antarctica were higher than previously measured in mosses sampled in Ny-Ålesund in Arctic Norway in 2012 (Na et al., 2015). The average concentrations of DP in lichen from Antarctica were similar to those in reeds in northeastern China (0.63 ng/g wet weight (ww)) (Wang et al., 2012) and in lichen in the southeast Tibetan Plateau (167 pg/g) (Yang et a., 2016a) but lower than in tree bark from areas in the northeastern US (0.03–115 ng/g) and South Korea (1.4 ng/g) (Qiu and Hites, 2008)."

The Institute of Marine Research in Norway analysed dechloranes in sediments in the MAREANO area, including samples from 30 locations in the Norwegian Sea and Barents Sea. Among the analysed dechloranes, syn- and anti-DP were most frequently detected. The maximum measured sumDP concentrations ranged between 0.22 and 0.41 µg/kg dw. This is lower than levels reported from the Oslofjord (Norwegian Environment Agency, 2019a), but similar to those measured in other parts of the world (Fang et al., 2014, Sverko et al., 2011).

Summary

In summary, DP is released to the environment from human activities. It is detected in humans, wildlife and environmental samples in all global regions, including the Arctic and Antarctic. DP is also measured in environmental samples near production sites and urban areaa, dust, sludge and wastewater.

B.10. Risk characterisation

It is not relevant to perform quantitative risk assessments of vPvB substances, due to the uncertainties regarding long-term exposure and effects. Therefore, the risks of vPvB substances, such as DP, to the environment or to humans cannot be adequately addressed in a quantitative way. The overall aim for vPvB substances is to minimise the exposures and emissions to humans and the environment (REACH Annex I, section 6.5).

Annex C: Justification for action on a Union-wide basis

DP is identified as an SVHC based on its very persistent and very bioaccumulative (vPvB) properties according to Article 57(e) of Regulation (EC) No 1907/2006 (REACH).

The substance 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 upon continued releases. DP is also widely dispersed in both the aquatic and terrestrial food chains, including top predators. It is frequently detected in remote regions which shows that the compound is transported over long distances from point sources and production facilities.

Humans are also exposed to DP and the substance has 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.

There is no EU manufacture of DP, but it is imported to the EU. According to the registrant information, DP is used as a flame retardant in adhesives/sealants and polymers. Furthermore, DP is used as an extreme pressure additive in greases. The substance is used in a wide range of products, such as computers, electronic and optical products, vehicle textiles, automobiles, aerospace and defence engines, as well as in fireworks (see Annex A: Manufacture and uses). There is a potential for release of DP to the environment during processing and use, as well as from waste disposal and recycling activities (see B.9. Exposure assessment). Products imported in one Member State may be transported to and used in other Member States.

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 will 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.

Another aspect worth considering is the political goal to phase out the use of vPvB substances, see for example the recent Chemicals Strategy for Sustainability Towards a Toxic-Free Environment (European Commission, COM(2020) 667 final). Furthermore, Recital 70 of the REACH Regulation 1907/2006 states that exposure of the environment and humans from SVHC's should be reduced as much as possible.

Norway proposed to list DP as a POP under the Stockholm Convention in May 2019 (UNEP, 2019) If the substance is listed, EU will include the listing into Regulation (EU) 2019/1021 (the POPs regulation). The Persistent Organic Pollutants Review Committee (POPRC) currently assessed the intrinsic properties of DP (UNEP/POPS/POPRC.16/9) and decided to defer its decision on the draft risk profile for DP to the next meeting, tentatively scheduled to September 2021. However, POPRC noted that the information on persistence, bioaccumulation and the potential for long-range environmental transport was conclusive but the Committee was unable to agree that the information on adverse effects was sufficient to reach a conclusion on the risk profile for DP (UNEP/POPS/POPRC.16/9, Annex I, Decision POPRC-16/1) (POPRC, 2021a). If the risk profile is approved by POPRC, the next step towards a global regulation is preparation of a risk management evaluation that includes an analysis of possible control measures for DP.

An EU restriction will be an important step to reduce the risks from DP within the EU internal market. It is desirable to go ahead with a restriction under REACH in order to benefit from an earlier implementation of a restriction of a substance presenting an unacceptable risk in the Union before it is superseded by a listing in the POP Convention (EC, 2014). It will also assist the global regulation by the POPs Convention by analysing the impact in the EU of an equivalent global regulation. If the result of the assessment under the POP Convention is that DP does not fulfil the criteria for a POP, DP still poses an unacceptable risk in the Union due to its vPvB-properties. Hence, it is good practice to initiate the restriction procedure under REACH following the nomination for listing of DP under the POP Convention. Where, following the listing in Annex XVII to REACH, DP is also listed under the Convention, the REACH restriction should - in principle - be removed from REACH Annex XVII (EC, 2014).

National regulatory actions are not considered adequate to manage the risks of DP. Union-wide action is proposed to avoid trade and competition distortions, thereby ensuring a level playing field in the internal EU market as compared to action undertaken by individual Member States.

Furthermore, since a considerable share of articles containing DP may be imported from outside the EU, the inclusion of DP on the list of substances subject to authorisation (REACH Annex XIV) would create an uneven playing field.

A short description of different Union-wide legislative options that may have the potential to influence emissions of DP to the environment is presented in Annex E.1.3. Other Union-wide risk management options than restriction. An EU-wide restriction will prevent and reduce the releases of the substance and is the most efficient and appropriate way to limit the risks (due to further releases into the environment) for human health and the environment on an EU level.

Annex D: Baseline

D.1. Introduction

The "baseline" is the scenario in the absence of any restriction or other Risk Management Options (RMO) or interventions (e.g. Persistent Organic Pollutants (POP) regulation) implemented to reduce the environmental risks from manufacture, import and use of DP. The baseline is a projection of future DP volumes used in the EU and the corresponding projected releases of DP into the environment. The projections consider other external factors that could affect the market, such as implementation of new legislations/regulations or changes to existing ones that may affect the releases of DP.

In this analysis the consideration of DP for inclusion in the Stockholm Convention on POPs is excluded from the baseline scenario, i.e. there is no regulations of DP in the EU or globally under the baseline. If one would instead assume that the global restriction would move forward without the REACH restriction, both the impacts of and the justification/need for the REACH restriction would be minimal. Since the REACH restriction and the listing under the Stockholm Convention is considered to some extent interlinked, their separate effects have not been further investigated in this analysis.

The baseline was developed based on the data gathered on the manufacture, import and use of DP within the EU as presented in Annex A: Manufacture and uses. Since import and use are symmetrical, i.e. tonnes imported equal tonnes used, we will only focus on use in this Annex D.

The period over which the baseline is derived was chosen to be 2023 – 2042, as 2023 is considered the earliest, realistic Entry into Force (EiF) for a potential REACH restriction on DP and 20 years is the analytical period used for most restriction proposals.

D.2. Existing regulations affecting the manufacture and use of Dechlorane Plus

There are currently no restrictions on the manufacture, import or use of DP in the EU. However, the REACH restriction on decaBDE, which entered into force on 2 March 2019, as well as the listing of decaBDE as a POP under the Stockholm Convention are expected to increase demand for DP, as it is a known alternative to decaBDE. Therefore, it is possible that DP may replace parts of the historic market for decaBDE in the absence of further regulations on DP.

D.3. Use of Dechlorane Plus

D.3.1 Current use of Dechlorane Plus

Annex A: Manufacture and usespresented available data on manufacture, import, and use of DP from REACH registrations, literature and new information received in the stakeholder consultation, summarised in Section

A.2.4. Summary and conclusions. Table 65 below provides a sector breakdown of the volumes used in the EU and is considered the most reliable breakdown available and hence used for the socio-economic analysis[37]. It has not been possible to distinguish the sectors in which imported articles containing DP are used, so volumes in imported articles have been included in the "Other applications" category.

The *Central* estimates was derived by taking a simple average of the *Low* and *High* estimates.

Table 65: Current use of Dechlorane Plus in the EU

Downstream use	**EU use – tonnes per year (t/y)**		
	Low	Central	High
Automotive applications	68	99	130
Aerospace and defense applications	9	16	23
Other applications, including use in computers, electronics and imported articles	14	45	77
TOTAL	**90**	**160**	**230**

Note: Sums may not add up due to rounding.

The presented tonnage bands are broad, and it is therefore expected that the actual volume would fall somewhere within the presented range. However, discrepancies in data provided by various stakeholders on market share of each sector warrants caution when concluding on the relative market shares.

D.3.2. Baseline use volumes of Dechlorane Plus

As mentioned above, the recent entry into force of the restrictions on decaBDE, both in the EU and globally, may result in (in the absence of further regulatory action on DP) increased demand and use of DP. On the other hand, DP was not mentioned as an alternative to decaBDE by the Dossier Submitter nor by stakeholders during the REACH restriction process. It is therefore difficult to conclude what proportion of the market for decaBDE could potentially be replaced by DP in the absence of further restrictions on DP. The core analysis will therefore be based on tonnage used reported by stakeholders, whilst the potential switch from decaBDE to DP will be tested in the sensitivity analysis.

No specific growth rate for the consumption of DP was provided in the stakeholder consultation, so the growth rates have been derived based on more general market considerations, and the same growth rate has been applied to all uses.

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[37] See Annex A for further explanations of the current use estimates

From 2022 to 2030, it is expected that developments in the volume of DP used in the EU will be dominated by the market trends in the automotive industry, as this was identified as the largest user of DP. According to PwC (2017), EU vehicle sales are expected to increase from 18 million in 2017 to 24 million in 2030. The implied compound annual growth rate (CAGR) between 2022 and 2030 is thus 2.2% per year.

Post 2030 the uncertainty in any projection increases makes it difficult to identify the driving factors for the use of DP. In the absence of information on market development after 2030, a growth rate equal to the projected population growth in the EU of -0.05% was used (Eurostat, 2020c).

Figure 7 below shows the development in DP volumes used in the EU between 2020 and 2042, estimated based on the abovementioned growth rates. The central estimate is shown in green, whilst blue and orange represent the low and high estimate, respectively.

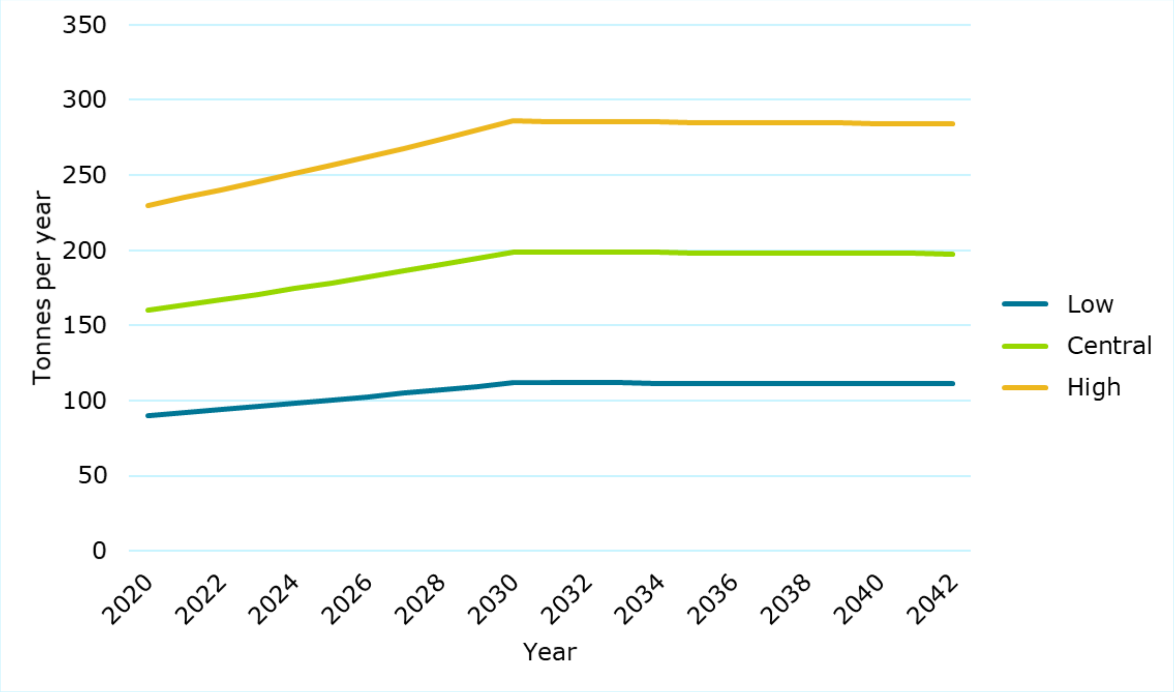

Figure 7: Expected development in the use of Dechlorane Plus between 2020 and 2042 within the EU

The total volumes used over the analytical period (2023-2042) and the average volumes used per year was estimated based on the timeline presented in Figure 7. **The total EU use volume is estimated to be around 3 900 tonnes** (central estimate) between 2023-2042 with an average use volume of **190 tonnes per year** (central estimate).

The *Low*, *Central* and *High* baseline use volumes are shown in Table 66.

Table 66: Total and average use volumes used in the EU between 2023-2042

	Total use volumes (tonnes)	**Average use volumes (tonnes/year)**
Low	2 175	109
Central	3 867	193
High	5 559	278

Note: Annual averages were derived by dividing total use volumes by 20 (i.e. the analytical period).

Table 67 shows the breakdown per sector under the central estimate only, assuming that the best estimate of consumption split between the sectors (as derived in Annex A: Manufacture and uses) will remain constant over the analytical period.

Table 67: Total and average baseline volumes used in the EU (central estimate) between 2023-2042

Sector/use	**Total use volumes (tonnes)**	**Average use volumes (tonnes/year)**	**Share of total**
Automotive	2 387	119	62%
Aviation	387	19	10%
Other including imported articles	1 094	55	28%
All uses	**3 867**	**193**	**100%**

Note: Sums may not add up due to rounding.

It has not been possible to exclude the UK from the EU data and report this separately. The EU emissions are therefore likely to be overestimated.

D.3.3. Current emissions of Dechlorane Plus to the environment

The current emissions of DP to the environment from various sources of DP in 2020 were derived in Annex B.9. Exposure assessment. These are summarised in Table 68, which also includes a *Central* estimate derived by taking a simple average of the *Low* and *High* estimates.

It should be noted that the emissions of DP were derived using a static exposure model, i.e. it implicitly assumes that emissions occur simultaneously with the use. This means that emissions from articles manufactured prior to 2020 are not included in the estimates, and future emissions from service life, recycling and disposal of articles manufactured in 2020 are allocated to 2020. The exclusion of emissions of historic use will lead to an underestimation of emissions in 2020, whilst the inclusion of future emissions from service life and disposal indicates overestimation. It is therefore not possible to conclude whether the derived, current emissions are over - or underestimated.

Table 68: Estimated total EU releases for Dechlorane Plus per environmental compartment

Environmental compartment	**Estimated EU emissions in 2020 (t/y)**		
	Low	**Central**	**High**
Air	5.9	12.7	19.5
Water	0.4	0.7	1.1
Agricultural soil	1.2	2.1	3.1
Industrial soil	0.1	0.1	0.2
Total	**7.5**	**15.7**	**23.8**

Note: Sums may not add up due to rounding.

D.3.4. Baseline emissions of Dechlorane Plus

The emissions projections for the EU were developed considering the changes in demand for DP over time as set out in D.3.2. Baseline use volumes of Dechlorane Plus. It is assumed that the market composition, in terms of applications and their market shares, remains constant over the analytical period. The corresponding projected emissions of DP from 2020 to 2042 is shown in Figure 8. The central estimate is shown in green, whilst blue and orange represent the low and high estimates, respectively.

Similarly, as for the derivation of current emissions (Section D.3.3. Current emissions of Dechlorane Plus to the environment), it has not been possible to include emissions from historic use of DP, nor the time delay between use and parts of the emissions (e.g. release from service life). This is not expected to have a large impact on the total baseline emissions, as it is assumed that DP will continue to be used by the same sectors over the analytical period. A small to moderate overestimation is likely, due to the market growth in the beginning of the period.

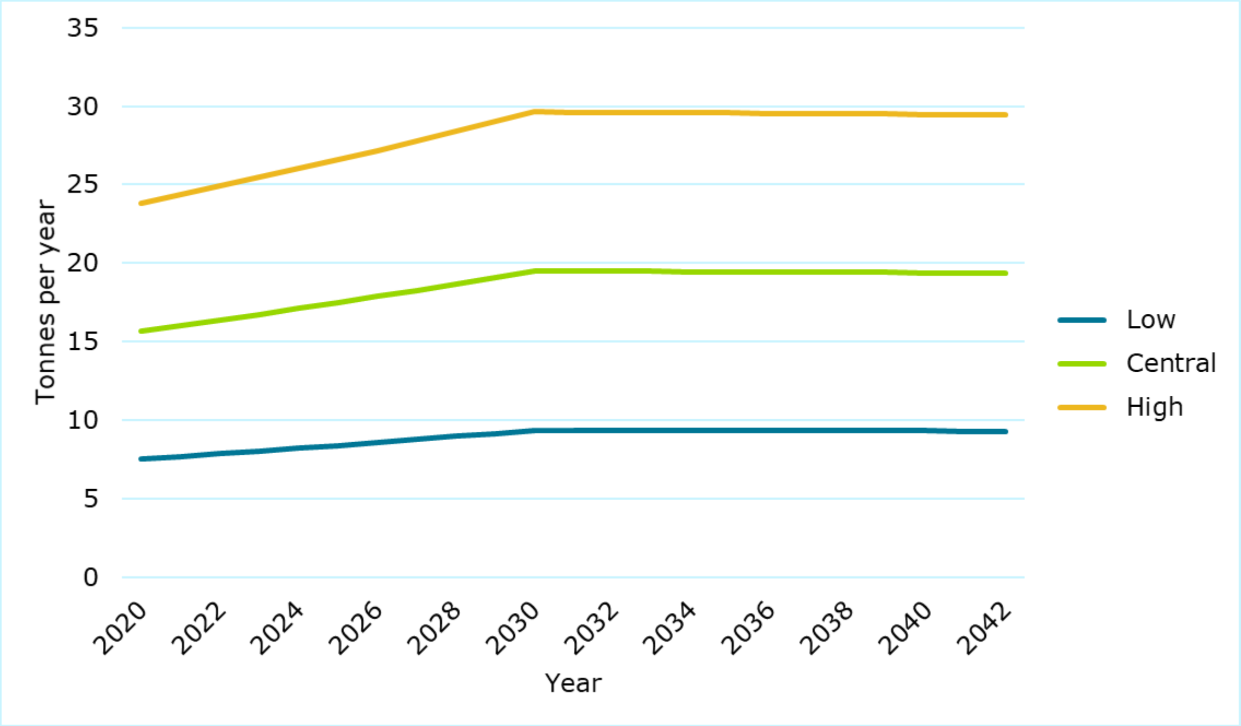

Figure 8: Expected emissions of Dechlorane Plus between 2020 and 2042

The total emissions of DP over the analytical period (2023-2042) and the average annual emissions (tonnes per year) were estimated based on the timeline presented in Figure 8**. The total EU emissions of DP are estimated to be around 379 tonnes** (central estimate) between 2023-2042 with average annual emissions of **19.0 tonnes per year** (central estimate). The *Low*, *Central* and *High* baseline emission estimates are shown in Table 69.

Table 69: Total and average emissions between 2023-2042 in tonnes

	Total emission (tonnes)	**Average emission (tonnes/year)**
Low	182	9.1
Central	379	19.0
High	576	28.8

Note: Annual averages were derived by dividing total use volumes by 20 (i.e. the analytical period).

Table 70 shows the breakdown per sector, assuming that the split between the sectors will be the same as in the baseline and remain constant over the analytical period.

Table 70: Total and average baseline emission volumes (central estimate) between 2023-2042

Sector/use	**Total emission (tonnes)**	**Average emission (tonnes/year)**	**Share of total**
Automotive	234	11.7	62%
Aviation	38	1.9	10%
Other including imported articles	107	5.4	28%
All uses	**379**	**19.0**	**100%**

Note: Sums may not add up due to rounding.

It has not been possible to exclude the UK from the EU data and report this separately. The EU emissions are therefore likely to be overestimated.

Annex E: Impact Assessment

E.1. Risk Management Options

In Section 1.3 (and Annex C: Justification for action on a Union-wide basis) it was justified why a restriction is required at EU wide level. This section E.1 therefore focuses on what the scope of such a restriction might be. Annex E.1.1. Assessed option(s) for restriction sets out the three different restriction options (RO1, RO2 and RO3) that are included in the socio-economic analysis. Each of the ROs vary in terms of the scope (and severity of impacts) of the possible restriction.

Restriction Option 1 (RO1) presents the proposed restriction which is subject to comments from stakeholders, the Risk Assessment Committee (RAC) and the Committee for Socio-Analysis Committee (SEAC).

However, it is important to note that a full socio-economic analysis has also been carried out on Restriction Option 2 (RO2) and Restriction Option 3 (RO3). Therefore, stakeholders and the two committees can also comment on the proportionality of all three ROs. Further details on all three options can be found in Sections E.3. Restriction scenario(s)- E.8. Proportionality and comparison of restriction options and Annex F: Assumptions, uncertainties and sensitivities.

As all three ROs are fully assessed, only short justifications for the restriction options are provided in this section below.

E.1.1. Assessed option(s) for restriction

E.1.1.1. Proposed restriction option: RO1 - Total ban

RO1: A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF[38] + 18 months.

E.1.1.2. Justification for the selected scope of the proposed restriction option

RO1 is the restriction option with the highest risk reduction potential and thus the option that would give the highest environmental and human health benefits related to reduced risks associated with the use of DP.

Under RO1, there are no derogations granted, which would mean that all uses of DP must cease by the end of the transition period (EiF + 18 months). This is the only restriction option (RO) that will effectively mitigate all new sources of emissions of DP in the EU.

The analysis in E.8. Proportionality and comparison of restriction options shows that RO1 is not necessarily the most cost-effective option, but the inherent uncertainties in the analysis

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[38] Entry into Force

prevents a robust conclusion on proportionality. The uncertainties are primarily driven by lack of information on technical function (why DP is needed), potential alternatives and their feasibility, cost of transitioning to alternatives and the time needed.

Without the necessary information to firmly conclude on which restriction option is the most beneficial to society, it was deemed most appropriate to propose a restriction option minimising potential adverse effects on human health and the environment. This is in line with REACH recital 70 which states that "*… substance for which it is not possible to establish a safe level of exposure, measures should always be taken to minimise, as far as technically and practically possible, exposure and emissions with a view to minimising the likelihood of adverse effects.*"

The need for derogations, if any, can be reassessed if new information justifying such derogations is received in the public consultation. If no such information is received, it is reasonable to conclude that the restriction poses an acceptable burden for industry and society as a whole. On this basis, combined with RO1 providing the maximum risk reduction of DP is a strong indicator for RO1 being the most appropriate restriction option.

E.1.1.3. RO2 – Derogation for use in spare parts

RO2: A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF + 18 months.

A derogation shall apply for the use in:

1) Production of aircrafts before EiF + 5 years; and

2) Production of spare parts for:

    i) aircrafts covered by the derogation described in 1); and

    ii) motor vehicles manufactured before EiF + 18 months.

Note that the provision in 2) 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 definition of aircraft and motor vehicle is defined as in Regulation (EC) No 1907/2006 on decaBDE. Derogations for electrical and electronic equipment, in line with derogation set out in Regulation (EC) No 1907/2006 on decaBDE, might be needed.

E.1.1.4. Justification for the selected scope of the RO2

RO2 is also considered a strict restriction option, but it allows continued use of DP in aircrafts for a limited time period (EiF + 5 years). It also includes a derogation for the use in spare parts for both aircrafts and motor vehicles, for which it is known that substitution is not feasible. This restriction option follows a similar (but not identical) approach adopted for the REACH restriction on decaBDE.

The aviation sector is subject to strict regulations, where some parts need rigorous testing and compliance demonstrations in order to be certified for use. New materials or design changes can only be introduced on the aircraft if testing and compliance demonstrations has been approved. The approval will result in the issuance of a Supplemental Type Certificate (STC), change approval or repair approval (ECHA, 2015b). This implies that transitioning to alternatives can be more time consuming for the aviation sector than for some other industries. In the decaBDE REACH restriction, a derogation for use in aircrafts was granted for 10 years. Under RO2, a shorter time period (5-year) period is proposed, as information from stakeholders indicated that one or more actors have already started the substitution process. Still, it is not expected that all companies will be able to complete the transition to alternatives within this period, which will induce additional costs.

The main benefits of allowing use in spare parts is that it would avoid premature replacements of motor vehicles and aircrafts. Premature replacements will induce costs to society both in terms of additional resource use to manufacture new vehicles and aircrafts, but also environmental costs like increased energy use and wastes.

This restriction option is considered highly effective, as most of the primary sources of DP in the environment are removed. Emissions from use in aircrafts is limited to a short time-period, and the emissions from spare parts will naturally decline over time as vehicles and aircrafts are replaced with newer models which would not contain DP.

Not allowing a derogation for the use in motor vehicles will ensure a high level of emission reductions but is also expected to induce additional costs.

E.1.1.5. RO3 – use-specific derogations

RO3: A restriction on the manufacture, use and placing on the market in the EU of DP in concentrations > 0.1% w/w, from EiF + 18 months.

A derogation shall apply for the use in:

1) Production of aircrafts before EiF + 10 years; and

2) Production of motor vehicles before EiF + 5 years.

3) Production of spare parts for:

    i) aircrafts covered by the derogation in 1); and

    ii) motor vehicles covered by the derogation in 2)

Note that the provision in 3) 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 definition of aircraft and motor vehicle is defined as in Regulation (EC) No 1907/2006 on decaBDE. Derogations for electrical and electronic equipment, in line with derogation set out in Regulation (EC) No 1907/2006 on decaBDE, might be needed.

E.1.1.6. Justification for the selected scope of restriction option 3

RO3 is the most lenient of the three restriction options and the option with the lowest emission reduction capacity. RO3 is still expected to reduce the majority of the emissions of DP, as the proposed derogations are time limited. A 10-year derogation for the use in aircrafts and a 5-year derogation for the use in motor vehicles are included in this option, in addition to the use in spare parts.

The automotive industry has indicated that they will need five years to transition to an alternative, so it is expected that almost all actors will be able to substitute by the end of the transition period for use in motor vehicles (EiF + 5 years). Similarly, it is expected that a 10-year transition period will be sufficient for the aviation sector to identify and implement alternatives to DP. The cost to these industries is therefore expected to be small.

This restriction option will have a lower emission reduction capacity than RO1 and RO2, but it is believed that reductions in financial costs will outweigh this reduction in environmental benefits.

E.1.2. Discarded restriction options

Actors or sectors that would be heavily impacted by a restriction (e.g. when DP is a critical use) have a vested interest in putting forward evidence that a derogation for their use is needed. Since no stakeholders outside the automotive and aviation sectors provided such information, this would indicate that a restriction of DP would not result in disproportionate costs for their uses/sectors, and therefore it is concluded that derogations are not needed in any other sectors. Restriction options with derogations for uses outside the automotive and aerospace sectors have therefore not been considered. It remains a risk that there are actors with critical uses of DP who did not respond to the CfE or the stakeholder consultation, but in the absence of any such evidence, increasing the risk to the environment by choosing a more lenient restriction option is not justified.

Restricting DP without a derogation for recycling could reduce the recycling rate for affected waste streams in the short run. Over time, however, the removal of hazardous chemicals from the waste streams will allow for more materials to be recycled which is in line with the European Commission’s recently published *Circular Economy Action Plan For a cleaner and more competitive Europe* (EC, 2020b).

If DP is listed under the Stockholm Convention, this will impose obligations on Parties for how to handle waste, including products and articles upon becoming waste, that contain DP as well as for the recovery, recycling, reclamation, direct reuse and alternative use of DP containing wastes. More specifically Article 6 of the Stockholm Convention sets out that waste shall 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 disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option. It furthermore specifies that waste containing POPs are not permitted to be subjected to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of POPs. With the exeption of hexa-, and heptaBDE and tetra- and pentaBDE, no other 28 POPs have been listed with an exemption for recycling.

If a REACH restriction is in place for a substance, the common practice when a substance is listed as a POP under the Stockholm convention is to amend the appropriate Annex(s) and remove the REACH restriction from Annex XVII (EC, 2014). Regulatory uncertainty would therefore arise if there is an existing derogation for recycling of materials containing DP, which potentially would be removed if DP is listed under the Stockholm Convention. Although the outcome of the Stockholm Convention process is uncertain, harmonisation of the regulations should be considered when deciding on the scope of the REACH restriction.

A derogation for recycling was considered in the decaBDE REACH restriction process, but the Committees (RAC and SEAC) concluded that recyclers would be able to meet the 0.1% concentration limit, and no derogation for recycled materials was proposed nor granted for decaBDE. Similarly, decaBDE was listed in the Stockholm Convention without an exemption for recycling. Considering the similarities in the properties and uses of DP and decaBDE, as well as the lack of information from recyclers, it is considered likely that recyclers will be able to meet the conditions under all three restriction options.

Based on these considerations, derogations for recycled materials containing DP have therefore not been included.

Restriction options with application-specific derogations within the automotive or aviation sectors (rather than the proposed broader use derogations) have also been discarded, due to lack of information on which applications DP have critical functions in.

E.1.3. Other Union-wide risk management options than restriction

This section gives a short description of other Union-wide legislative options that have the potential to influence emissions of DP to the environment.

E.1.3.1 Waste management

A mandatory destruction (incineration) scheme could be considered as a risk management option for the waste life-stage. However, this option is not currently considered to be feasible because of the implementation challenges associated with harmonising waste management practices across the EU and the identification of the articles containing DP.

E.1.3.2 Authorisation

DP was identified by ECHA for prioritisation to Annex XIV of REACH (substances subject to Authorisation) in its 9th draft recommendation (ECHA, 2019a). However, this risk management option may lead to potential regulatory uncertainty resulting from the nomination of DP to the Stockholm Convention. For example, the *REACH and the Stockholm Convention as well as the UNECE POP Protocol: A Common Understanding* (EC, 2014) states that if a substance is included in Annex XIV and subsequently banned under the Stockholm Convention, *not only should all existing authorisations be withdrawn but all applications for authorisation should be refused*. Authorisation is thus not considered an appropriate risk management option. This is in line with what the European Commission decided when decaBDE went through the same process in 2014-15.

E.1.3.3 Stockholm Convention on POPs

Regulation (EU) 2019/1021 (the POPs regulation) implements the Stockholm Convention on POPs in the EU. Norway proposed to list DP as a POP under the Stockholm Convention in 2019 and the draft risk profile is still under scrutiny (POPRC, 2021a, POPRC, 2021b). This means that the REACH restriction process will finalise earlier, and the conclusions can be used to inform the Stockholm Convention process. If a substance is listed under the Stockholm Convention on POPs the practice is to implement this in EU law by amending the POPs regulation and by removing the corresponding restriction from Annex XVII of REACH (EC, 2014).

E.1.3.4 RoHS Directive

Based on the information described in A.2. Uses, there are uses of DP that may fall within the scope of Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS). The RoHS Directive restricts (with exceptions) the use of listed hazardous substances in the manufacture of various types of electronic and electrical equipment (EEE).

Although DP is not currently listed as a restricted substance under RoHS, the Dossier Submitter notes that the Directive applies to some types of EEE that may contain DP, such as large and small household appliances and monitoring and control instruments.

The RoHS Directive, however, does not apply to other relevant applications of DP, such as "means of transport for persons or goods, excluding electric two wheeled vehicles which are not type approved." Considering that both the automotive and aviation sectors were found to be important sources of DP in the stakeholder consultation (see section A.2.4. Summary and conclusions), the exemption of these main applications from the RoHS Directive indicate that this risk management option would not be effective in reducing emissions of DP.

E.1.3.5 Industrial Emissions Directive (IED)

The Industrial Emissions Directive (2010/75/EU) requires operators of industrial installations to obtain a permit from the national authorities to continue operating. Permits place a requirement for the use of Best Available Techniques (BAT) to reduce emissions and the impact on the environment as a whole.

The IED has the potential to limit emissions from permitted sites. However, many downstream users, such as manufacturers of articles containing DP, are unlikely to require a permit and be subject to IED. Additionally, IED only control parts of the lifecycle and will thus have no effect on the service life emissions or release from the waste stage of DP containing articles.

On the basis that the provisions of the IED will not apply to all sites where DP may be used, and that the provisions do not apply to key life cycle stages that may create a substantial part of the emissions (see Table 57), the Dossier Submitter considers that the provisions of the IED will not achieve the goal of minimising all environmental emissions from DP.

E.2. Alternatives

This section identifies and analyses potential alternatives to DP in terms of hazards, technical feasibility, economic feasibility, and availability. Section E.2.1. sets out the functions and corresponding identified uses of DP, but only for those uses confirmed in the stakeholder consultation as still being used, are assessed for alternatives.

Section E.2.2 sets out the approach for identifying and screening alternative substances to DP (Section E.2.2.2), a discussion on selecting alternative substances to DP as a flame retardant (Section E.2.2.3) and a discussion on selecting alternative substances to DP as an extreme pressure additive (Section E.2.2.4). Non-chemical alternatives are inherently different than chemical alternatives and have therefore been treated separately in Section E.2.2.5.

The assessment of hazards, technical feasibility, economic feasibility and availability of each shortlisted alternatives are presented in Section E.2.3., whilst the conclusions from the assessment of alternatives are summarised in Section E.2.4.

E.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 hexachlorocyclopentadiene. 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.

E.2.1.1. 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 release would be limited[39] (see also B.9. Exposure assessment).

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, 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 the automotive and the aviation sectors were grouped into "other uses" (15 – 33%), which also includes imported articles (Section A.2.4. Summary and conclusions). 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:

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[39] 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.

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.

E.2.1.2. 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 71 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 71) 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 71 was collected from prior literature (as referenced in the table) and the stakeholder consultation carried out for this restriction proposal (see Section A.2.3. Information from stakeholders) and builds directly on the narrative discussion of uses presented in Section A.2. Uses.

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 71 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 EU. In the following sections, the term "confirmed use" relates to uses which has 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 71 and in the conclusions of Section A.2. Uses.

Table 71: 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 A.2.3. Information from stakeholders)**
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 A.2.3. Information from stakeholders)**

Polymer (or other substrate)	**Application type**	**Notes on technical function, loading rate and synergist systems**	**Comments**
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 (see Section A.2.3. Information from stakeholders)**
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)

Polymer (or other substrate)	**Application type**	**Notes on technical function, loading rate and synergist systems**	**Comments**
Hypalon	Elastomers	FR at 5-6% with antimony trioxide (OxyChem, 2007 manual)	No further information found
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

E.2.1.3. 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 A.2. Uses). Table 72 shows the confirmed uses of DP in non-polymers.

Table 72: Use of DP in materials other than 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 A.2.3. Information from stakeholders).**
Caulk	Building materials		Potential commercial use (see Section A.2. Uses).
Greases		Dual function: FR and seizure resistance (pers comm – stakeholder consultation feedback)	**Confirmed commercial use of DP (see Section A.2.3. Information from stakeholders).**
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 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 A.2. Uses)
Foam	Foams / sound-absorbing panels		**Confirmed commercial use of DP (see A.2.3. Information from stakeholders).**
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 A.2. Uses).

Material	**Application type**	**Technical function, loading rate and synergist systems**	**Comments**
Non-woven wallpaper	Wall papers		Relevance in EU is uncertain (see Section A.2. Uses)
PVC/paper	Wall papers		Relevance in EU is uncertain (see Section A.2. Uses)
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 A.2.3. Information from stakeholders) and commercially available for the use in fireworks (Impag, 2018).**
Textiles	Textile coating (i.e. finishing product) / clothing / curtains	Application of auxiliary padding liquor at normally up to 50 kg/t textile (OECD textile ESD, 2004[40]).	Further information on the nature of the coating is not available (see Section A.2. Uses). 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 A.2. Uses)
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 A.2. Uses)
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
			No further information found

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

Material	**Application type**	**Technical function, loading rate and synergist systems**	**Comments**
Unknown (food packaging and storage)			

E.2.1.3.1 Dechlorane Plus 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 CfE, the automotive industry indicated an essential use for DP in greases (see Section A.2.3. Information from stakeholders). 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.

E.2.1.4. Summary of function and uses

Table 73 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 73: 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

Table 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 Annex XV restriction proposal 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 where provided by stakeholders.

E.2.2. Identification of potential alternative substances and techniques fulfilling the function

E.2.2.1. 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, Section E.2.2.5. Non-chemical alternatives 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.

E.2.2.2. 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 technically and economically feasible, but also have a favourable hazard profile to avoid regrettable substitution and subsequent regulatory action on the alternative.

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. 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, 2021b), 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.

E.2.2.2.1. First screening of Dechlorane Plus 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 (EU) 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.

E.2.2.2.2. 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):

1) Substance appears to be suitable for both plastics (P) and coatings (C);

2) Substance appears in at least five literature sources as a potential alternative for use in polymers;

3) Substance appears as potentially suitable for use in coatings, and in the absence of detailed information this includes adhesives and sealants; and

4) 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 Section E.2.2.4. Discussion of alternatives to Dechlorane Plus as an extreme pressure additive.

E.2.2.2.3. 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 74 were retained after applying the screening criteria described in Section E.2.2.2.2. Initial screening criteria (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 E.2.3. Hazard comparison, technical and economic feasibility, and availability of alternatives for more details).

Table 74: Shortlist of potential alternatives to DP

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	✓		*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)*
1309-42-8 13760-51-5	Magnesium hydroxide	✓	✓	*KemI (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	✓		*KemI (2004, 2005, 2009), Albemarle (2013) Chemtura (2011), ICL Industrial Products (2013)*
14728-39-9 68333-79-9	Ammonium polyphosphate	✓	✓	*KemI (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	✓	✓	*KemI (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, Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*
21850-44-2	Tetrabromobisphenol-A bis (2,3-dibromopropyl ether)	✓		*KemI (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	✓	✓	*KemI (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	✓		*KemI (2004, 2005, 2009), Lassen et al. (2006), PAKALIN ET AL. (2007), US EPA (2012-2014), Illinois EPA (2007), Troitzsch (2011), UK*

CAS No.	**Alternative Substance**	**Plastics**	**Coatings**	**Literature source**
	(Diethylphosphinic acid, aluminum salt)			*HSE (2012), PINFA (2010a), PINFA (2010b), PINFA (2010c), PINFA (2013)*
26444-49-5	Cresyl diphenyl phosphate	✓	✓	*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), Albemarle (2013) Chemtura (2011) ICL Industrial Products (2013)*
32588-76-4	Ethylene bis(tetrabromophthalimide)	✓	✓	*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)*
37853-59-1	Bis(tribromophenoxy)ethane	✓		*KemI (2004, 2005, 2009), Lassen et al. (2006), Washington State (2006), PAKALIN ET AL. (2007), 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,*

CAS No.	Alternative Substance	Plastics	Coatings	Literature source
				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.

E.2.2.3. Discussion of alternatives to Dechlorane Plus as a flame retardant

The literature sources detailed in Table 74 (initial screening – step 1) described in Section E.2.2.2.2 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 Section E.2.2.2. Approach for selecting alternative substances to Dechlorane Plus). 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.

- Chlorendic anhydride;
- Ammonium polyphosphate;
- Aluminium hydroxide; and
- Ethane-1,2-bis (pentabromophenyl) (EBP).

E.2.2.4. Discussion of alternatives to Dechlorane Plus as an extreme pressure additive

Section E.2.1.3. Non-polymer uses of Dechlorane Plus 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[41]:

- 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

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

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.

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 (see Section A.2.3. Information from stakeholders). 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.)[42]:

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.*

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

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°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°C. Worm gearsets*[43] *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.*
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).

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

E.2.2.4.1. 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 polyolester 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.

E.2.2.4.2. 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.

E.2.2.4.3. 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).

E.2.2.4.4. Possible shortlist of alternatives for Dechlorane Plus 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 A.2.3. Information from stakeholders).

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 candiate 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 regaded 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 mentioned in Section E.2.2.4. Discussion of alternatives to Dechlorane Plus as an extreme pressure additive 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 alternatives for lubricant function in extreme pressure additives are summarised in Table 75 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 75: 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	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.
	Medium chain chlorinated paraffins (MCCP) (alkanes, C14-17, chloro) CAS 85535-85-9	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).

E.2.2.5. Non-chemical alternatives

E.2.2.5.1 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, see Section E.2.2.5.2. Alternative techniques to DP in its function as a Flame Retardant.

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 (see A.2.3. Information from stakeholders). 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.

E.2.2.5.2. Alternative techniques 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; Vaziri et al, 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 (Albemarle, 2015, Great Lakes Solutions, 2013, UK HSE, 2012). 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 Center 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.

E.2.2.5.3. 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.

E.2.2.6 Summary and Shortlist of Alternatives to Dechlorane Plus

Given the wide range of 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 76 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 E.2.3. Hazard comparison, technical and economic feasibility, and availability of alternatives that discusses the risk reduction, technical and economic feasibility, and availability of these DP alternatives.

Table 76: Shortlist of alternatives to DP in its function as both a flame retardant and as an extreme pressure additive in grease/lubricant

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).*

E.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 E.2.2. Identification of potential alternative substances and techniques fulfilling the function 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, E.2.3.1 – E.2.3.7 detail the technical feasibility of alternatives that have been confirmed with each section comprising of the following subsections:

- 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 affect) and price. Due to a lack of available information, it was not possible to factor any other cost parameters.

E.2.3.1. Assessment of chlorendic anhydride (CAS No. 115-27-5)

E.2.3.1.1. Availability of chlorendic anhydride

The REACH registration tonnage band for chlorendic anhydride is 1 000 – 10 000 tonnes per annum. 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.

E.2.3.1.2. 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.

E.2.3.1.3. 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, 2020g) are summarised in Table 77.

Table 77: Predicted properties of 1-chlorendic anhydride (from REACH dissemination dossier (accessed March 2021))

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 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, 2018a). Chlorendic anhydride hydrolyses rapidly to chlorendic acid and exposure to the hydrolysis product may occur when hydrolysis during use is significant.

E.2.3.1.4. 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 detailed in Section E.2.2. Identification of potential alternative substances and techniques fulfilling the function.

E.2.3.1.5. 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 78.

Table 78: Prices for chlorendic anhydride

Price (€/kg)	Price compared to DP	Sources
22	See Table H4	Alibaba.com (2020a)
111	See Table H4	Alibaba.com (2020a)
63	See Table H4	Molbase.com (2020a)
106	See Table H4	(P212121, 2020)
6	See Table H4	(Zauba.com, 2015)
6	See Table H4	(Hangzhou Trigger Chemical, 2020)
74	See Table H4	(Alfa Aesar, 2020)
Average 56	**> DP Price**	

E.2.3.1.6. Conclusions on chlorendic anhydride

Table 79 summarises the conclusions on feasibility and suitability of chlorendic anhydride as an alternative for DP.

Table 79: 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 on environmental effects have been requested. For the main hydrolysis product (chlorendic

Category	Conclusion
	acid) testing for the mutagenicity is required. 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 detailed in E2.2.2.
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 substitute for DP.

E.2.3.2. 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 E.2.2. Identification of potential alternative substances and techniques fulfilling the function.

E.2.3.2.1. Availability of ammonium polyphosphate

The REACH registration tonnage band for ammonium polyphosphate is 10 000 – 100 000 tonnes per annum. 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.

E.2.3.2.2. 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.

E.2.3.2.3. 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, 2020f) is summarised in Table 80.

Table 80 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.

E.2.3.2.4. 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 E.2.2. Identification of potential alternative substances and techniques fulfilling the function.

E.2.3.2.5. 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 81 presents information found on loading in available literature.

Table 81: Loading for ammonium polyphosphate

Loading (% w/w)	Material / Use	Sources
30%	PP	(Wu et al., 2008)
18%	PP / PE	(Fr.polymerinsights.com, n.d.)
25%	PP / PE	Fr.polymerinsight.com (n.d.)
19%	PU	(Yao et al., 2017)
20%	PP / PVC / PE	Changsha Green Mountain Chemical Co (n.d.)
20%	PP / PVC / PE / PU	Connect Chemicals (2020)
80%	PP	(Yang et al., 2019)
35%	PP	(Shao et al., 2014)

Tables 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 82.

Table 82: Prices for ammonium polyphosphate

Price (€/kg)	Price compared to DP	Sources
1.7	See Table H5	Alibaba.com (2020b)
4.4	See Table H5	Alibaba.com (2020b)
2.3	See Table H5	(Zauba.com, 2016)
2.9	See Table H5	Zauba.com (2016)
1.1	See Table H5	Made-in-china.com (2020a)
5.5	See Table H5	Made-in-china.com (2020a)
1.8	See Table H5	(Shandong Chenxu New Material, 2020a)
2.1	See Table H5	Shandong Chenxu New Material (2020a)
1.3	See Table H5	dir.indiamart.com (2020a)
3.5	See Table H5	dir.indiamart.com (2020a)
Average 2.7	**< DP Price**	

E.2.3.2.6. Conclusions on ammonium polyphosphate

Table 83 summarises the conclusions on feasibility and suitability of ammonium polyphosphate as an alternative for DP.

Table 83: 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.

E.2.3.3. 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).

E.2.3.3.1. Availability of aluminium hydroxide

The REACH registration tonnage band for aluminium hydroxide is 1 000 000 – 10 000 000 tonnes per annum. 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.

E.2.3.3.2. 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.

E.2.3.3.3. 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 84.

Table 84: 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 biomagnify	BCF values range from ~100 l/kg to up to 11 000 l/kg depending upon the exposure conditions.
PNECs	$PNEC_{water}$ = no hazard identified $PNEC_{marine\ water}$ = no hazard identified $PNEC_{sediment}$ = insufficient data available $PNEC_{marine\ sediment}$ = insufficient data available $PNEC_{soil}$ = insufficient data available $PNEC_{oral\ (secondary\ poisoning)}$ = 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.

E.2.3.3.4. 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 E.2.2. Identification of potential alternative substances and techniques fulfilling the function.

E.2.3.3.5. 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 85 presents information found on loading in available literature.

Table 85: Loading for aluminium hydroxide

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

Table 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 86 shows the price information found for aluminium hydroxide.

Table 86: Prices for aluminium hydroxide

Price (€/kg)	Price compared to DP	Sources
0.3	See Table H5	alibaba.com (2020c)
0.9	See Table H5	alibaba.com (2020c)
0.9	See Table H5	Molbase.com (2020b)
2.2	See Table H5	Molbase.com (2020b)
0.5	See Table H5	Shandong Chenxu New Material (2020b)
2.2	See Table H5	Shandong Chenxu New Material (2020b)
0.4	See Table H5	Made-in-china.com (2020b)
Average 1.1	**<< DP Price**	

E.2.3.3.6. Conclusions on aluminium hydroxide

Table 87 summarises the conclusions on feasibility and suitability of aluminium hydroxide as an alternative for DP.

Table 87: 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.
Technical feasibility	The most common use of aluminium hydroxide is in ‘Low Smoke Flame Retardant’ cables. It is considered a technically feasible alternative to DP for the function flame retardancy where DP functions as a fire retardant in cables.

Category	Conclusion
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.

E.2.3.4. Assessment of ethane-1,2-bis (pentabromophenyl) (EBP) (CAS No. 84852-53-9)

E.2.3.4.1. 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.

E.2.3.4.2. 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.

E.2.3.4.3. 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 88. Where different data are reported in the disseminated registration dossier on the ECHA website (ECHA, 2020i) this is noted in the comment column.

Table 88: 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 <1×10^{-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, ECHA, 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.

E.2.3.4.4. Technical and economic 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 E.2.2. Identification of potential alternative substances and techniques fulfilling the function.

E.2.3.4.5. 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 89. The loading reported by ECHA indicates that EBP is used in similar concentrations as DP.

Table 89: Loading for EBP

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

Table 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 found for this substance is shown in Table 90.

Table 90: Prices for EBP

Price (€/kg)	Price compared to DP	Sources
5.5	See Table H7	alibaba.com (2020d)
11.1	See Table H7	alibaba.com (2020d)
6.8	See Table H7	Guanzhou Realise Green Chemical Technology (2008)
6.9	See Table H7	Guanzhou Realise Green Chemical Technology (2008)
3.3	See Table H7	Chongqing Caifchem (2020)
3.9	See Table H7	Chongqing Caifchem (2020)
5.0	See Table H7	Qingdao Richkem (2020)
4.4	See Table H7	ECHA (2015b)
5.0	See Table H7	ECHA (2015b)
Average 5.8	**< DP Price**	

E.2.3.4.6. Conclusions on ethane-1,2-bis (pentabromophenyl)

Table 91 summarises the conclusions on feasibility and suitability of EBP as an alternative for DP.

Table 91: 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, ECHA, 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, which combined implies that the alternative is economically feasible.

Category	Conclusion
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.

E.2.3.5. Assessment of long chain chlorinated paraffins (CAS No. 63449-39-8) - LCCP

E.2.3.5.1. Availability of long chain chlorinated paraffins

The REACH registration tonnage band for long chain chlorinated paraffins is 10 000 – 100 000 tonnes per annum. 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.

E.2.3.5.2. 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.

E.2.3.5.3. 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., 2009b). The relevant property information from Brooke et al. (2009b) is summarised in Table 92.

Table 92: Predicted properties of long chain chlorinated paraffins (from (Brooke et al., 2009b) 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	~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 25°C 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)

Property	**Value**	**Comment**
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 (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/vPvB-properties of those common constituents.

Brooke et al. (2009b) 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., 2009b). 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 (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.

E.2.3.5.4. Technical and economic 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 E2.2.

E.2.3.5.5. 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 lower than that of DP. Price information found for LCCPs is presented in Table 93.

Table 93: Prices for LCCPs

Price (€/kg)	Price compared to DP	Sources
2	See Table H8	alibaba.com (2020e)
1	See Table H8	alibaba.com (2020e)
1	See Table H8	Shandong Chenxu New Material (2020c)
Average 1	**< DP Price**	

E.2.3.5.6. Conclusions on long chain chlorinated paraffins

Table 94 summarises the conclusions on feasibility and suitability of LCCPs as an alternative for DP.

Table 94: Conclusions 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.

E.2.3.6. Assessment of tricresyl phosphate (CAS No. 1330-78-5; EC 809-930-9) - TCP

E.2.3.6.1. Availability of tricresyl phosphate

The REACH registration tonnage band for tricresyl phosphate is 1 000 – 10 000 tonnes per annum. 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.

E.2.3.6.2. 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 (assessed 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, 2016c). 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.

E.2.3.6.3. Environment risks related to tricresyl phosphate

The notified classifications in the ECHA classification and labelling inventory 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., 2009a). The relevant property information from (Brooke et al., 2009a) is summarised in Table 95.

Table 95: Predicted properties of tricresyl phosphate (from (Brooke et al., 2009a) 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

Property	Value	Comment
		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. (2009a) 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, 2016c).

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.

E.2.3.6.4. Technical and economic feasibility of tricresyl phosphate

As described in Section E.2.2. Identification of potential alternative substances and techniques fulfilling the function 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 E.2.2. Identification of potential alternative substances and techniques fulfilling the function.

E.2.3.6.5. 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 96.

Table 96: Prices for TCP

Price (€/kg)	Price compared to DP	Sources
4	See Table H9	Alibaba.com (2020f)
6	See Table H9	Alibaba.com (2020f)
7	See Table H9	Molbase.com (2020c)
8	See Table H9	Molbase.com (2020c)
9	See Table H9	(dir.indiamart.com, 2020b)
10	See Table H9	dir.indiamart.com (2020b)
11	See Table H9	N SHASHIKANT & CO (n.d)
Average 8	**< DP Price**	

E.2.3.6.6. Conclusions on tricresyl phosphate

Table 97 summarises the conclusions on feasibility and suitability of tricresyl phosphate as an alternative for DP.

Table 97: 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.

E.2.3.7. Assessment of diallyl chlorendate (CAS No. 3232-62-0)

E.2.3.7.1. 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.

E.2.3.7.2. 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).

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).

E.2.3.7.3. Environment risks related to diallyl chlorendate

Very limited information on the environmental risks from diallyl chlorendate is available. The properties in Table 98 have been predicted for the substance by the (US EPA, 2021).

Table 98: 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.

E.2.3.7.4. 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.

E.2.3.7.5. Economic feasibility of diallyl chlorendate

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

E.2.3.7.6. Conclusions on diallyl chlorendate

Table 99 summarises the conclusions on feasibility and suitability of diallyl chlorendate as an alternative for DP.

Table 99: 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.

E.2.4. 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 also found to be potentially suitable for DP when used as extreme pressure additive – LCCPs and TCP.

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 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.

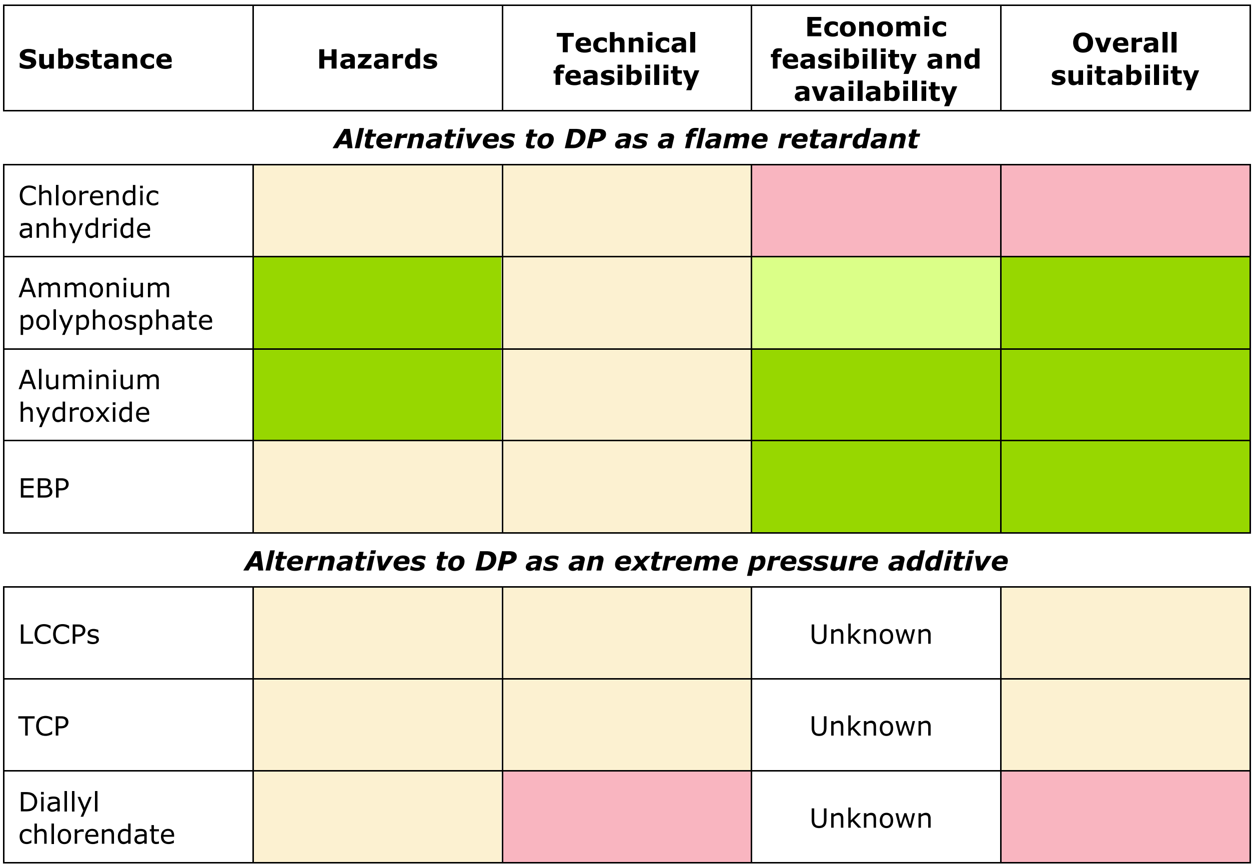
Since only the affected actors have the specific information required to fully assess the alternatives to DP, it is considered their responsibility to provide the necessary data to enable the public to carry out a fair assessment. Since no specific technical criteria has been provided, it is assumed that the assessment of alternatives for the functions of DP as a flame retardant and lubricant and its conclusions are valid.

If affected actors do not agree with the conclusions, it is strongly recommended that they provide information in the public consultation allowing the Dossier Submitter to revise this analysis and its conclusions.

Table 100 summarises the conclusions from the assessment of alternatives carried out for the confirmed used of DP. Color-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 100: Summary of assessment of alternatives



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

E.3. Restriction scenario(s)

The restriction scenarios are defined by the anticipated behaviour of affected actors (current downstream users of DP) in response to the restriction options. All actors will not necessarily react the same way when faced with a restriction, but they will choose amongst the options that are available to them. These so-called behavioural responses must be defined so that they can be included in the socio-economic analysis in a meaningful way.

The stakeholder consultation did not provide much information in terms of most likely behavioural responses to a possible restriction on DP. Contextual information is therefore used to build plausible scenarios for such behavioural responses. If new information is received by industry, these behavioural responses can be adjusted accordingly, and a more accurate assessment of impacts would be possible.

The behavioural options deemed most plausible are:

1) **Switch to an alternative, resulting in transfer of market shares between EU actors**: This option is only available for the uses for which alternatives are available

from the EiF + allowed transition period, where the transition period may vary between sectors. Those that can switch to an alternative sooner may gain a greater EU market share (e.g. first mover advantage).

2) **Temporarily cease parts of production until an alternative is found**: If there are no alternatives available at EiF + allowed transition period, production of products depending on DP will have to cease. During the downtime, loss of sales, market share and possibly loss of jobs will occur.

3) **Relocation (requires non-EU customers)**: For the users that have customers outside the EU, relocations of (parts of) their operations is a possible response to an EU-wide restriction.

4) **Permanently reduced production (full or partial closure)**: For users that cannot find an alternative or the cost of transitioning is too high, the remaining option is to cease parts or all production.

The responses will vary between the three restriction scenarios and it is not expected that each downstream user sector will respond in the same way. It is also important to highlight that the assumed responses set out below reflect the share of DP used that falls within each response category, not the share of actors. An illustrative example is set out below:

Actor A and Actor B produce goods containing DP that account for 50% of the market each. Actor A is able to find an alternative in time, whilst actor B is not. When use of DP ceases, Actor A is able to increase its productions and as a result increases its overall market share to 80%, while Actor B is still looking for an alternative. The total response of the market will then be that 80% of the market switch to alternatives, i.e. distributional effects are not quantified as costs or benefits as they cancel each other out.

The assumed behavioural responses associated with each RO are based on information received from stakeholders, publicly available information and expert judgements, and the reasoning is set out in SectionE.3.3. Other uses, including imported articles.

E.3.1. Automotive sector market response

The three restriction options have the following requirements set out for the automotive sector:

RO1: A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF + 18 months.

RO2: A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF + 18 months.

A derogation shall apply for the use in:

2) ii) production of spare parts for motor vehicles manufactured before EiF + 18 months.

RO3: A restriction on the manufacture, use and placing on the market in the EU of DP in concentrations > 0.1% w/w, from EiF + 18 months.

A derogation shall apply for the use in:

> 2) Production of motor vehicles before EiF + 5 years.
>
> 3) ii) A derogation shall apply for the use in production of spare parts for motor vehicles manufactured before EiF + 5 years.

Note that under RO2 and RO3 allows continued production of spare parts for the remaining lifetime of any motor vehicle manufactured before EiF + 18 months and EiF + 5 years respectively. Derogations for electrical and electronic equipment, in line with derogation set out in Regulation (EC) No 1907/2006 on decaBDE, might be needed.

For the purpose of this analysis the following timeline is assumed:

- EiF = mid-2023;
- EiF + 18 months = Beginning of 2025
- EiF + 5 years = mid-2028.
- EiF + 10 years = mid-2033

The automotive industry indicated in the stakeholder consultation carried out for this restriction proposal that they were not aware of any suitable alternatives to DP. However, some stakeholders also believed that industry-wide use of alternatives could likely be implemented if a 5-year transition period was granted for the sector. Additionally, it was indicated that it is not feasible to substitute DP in spare parts, due to regulatory challenges. According to ACEA (2020b) the automotive sector spends the most on R&D in the EU (~€60 billion per year), which indicates that rapid technological changes may occur in the sector. It is therefore possible that some actors will be able to substitute in less than five years.

The strictest restriction scenario (RO1) has an 18-months transition period for all sectors. The EiF is assumed to be mid-2023, which means that manufacture, use and placing on the market of DP must cease by 2025 (EiF + 18 months) under this scenario. For the purpose of this analysis, it is assumed that most actors will not start the substitution process until EiF (2023). However, considering that the substance was identified as an SVHC in 2018, recommended for Annex XIV in 2019 (ECHA, 2019c), proposed listed as a POP under the Stockholm Convention in 2019 and the recent announcement of the initiation of the restriction process may have triggered/accelerated R&D efforts to find an alternative to DP. For RO1 it is therefore assumed that half of the DP market will be able to transition to alternatives by 2025, which includes the transfer of market shares from companies that started the transition period late to companies that started the process earlier (early movers). Only 10% of the market is assumed to be permanently reduced either due to relocation or reduced production. The remaining 40% will be faced with a temporary reduction of production until they are able to transition using an alternative.

For the automotive sector, the only difference between RO1 and RO2 is that an exemption for use of DP in spare parts is granted. In this analysis it has been assumed that 10% of DP is used in spare parts, and as such, the derogation for spare parts will not induce major differences in terms of behavioural responses within the sector. The most important difference is that there will be less permanent loss of production - reduced from 10% under RO1 to 5% under RO2.

Under RO3 the automotive sector is granted an extended transition period of 5 years instead of 18 months. If companies start the substitution process at EiF (mid-2023) they will, according to information provided by stakeholders, complete the process by mid-2028. It is therefore expected that almost the entire market (95%) will transition to alternatives without severe interruptions of activity. The remaining 5% is assumed to be niche applications for which some additional time is needed to fully transition to alternatives, whilst no permanent reduction in production or relocation is deemed necessary.

Another response that actors may choose in order to mitigate costs is to manufacture more of the affected parts/products before EiF + transition period and actors (e.g. OEMs or suppliers) stockpile these parts. This is not set out as a separate behavioural response, due to the difficulties of including this in the emissions estimation and cost calculations. The result of such behaviour would be to delay emission reductions, as well as avoiding some economic costs (i.e. lost sales avoided).

Another cost mitigation option is to delay delivery of orders, resulting in a so-called backlog. The typical backlog in the automotive sector is short (maximum a few months), so it is not expected that this will be a widespread market response. A backlog could be an option in the cases where the actor is close to fully transitioned to an alternative and need a short transition period before delivery can be made. There is, however, some risk that the actor(s) will lose market shares or receive financial penalties due to contractual requirements as a result, if the backlog gets too long. This response has not been explicitly modelled, but if included, it could to some extent reduce the costs of the restriction as profit losses would be reduced.

The assumed behavioural responses for the automotive sector associated with each of the restriction options (RO1-RO3) are set out in Table 101.

Table 101: Assumed behavioural responses in the automotive sector

Behavioural responses	**Share of DP volume**		
	RO1	**RO2**	**RO3**
Switch to an alternative, including transfer of market shares between EU actors.	50%	50%	95%
Temporarily cease parts of production, until an alternative is found	40%	45%	5%
Relocation (requires non-EU customers) and permanently reduced production	10%	5%	0%

Note: Relocation and full closure is grouped, as the impacts to the EU society will be the same from these two behavioural responses

E.3.1.1. Uncertainties in the time needed to transition to alternatives

In the case of DP, industry has not provided any specific technical or economic reasons for why alternatives to DP are considered infeasible. The only justification provided was the lack of knowledge of any feasible alternatives. In the analysis of technical feasibility several potential alternatives to DP were found, all of which were considered technically feasible. If more specific information on functional criteria was available, this conclusion may or may not change, but in the absence of such information, it is reasonable to assume that (a combination of) these alternatives would be able to replace DP.

The behavioural responses set out in Table 101 is based on information from stakeholders, i.e. that there are currently no known alternatives and time is needed to identify potential substances before testing and implementation can be carried out. However, if the conclusions from the analysis of technical feasibility holds, the time needed might be shorter and hence the share able to switch to alternatives by 2025 (EiF + 18 months) could be higher than indicated. The automotive industry also indicated that an extended transition period was needed for decaBDE during the beginning of the REACH restriction process for this substance, whilst it later became apparent that an extended transition period was not needed, which could be the case for DP as well. However, based on current evidence, it has not been possible to firmly conclude on the time needed to transition to alternatives nor the share of the market that can successfully transition to alternatives under the three restriction scenarios.

Specific questions on alternatives and the substitution process will be posed in the public consultations. If new information is provided, the abovementioned assumptions can be refined.

E.3.2. Aviation sector market response

The three restriction options have the following requirements set out for the aviation sector:

RO1: A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF + 18 months.

RO2: A restriction on the manufacture, use and placing on the market in the EU of Dechlorane Plus (DP) in concentrations > 0.1%, from EiF + 18 months.

A derogation shall apply for the use in:

1) Production of aircrafts before EiF + 5 years; and

2) i) Production of spare parts for aircrafts covered by the derogation described in 1).

RO3: A restriction on the manufacture, use and placing on the market in the EU of DP in concentrations > 0.1% w/w, from EiF + 18 months.

A derogation shall apply for the use in:

1) Production of aircrafts before EiF + 10 years; and

3) i) Production of spare parts for aircrafts covered by the derogation described in 1).

Note that under RO2 and RO3 continued production of spare parts for the remaining lifetime of any aircraft manufactured before EiF + 5 years and EiF + 10 years respectively. Derogations for electrical and electronic equipment, in line with derogation set out in Regulation (EC) No 1907/2006 on decaBDE, might be needed.

For the purposes of this analysis the following timeline is assumed:

- EiF = mid-2023;
- EiF + 18 months = Beginning of 2025
- EiF + 5 years = mid-2028; and
- EiF + 10 years = mid-2033.

The aviation sector is subject to strict regulations, where some parts need rigorous testing and compliance demonstrations in order to be certified for use. New materials or design changes can only be introduced to the aircraft if testing and compliance demonstrations has been approved. The approval will result in the issuance of a Supplemental Type Certificate (STC), change approval or repair approval (ECHA, 2015b). This implies that transitioning to alternatives can be more time consuming for the aviation sector than for other industries.

It is known that at least one large company has started that substitution process and might be able to transition to alternatives by 2025, and possibly capture some of the market shares of other companies. However, transition of market shares from one actor to another may be more difficult in this sector than for automotive uses due to more specialised and complex equipment as well as long-term contractual arrangements. RO1 is therefore expected to be challenging for the aviation sector and hence it is assumed that a large part of the market (70%) will experience a temporary cease of production under this scenario. The fact that at least one company has started the substitution process is used as the basis for the assumption that 20% of the market is able to successfully transition to alternatives before 2025. 10% of the market is expected to relocate or permanently cease production under this scenario.

Based on (limited) information from stakeholders, it is expected that substitution is feasible for most uses by mid-2028, which is reflected in the assumed 70% market share being able to continue without major interruptions of activities under RO2. The share of the market that permanently cease or relocate is reduced to 0%, whilst the remaining 30% of the market is assumed to experience a temporary production halt.

RO3 allows manufacture using DP up until mid-2033 and thereby assumed to enable ~95% of the market to transition to alternatives without major disruptions of activities. The remaining 5% of the market is assumed to be niche products, for which some additional time is needed (assumed 2 years) to fully transition to alternatives.

Stockpiling is, as in the automotive sector, a viable option (although not preferred from an environmental point of view). Again, this will lead to lower emission reductions and reduced costs, neither of which have been included in this analysis.

An extensive backlog seems to be more common in the aviation sector than was found for the automotive sector. In February 2020, Boeing had an all-time high backlog of 5 964 aircrafts, representing 8.9 years of shipments (Forecast International, 2020). Extending the backlog, for a limited amount of time, until an alternative is implemented may therefore be a viable option for some actors. An extended backlog is not included as a separate response but is reflected in the chosen share that is able to transition to alternatives without production halts.

The assumed behavioural responses for the aviation sector associated with each of the restriction options (RO1-RO3) are set out in Table 102.

Table 102: Assumed behavioural responses in the aviation sector

Behavioural responses	**Share of DP volume**		
	RO1	**RO2**	**RO3**
Switch to an alternative, including transfer of market shares between EU actors.	20%	70%	95%
Temporary cease parts of production until an alternative is found	70%	30%	5%
Relocation (requires non-EU customers) and permanently reduced production	10%	0%	0%

Note: Relocation and full closure is grouped, as the impacts to the EU society will be the same from these two behavioural responses

E.3.2.1. Uncertainties in the time needed to transition to alternatives

As was the case for the automotive industry, the aviation industry has not provided any specific technical or economic reasons for why alternatives to DP are considered infeasible. No specific information on functional criteria was made available, which means that it cannot be excluded that alternatives identified as feasible in Annex E.2.3. Hazard comparison, technical and economic feasibility, and availability of alternatives are suitable for uses of DP in aircrafts.

The behavioural responses set out in Table 102 is based on information from the stakeholders, i.e. that there are currently no known alternatives and time is needed to identify potential substances before testing and implementation can be carried out. However, if the conclusions from the analysis of technical feasibility hold, the time needed might be shorter and hence the share able to switch to alternatives by 2025 (EiF + 18 months) and by 2028 (EiF + 5 years) could be higher than indicated. However, based on current evidence, it has not been possible to firmly conclude on the time needed to transition to alternatives nor the share of the market that can successfully transition to alternatives under the three restriction scenarios.

Specific questions on alternatives and the substitution process will be posed in the public consultations. If new information is provided, the abovementioned assumptions can be refined.

E.3.3. Other uses, including imported articles

The three restriction options have the following requirements set out for all other uses of DP, including imported articles:

RO1 - 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 + 18 months.

For the purposes of this analysis the following timeline is assumed:

- EiF + 18 months = Beginning of 2025.

No other sectors indicated during the stakeholder consultation that a REACH restriction would pose a problem for their activities, and hence no derogations were considered for uses outside the automotive and aviation sectors. It is therefore also assumed that all other uses, including imported articles, would be able to transition to alternatives by 2025 (EiF + 18 months).

The assumed behavioural responses for other uses of DP associated with each of the restriction option (RO1-RO3) are set out in Table 103.

Table 103: Assumed behavioural responses for other uses, including imported articles

Behavioural responses	**Share of DP volume**		
	RO1	**RO2**	**RO3**
Switch to an alternative, including transfer of market shares between EU actors.	100%	100%	100%
Temporary cease parts of production until an alternative is found	0%	0%	0%
Relocation (requires non-EU customers) and permanently reduced production	0%	0%	0%

Note: Relocation and full closure is grouped, as the impacts to the EU society will be the same from these behavioural responses

E.4. Economic impacts

E.4.1. Overview of approach

A restriction can induce several types of costs, including substitution costs, costs of enforcement, environmental costs (e.g. increased greenhouse gas emissions) and other. Due to a lack of data, it has only been possible to quantify a few cost components. The quantitative analysis includes partly quantified substitution costs (E.4.2.) and costs/lost profits associated with temporary or permanent reductions in production as well as relocation (E.4.3. Cost).

The costs of the three restriction options (RO1, RO2 and RO3) are estimated based on the behavioural assumptions set out in E.3. Restriction scenario(s). All costs are presented as equivalent annual values (EAV), using a discount rate of 4%, an analytical period of 20 years, and 2020 as the monetary base year.

E.4.2. 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.

Information on substitution costs was sought in the stakeholder consultation, but the information received was very limited. No information was provided on possible R&D activities, investments costs and other substitution costs. This limits the options of how to estimate the cost of transitioning to alternatives. Available information found on prices and loading for alternative flame retardants, presented in E.2. Alternatives and in the Confidential Annex H was therefore used as the basis for the estimation of substitution costs.

In E.2. Alternatives it was concluded that several substances could be feasible alternatives to DP. The stakeholder consultation revealed that stakeholders were not aware of any feasible alternatives. This makes it difficult to reach a robust conclusion as to which substances are the most likely alternatives to be used if a restriction on DP is implemented. In the absence of information from stakeholders, the conclusions from the assessment of alternatives are used to select the most likely alternatives.

E.4.2.1. Costs of chemicals

E.4.2.1.1. Use as a flame retardant

Section E.2. Alternatives revealed that the most suitable alternatives to DP, when used as a flame retardant are:

- Ammonium polyphosphate;
- Aluminium hydroxide and
- Ethane-1,2-bis pentabromophenyl (EBP).

Relevant available information on these substances found in the public domain is set out in Table 104, with further details including sources provided in E.2. Alternatives and H.3. Alternatives in the Confidential Annex H.

Table 104: Available information on the most likely alternatives to DP as a flame retardant

Flame retardant	**Share of DP substituted**	**Price €/tonne**	**Loading**	**Price x loading compared to DP**
Dechlorane Plus	-	6 000 - 10 000	17%	100%
Aluminium hydroxide	40%	964	65%	40% - 60%
Ammonium polyphosphate	30%	2 675	31%	50% - 80%

Flame retardant	Share of DP substituted	Price €/tonne	Loading	Price x loading compared to DP
Ethane-1,2-bis (pentabromophenyl) (EBP)	30%	5 782	17%	60% - 100%

Note:

- When *Price x Loading vs. DP* is < 100% it is cheaper to use the alternative than using DP, and conversely more expensive if >100%.
- The accurate price for DP was claimed confidential by ADAMA. See Table H10 in Annex H: Confidential information for more precise estimates.

The total costs of using a substance (per unit of finished material produced) are given by the price multiplied by the necessary concentration (loading) needed to fulfil the function as a flame retardant. Based on the available information, aluminium hydroxide seems to be the overall cheaper alternative, which is why it is assumed that the majority (40%) of companies affected will choose this alternative. Alternatively, one could argue that all actors would choose the cheapest alternative. However, there will likely be different technical criteria for different applications, and it is unlikely that one alternative would be suitable for all uses. This is in line with information from stakeholders indicating that there are no drop-in alternatives to DP.

In order to calculate the change in the cost of chemicals induced by a potential restriction, it is necessary to estimate how much DP will continue to be used and how much is substituted under each restriction scenario. These volume estimates were derived using the behavioural responses set out in Table 101 - Table 103 and the associated timeline for when substitution will happen, as well as information on loading presented in Table 104. Table 105 presents the resulting volumes of DP substituted under each scenario and the corresponding increase in the use of the alternatives.

Note that the reason why the tonnage substituted under RO1 is lower than under RO2 is that RO1 lead to a higher share of relocations, permanent and temporary closures. In the case of relocation or closures, no (immediate) substitution will take place, hence the total volume DP substituted will be reduced. The avoided emissions are higher for RO1 than for RO2 (as shown in Table 111), although the total volumes substituted is slightly lower.

Table 105: DP use substituted (not ceased) and increased use of alternative substances compared to the baseline, in tonnes per year

Substance	RO1	RO2	RO3
Dechlorane Plus	-161	-164	-150
Aluminium hydroxide	253	258	235
Ammonium polyphosphate	90	92	84
Ethane-1,2-bis (pentabromophenyl) (EBP)	50	51	46

Note:

- Negative number indicate a reduction in use compared to the baseline.

- The sum of the volumes of alternatives to DP used will be higher than DP reduction due higher loading required to achieve required flame retardancy

Combining the tonnage data with the price information allows estimation of the total cost of using different chemicals and the corresponding annual costs. Since all three alternatives are cheaper than DP, the cost of chemicals will be lower compared to the baseline under all the restriction scenarios, as shown in Table 106. The differences in the cost of chemicals are fairly small between the three scenarios and is therefore masked by the range that can be reported publicly. Exact estimates are presented in Table H11 in Annex H: Confidential information.

Table 106: Change in cost of using different chemicals to DP, EAV in € million per year

Sector	**RO1**	**RO2**	**RO3**
Automotive	-5 - 0	-5 - 0	-5 - 0
Aviation	-5 - 0	-5 - 0	-5 - 0
Other, including imported articles	-5 - 0	-5 - 0	-5 - 0
Total change in cost of chemicals	**-15 - 0**	**-15 - 0**	**-15 - 0**

Note:

- Negative numbers indicate a reduction in costs compared to the baseline.
- The accurate price for DP was claimed confidential by ADAMA. See Table H11 in Annex H: Confidential information for more precise estimates.
- The category *"Other, including imported articles"* represents all uses for which immediate substitution is assumed possible.

E.4.2.1.2. Use as a lubricant

The most suitable alternatives for DP when used as a lubricant were found to be

- Long chain chlorinated paraffins (LCCPs); and
- Tricresyl phosphate (TCP).

The relevant price available information found in the public domain on these substances is set out in Table 107, with further details including sources provided in E.2. Alternatives and H.3. Alternatives in the Confidential Annex H.

Table 107: Available information on the most common alternatives to DP used in lubricants

Flame retardant	**Price €/tonnes**
Dechlorane Plus	6 000 – 10 000
Long chain chlorinated paraffins (LCCPs)	4 000
Tricresylphosphate (TCP)	9 000

Due to a lack of information on loading, it was not possible to quantify the change in the cost of chemicals when used as an extreme pressure additive in greases/lubricants. However, by comparing the prices, it can be concluded that the loading of the substances must be considerably higher than that of DP for the cost of chemicals to be significant. Furthermore, the share of the total tonnage of DP used as a lubricant is ~2%, which means that omission of these costs or cost savings is not likely to have a major impact on the estimated total costs of the restriction options.

E.4.2.2. Other costs of substitution

Transitioning to alternatives is usually associated with R&D and investment costs (e.g. changes in the production process) unless the alternative is a known drop-in alternative. In the case of DP, information found in literature and information received from stakeholders both indicate that there are no drop-in alternatives available. It is therefore reasonable to assume that R&D and investment costs will be incurred. Additional operational costs such as increased energy or water use may also contribute to the overall costs, however, no information has been found related to R&D investments or other operational costs. Due to a lack of information, it was not possible to quantify these other costs.

E.4.2.3. Total costs of substitution

Due to a lack of information, it was only possible to quantify changes in the cost of chemicals when used in flame retardants. Interestingly, the cost of identified chemical alternatives is overall cheaper than DP (both price and loading accounted for), which means that cost savings are expected rather than cost increases. 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 these feasible alternatives exist, e.g. because R&D has not been carried out to identify alternatives to DP.

Table 108 summarises the information on the key components of the substitution costs. The differences in the cost of chemicals are fairly small between the three scenarios and is therefore masked by the range that can be reported publicly. Exact estimates of the cost of chemicals are presented in Table H12 in Annex H: Confidential information.

Table 108: Total cost of substitution, EAV in € million per year

Type of cost	**RO1**	**RO2**	**RO3**
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 costs	**n/a**	**n/a**	**n/a**

Note:

- n/a indicates that the cost element is unknown both in value and sign
- The accurate price for DP was claimed confidential by ADAMA. See Table H10 in Annex H: Confidential information for more precise estimates.

Available information did not allow for estimation of an order of magnitude of the total substitution costs.

E.4.3. Cost of temporarily and permanently reduced EU production

If companies have to temporarily or permanently reduce their EU production of products dependant on DP, there will be associated profit losses, which are considered as costs to society. It is generally difficult to accurately estimate such losses as the reliance on DP and DP-containing products/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 restriction on DP. The analysis is therefore based on publicly available information from Eurostat (i.e. Structural Business Statistics (SBS) and PRODCOM), which has been used in conjunction with the behavioural responses set out in Table 101, Table 102 and Table 103.

E.4.3.1. Profits

The 'sales at risks' are represented by products for which a reduction in sales as a result of a restriction on DP are most likely. The stakeholder information indicated that 93% of all DP is used in wire and printed circuit board housing or other plastic and rubber parts. Furthermore, applications within the automotive and aviation sectors collectively comprise 67% and 85%. The products and corresponding sales at risks was therefore defined using the PRODCOM codes shown in Table 109.

Total sales at risk were estimated by averaging turnover between 2015 and 2019 (uplifted to 2020) for relevant PRODCOM codes for each sector. Due to the high uncertainty in the sales at risk, the knock-on effects, i.e. an estimation of profits at risks in other parts of the supply-chain, have been excluded.

The analysis is based on assumptions (set out in Section E.3. Restriction scenario(s) on the necessary time to substitute for each industry, and the share of the market that eventually will be able to move to alternatives (90% - 100% depending on the RO). This means that most of the profits lost are treated as temporary and are only included up until successful transition to alternatives is achieved.

Sales outside the automotive and aviation sectors are not considered to be at risk, as it is assumed that the lack of input from stakeholders indicates that the restriction is not likely to pose an issue for other potential uses (if any) of DP. It is thus expected that all other uses can substitute DP before the end of the transition period of the strictest restriction scenario (RO1: Total ban) (EiF + 18 months).

Table 109: Products at risks and corresponding sales volumes, € million per year

Sector	**Relevant PRODCOM code**	**Description**	**Turnover at risk, € million per year**
Automotive	22299160	Plastic parts and accessories for all land vehicles (excluding for locomotives or rolling stock)	31 521
	29311000	Insulated ignition wiring sets and other wiring sets of a kind used in vehicles, aircraft or ships	

Sector	**Relevant PRODCOM code**	**Description**	**Turnover at risk, € million per year**
Aviation	22299180	Plastic parts for aircraft and spacecraft	2 577
	29311000	Insulated ignition wiring sets and other wiring sets of a kind used in vehicles, aircraft or ships	

Sources: PRODCOM (accessed: 2020)

Note: PRODCOM code 29311000 is cross-sectoral and has been split between land vehicles (80%), aircrafts (10%) and ships (10%).

PRODCOM does not provide information on profit margins, which is why older data (2003 – 2007) from Eurostat was used for this purpose. The following gross profit margins was used:

- Manufacture of motor vehicles, trailers and semi-trailers (NACE C29)[44]: 9.1%
- Manufacture of air and spacecraft and related machinery (NACE C30.3)[44]: 10.1%

The gross profit associated with sales of the products at risk were then calculated using the above turnover and gross profit margins. The estimated profits were assumed to be representative for profits of continued use of DP in the automotive and aviation sector respectively. Finally, profits (potentially) lost under each restriction scenario were estimated by multiplying the share of production lost per year with the expected profits from that production. As can be seen in Table 110, the profits potentially lost (i.e. at risk) under RO1 and RO2 are substantially higher than those under RO3. This can be explained by the extended transition period for the use of DP in the manufacture of motor vehicles granted under RO3. Under all scenarios, the automotive sector is by far the largest contributor to costs in terms of lost profits.

The profits potentially lost (i.e. at risk) are not linked to the tonnage of DP used but rather the value of manufactured products at risk, which is assumed to be the same regardless of the input chemical. This is why the estimates are not presented as “low – high” as was done for the substitution costs. Potential variations in the total costs induced by uncertainty in underlying input factors are investigated further in Annex F: Assumptions, uncertainties and sensitivities.

Table 110: Profit at risk, EAV in € million per year

Sector	**RO1**	**RO2**	**RO3**
Automotive	262	167	5
Aviation	41	9	2
Other, including imported articles	0	0	0
Total profits at risk	**303**	**175**	**6**

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[44] See (EC, 2010)

Note to Table 110:

- The category *"Other, including imported articles"* represents all uses for which immediate substitution is assumed possible.
- Sums may not add up due to rounding.

Note that the potentially lost profit estimates presented in Table 110 are not distributional effects, i.e. transfer of profits from one company to another, as this is already accounted for in the behavioural responses set out in E.3. Restriction scenario(s). This means that the estimates of profits at risk are net losses which already account for the possibility that some companies who can substitute earlier will gain market share and increased profits.

E.4.3.2. Caveats on using potential lost profits as a cost indicator

For most restriction proposals the focus of the cost analysis is substitution costs, whilst potential lost profit is rarely included in the analysis. For example, in the decaBDE restriction proposal potential lost profits were not considered at all either qualitatively or quantitatively. One of the reasons for omitting potential profit loss may be that it is difficult to accurately estimate and or that it is considered unlikely that the restriction will trigger such losses. Generally, it is unlikely that significant profit losses will occur if technically and economically feasible alternatives exist and there is sufficient time to acquire the necessary product authorisations (which may involve testing).

As mentioned in E.3. Restriction scenario(s), industry did not provide any specific technical or economic reasons for why alternatives to DP are considered infeasible besides the lack of knowledge of any feasible alternatives. If feasible alternatives do exist, the time to substitute would be shorter and as a result a substantial part of the profit lost would be avoided under RO1 and RO2. If there was more information on substitution costs, 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, we have opted to use lost profits as the primary cost element. This creates a risk that the costs associated with RO1 and RO2 are overestimated. On the other hand, the exclusion of potential profits lost in other parts of the supply chain (knock-on effects) may lead to an underestimation of the profits lost. Overall, it is therefore not known whether the profits at risk are over- or underestimated.

E.4.4. Enforcement costs

Each of the three restriction options will induce enforcement costs to public authorities. However, it is expected that enforcement can be carried out in parallel with enforcement of existing restrictions affecting similar products, e.g. decaBDE, so the additional costs of testing for the presence of one additional substance will likely be low. The enforcement costs will in all cases not be as significant compared to other costs of the restriction and have therefore not been investigated further.

E.5. Human health and environmental impacts

E.5.1. Benefits to 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, 2017a) (see Annex B.4.1. Degradation for more detail). 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 (see Annex B.4.3 Bioaccumulation, bioavailability and transformation in biota for more detail). The substance is also widely dispersed in both aquatic and terrestrial food chains including top predators (see Annex B.4.4. Environmental monitoring and trends for more details).

The ECHA Guidance for PBT/vPvB assessment (Chapter R.11) (ECHA, 2017e) 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, 2017c). The Dossier Submitter notes that potential adverse effects/toxicity of DP are currently discussed under the Stockholm Convention (UNEP/POPS/POPRC.16/9, Annex I, Decision POPRC-16/1) (POPRC, 2021a). Information on these adverse effects can be found in the draft POPs risk profile for DP (POPRC, 2021b).

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 (see section B.9.4. Biomonitoring and environmental monitoring data). 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 8. 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.

Another aspect of the vPvB concern worth considering is that there is a political goal to phase out the use of vPvB substances, see for example the recent European Commission *Chemicals Strategy for Sustainability Towards a Toxic-Free Environment* (EC, 2020c). Furthermore, Recital 70 of Regulation 1907/2006 states that exposure of the environment and humans from substances of very high concern should be reduced as much as possible.

E.5.2. Emission reductions as a proxy for potential benefits

Quantification of risks is not currently possible for PBTs or vPvB substances, 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).

For DP, factors which may indicate additional concern beyond the vPvB properties include the wide dispersive use (see Annex A.2. Uses) of the substance and that it has a long-range transport potential (see Annex B.4.2.3 Distribution modelling and long-range transport potential). A wide dispersive use may result in exposure of DP to a considerable part of the population (workers, consumers, general public) as well as the environment. The long-range transportation potential means that local control measures can be ineffective and there is a risk of build-up of DP in remote and pristine areas. This, combined with the vPvB properties, can potentially lead to severe impacts beyond that of substances with only localised emissions and exposure.

As mentioned above, the very high persistence of the substance will lead to increasing environmental stock over time if emissions of DP 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 restriction, will lead to substantial reductions in the environmental stock. The resulting benefits associated with any reductions in environmental stock will therefore also be spread out in time and may occur long after the end of the analytical period. For the same reason, any reduction in environmental stock from historic use, which cannot be attributed to a restriction, may occur within the analytical period. This combined with emissions from service life and disposal (described in Annex D: Baseline), makes modelling of changes in environmental stock particularly complicated.

As recommended by SEAC (ECHA, 2014), a cost-effectiveness analysis approach was taken, using emission reductions as a proxy for benefits. The advantage of this approach is that the total emission reduction associated with the implementation of a restriction is independent of the timing of the reductions, as long as they fall within the analytical period. As explained in Sections D.3.3. Current emissions of Dechlorane Plus to the environment - D.3.4. Baseline emissions of Dechlorane Plus, 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 restriction scenario.

Inaccuracies in the timing of emission reductions have been highlighted whenever applicable.

E.5.3. Changes in emissions

Contrary to the economic impacts, the expected emissions reduction that can be achieved under each restriction scenario will not be affected by the behavioural responses to the restriction. The reason for this is that the restriction sets out when manufacture and use must cease, and the emissions of DP will cease accordingly. Whether affected actors' transition to alternatives immediately or if production halts will be necessary, will not affect the emissions of DP (non-compliance with the regulation has not be considered). There is a possibility that some actors will voluntarily switch to alternatives to DP before entry into force, but if the reason for the switch is financial (i.e. it is more costly for them to not use DP) one can argue that the corresponding emission reduction is part of the baseline. If it is more costly for the actors to use alternatives, then it is considered unlikely that they would voluntarily switch to these alternatives before the ban enters into force. The determining factors for the emission reductions are therefore the scope, transition period and derogations of the restriction options.

Based on the baseline use of DP estimated in Section D.3.2. Baseline use volumes of Dechlorane Plus, the continued use of DP under each restriction scenario was estimated as illustrated in Figure 9. As mentioned above, the exposure model underlying the baseline modelling is static, and does not pick up emissions from use of DP prior to 2020. This leads to an underestimation of emissions in the beginning of the analytical period for the three restriction options, i.e. higher emissions should be observed due to continued emissions from historic use. Furthermore, the model also implicitly assumes that emission ceases when use of the substance in manufacture ceases. In reality, parts of the emissions will occur during the service life of the articles and a significant share of the emissions would occur at the waste stage. The reduction in emissions as compared to the baseline will therefore in reality be more spread throughout the analytical period than what is shown in Figure 9.

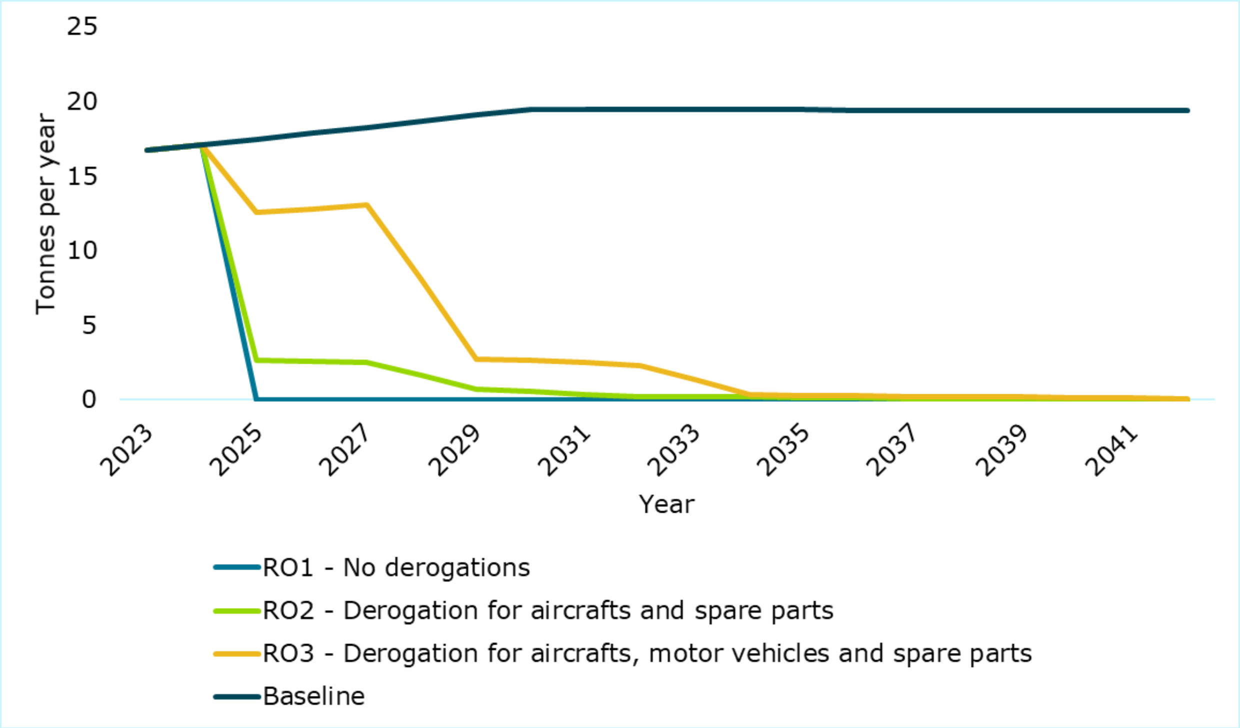

Figure 9: Continued emission of DP under each restriction scenario and the baseline

The overall emission reduction capacity of each RO was estimated by subtracting the total emission under each scenario from the total emissions under the baseline. This means that the abovementioned inaccuracies in the timing of the emission reductions will have less impacts on the emission reduction capacities of the ROs. The longer the analytical period used in the analysis, the more accurate the total emission reductions will be.

Since average annual emission reductions are estimated by dividing the total emissions by the number of years in the analytical period (20 years), the same level of uncertainties described for the total emission reductions will also be present for the annual estimates. The expected achievable emission reductions for each RO, presented in Table 111, was estimated using both the low and high baseline tonnages. As expected, the strictest restriction option (RO1) has the highest emission reduction of 8.3 – 26.2 tonnes per year, but all restriction options are fairly effective and result in high emission reductions - 75% - 91% of baseline emissions are removed. This is a result of only allowing time-limited derogations in all three restriction options (for the automotive sector in particular).

Table 111: Emission reduction under each restriction scenario, tonnes per year

Sector/use	**Baseline emissions (t/y)**	**Annual reduction (t/y)**		
		RO1	**RO2**	**RO3**
Automotive	5.6 - 17.8	5.1 - 16.2	5 - 15.9	4.1 - 13
Aviation	0.9 - 2.9	0.8 - 2.6	0.6 - 2	0.4 - 1.3
Other including imported articles	2.6 - 8.1	2.3 - 7.4	2.3 - 7.4	2.3 - 7.4
All uses	**9.1 - 28.8**	**8.3 - 26.2**	**8 - 25.3**	**6.8 - 21.7**
Scenario emission reduction capacity		**91%**	**88%**	**75%**

Note: Sums may not add up due to rounding.

E.6. Other impacts

E.6.1. Social impacts

Social impacts are impacts which may affect workers, consumers and the general public that are not covered under health, environmental or economic impacts (ECHA, 2008), including employment, working conditions, job satisfaction and education of workers and social security. A restriction on DP is not expected to have substantial social impacts (as defined by the guidance), besides effects on employment.

E.6.1.1 Employment

Impacts on EU employment are closely linked to what extent there might be any potential production halts, or any permanent reduction in production and relocation of production outside the EU under each restriction scenario. A similar approach as used to estimate profit losses was therefore deployed in order to calculate societal costs from potential EU jobs lost.

Data on the number of people employed associated with specific NACE codes is not available on PRODCOM and only available for high-level NACE codes on Eurostat. To narrow down the number of jobs associated with the high-level NACE codes to the jobs relevant for DP products, the ratio of turnover associated with the PRODCOM codes identified in E.4.3.1. Profits, and the turnover reported for the high-level NACE codes on Eurostat, have been used as a proxy for the ‘share of relevant jobs’. The share of the relevant jobs at risk under the restriction scenarios was assumed proportional to the share of profits at risk estimated in E.4.3.1. Profits. The relevant jobs associated with the use of DP and the share of these being at risk under the restriction scenarios are presented in Table 112.

Table 112: Jobs at risks within the EU

Sector	**Relevant jobs within the EU**	**Share of relevant jobs at risk**		
		RO1	**RO2**	**RO3**
Automotive	80 580	9.1%	5.8%	0.2%
Aviation	9 924	15.7%	3.3%	0.6%
Other, including imported articles	0	0%	0%	0%

The total number of 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 in the automotive and aviation sector are equally distributed between 2025 and 2030. As there is assumed to be no production halt or permanent loss of production in the EU for the "other" category, there is no estimated loss of EU jobs.

In line with the SEAC guidance (ECHA, 2008) on the estimation of the societal value of lost jobs, it was assumed that human resources will be redistributed over time, i.e. the jobs lost are considered temporary (ECHA, 2008). According to the SEAC guidance, the total societal value of a job lost is "*around 2.7 times the annual pre-displacement wages*". Since the number of jobs at risk in the various Member States is not known, the average annual gross salary in the EU (~ € 24 700[45]) was used. The resulting average annual jobs at risk and their net present value over the analytical period (2023 – 2042) is show in Table 113.

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[45] The average gross salary was estimated based on an average EU gross earning of €13.7 per h when uplifted to 2020 (Eurostat, 2018a), 40.3 hours work weeks (Eurostat, 2018b) and 33 holidays per year (European Data Portal, 2016)

Table 113: Average annual number of jobs at risk and their net present value (€ million per year), 2023-2042

Sector	RO1		RO2		RO3	
	Average annual jobs at risk	**Societal value (€ million/ year)**	**Average annual jobs at risk**	**Societal value (€ million/ year)**	**Average annual jobs at risk**	**Societal value (€ million/ year)**
Automotive	368	18.6	234	12	7	0.3
Aviation	78	3.9	16	0.8	3	0.2
Other, including imported articles	0	0	0	0	0	0
Total	**446**	**23**	**251**	**13**	**10**	**0.5**

Note:

- Average annual jobs are calculated by dividing the total number of jobs lost by 20 years.
- The actual jobs lost are assumed to happen over the first 5 years 2025 – 2030. This is accounted for when the net present value is calculated.
- Sums may not add up due to rounding. Decimals are only included for values < 1.

E.6.2. Wider economic impacts

The proposed restriction is not expected to affect competition between EU and non-EU actors placing products on the market in the EU, as both groups will have to comply with the restriction. There is a possibility that EU actors that currently export their products may lose market shares to non-EU actors. However, if DP gets listed as a Persistent Organic Pollutant (POP) under the Stockholm Convention, this will likely be prevented as the regulators would aim to harmonise the two regulations. A shift of competitive advantage between EU actors is covered under distributional effects in Section E.6.3. Distributional impacts.

As explained in E.1.2. Discarded restriction options, it is expected that recyclers will be able to comply with the overall concentration limit of 0.1%. The restriction is therefore not expected to affect recycling.

Most of the impacts associated with the restriction options are expected to be either small or temporary, so no further (significant) macroeconomic impacts are anticipated.

E.6.3. Distributional impacts

The distributional impacts are not societal costs as such, as a negative impact on one actor can be counterbalanced by an equal but positive impact on another actor. However, distributional impacts may still be important, in particular if 'losing' actors are part of a vulnerable group.

Information received in the stakeholder consultations indicates that the main sectors adversely affected by a restriction on DP are the automotive and aviation industries. These are both large sectors with a strong foothold in the EU and are, as industries, likely to be resilient to small-to-moderate changes in the market. The automotive industry informed that the original equipment manufacturers (OEMs) and their immediate suppliers are typically large corporations, whilst a large share of SMEs can be found further down the supply chain, which often manufacture ‘simple’ parts or materials. Although the industry as a whole is considered resilient, the SMEs within the supply chain might still be adversely affected, especially under RO1 and RO2. 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, but it is likely that similar impacts may be seen in this sector.

The most significant distributional effect associated with the restriction options 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 the early movers. As explained in Section E.3. Restriction scenario(s)these distributional effects are expected to occur under all restriction options 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 such as SVHCs. These incentives may reduce costs of subsequent regulations, as lost profits and increased unemployment are less likely to occur if alternatives are adopted earlier in the regulatory process.

E.7.Practicability and monitorability

E.7.1. Implementability and manageability

Practicability cannot be fully judged due to the inherent uncertainties regarding identification of proper alternatives and techniques to replace use of DP the time needed to substitute. Generally, it can be concluded that in some cases a longer transition period will increase the practicability, as it increases the probability for industry actors being able to transition to alternatives before the end of the transition period in the most cost-effective manner. As such, RO3 is considered most practicable for industry followed by RO2 and lastly RO1.

E.7.2. Enforcement and monitorability

Enforcement activities should cover the import of DP as such, in mixtures and in articles, and the production of articles in the EU. 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. Currently, 0.1% w/w is the limit that triggers the notification requirement under article 7(2)27 of REACH and the information requirement under article 33 of REACH. The proposed concentration limit of 0.1% w/w would therefore enhance the enforceability.

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 XRF (Abbasi et al., 2016). This rapid technique can be used as an efficient method to determine potential content of DP in waste streams. 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. Based on knowledge on use of DP listed in Section A.2.2. Information found in publicly available sources, it seems that use of DP in polymers containing chlorine in its building blocks is not that common and use of XRF for screening for DP in waste fractions thus is of great value. Other spectroscopic techniques like Fourier Transform Infrared Spectroscopy (FTIR) will be able to distinguish polymeric bound chlorine from chlorine bound in DP. This might open up for developing a FTIR based rapid screening method to distinguish between chlorine from DP and polymeric bound chlorine in waste fractions if nessecary (Becker et al., 2017).

Precise determination and quantification of DP and its isomers have been reported in almost all environmental matrixes (Cheng et al., 2019, Ganci et al., 2019, 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-LRMS, or GC-MS/MS or GC-HRMS (Brasseur et al., 2016, Shen et al., 2012, Zacs et al., 2019). As for many other high chlorinated compounds, negative chemical soft ionization techniques are preferred. Soft techniques reduce molecule fragmentation, which increase selectivity and often also much better sensitivity compared to electron impact ionization (Brasseur et al., 2016, De la Torre et al., 2010). The level of quantification (LOQ) for these methods are typically in the range of 5 – 30 pg/g depending on matrix, sample preparation, and instrumental methods (Badea et al., 2020, Neugebauer et al., 2018). By applying high resolution mass spectrometry (HRMS) LOQs between 0.04 to 5 pg/g 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 such as, 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.

The typical LOQ is significantly lower than the concentration limit proposed in the restriction entry. In conclusion, this imply that the available techniques are sensitive enough to produce reliable analytical results for all relevant matrices to enable compliance monitoring and enforcement.

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

E.8. Proportionality and comparison of restriction options

As highlighted in Section E.5. Human health and environmental impacts, the risks and thereby the benefits of PBTs and vPvB substances cannot be quantified, and in the case of vPvBs, there are no known impacts. This prohibits the use of a traditional cost-benefit analysis to assess proportionality. To evaluate the acceptability of regulatory options despite the lack of quantitative information on benefits, SEAC recommends using cost-effectiveness values and "a comparator or a "benchmark" on the level of costs that are deemed to be worthwhile taking when reducing emissions" (ECHA, 2014).

The total cost of introducing a restriction on DP is higher for the more stringent restriction options (RO1 and RO2), and the largest cost component by far is the potentially lost profits due to not being able to transition to alternatives by the end of the transition period. Equally, a more stringent restriction, such as RO1, leads to higher emission reductions and, by proxy, higher potential environmental benefits. The main trade-off on a societal level is the potential environmental benefits associated with reducing emissions of DP vs. the cost to society from potential profit and job losses. Based on the negative costs of chemicals, it is deemed unlikely that the total substitution cost (i.e. including R&D, investment costs and other substitution-related costs) will be a determining factor for the overall proportionality of the restriction options, unless new information is provided to substantiate large, unexpected R&D and investment costs associated with finding and switching to suitable alternatives for their uses.

As shown in Table 114, the cost associated with the more stringent ROs are potentially associated with fairly high losses in profit. However, the costs need to be considered in light of the caveats of using potential profit lost as a primary cost component (See Section E.4.3.2. Caveats on using potential lost profits as a cost indicator).

Table 114: Summary of costs associated with the restriction options, 2023 – 2042 € million per year

Type of cost	**RO1**	**RO2**	**RO3**
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
Lost profits	303	175	6
Value of jobs at risk	23	13	0.5
All uses	**~320**	**~180**	**> 0**

Note:

- Numbers have been rounded to avoid a false impression of precision as well as to ensure confidentiality of some of the input factors used. More precise estimates are provided in Table H13 and Table H14 (total costs per sector) in Annex H: Confidential information.
- Sums may not add up due to rounding

To determine whether the estimated costs are likely acceptable for the regulators and the EU society, SEAC recommends using benchmark (range) to compare the cost against. There are currently no agreed benchmarks for PBT and vPvB substances, but a comparator may, for example, be based on previous studies and estimated costs of regulations implemented in the past. Oosterhuis and Brouwer (IVM, 2015) and ECHA (2014) present a comprehensive list of cost-effectiveness estimates for different types of risk reduction measures for a large variety of substances. The overall conclusion drawn in the paper is that the costs below € 1 000 per kg (2015 prices) is generally deemed acceptable whilst costs above €50 000 per kg (2015 prices) is considered disproportionate (2015 prices). It is also stated that there is a "*'grey zone' (with margins [in] the order of magnitude somewhere between EUR 1 000 and EUR 50 000 per kg PBT substituted*" in which cost may be deemed either proportionate or disproportionate.

Table 115 shows the cost-effectiveness ranges estimated for each assessed restriction option. The corresponding central estimates are:

- **RO1:** ~ € 20 000 per kg DP emission reduced
- **RO2**: ~ € 10 000 per kg DP emission reduced
- **RO3**: ~ € 500 per kg DP emission reduced

Note that these estimates are rounded to avoid a false impression of precision as well as to ensure confidentiality of some of the input factors used. More precise estimates as well as cost-effectiveness per sector can be found in Tables H15 and H16 in Annex H: Confidential information.

Table 115: Cost-effectiveness ranges for RO1-RO3, € per kg

Sector/use	**Cost effectiveness €/kg DP**		
	RO1	**RO2**	**RO3**
All uses	13 000 – 39 000	8 000 – 23 000	0 – 1 000
Scenario emission reduction capacity	91%	88%	75%

Note:

- Numbers have been rounded to the nearest € 100 to avoid a false impression of precision as well as to ensure confidentiality of some of the input factors used.

Due to the many similarities, such as the uses and sectors involved with decaBDE, cost-effectiveness estimates derived for this substance could be an appropriate comparator. On the other hand, in the decaBDE restriction proposal only changes in cost of chemicals were estimated, i.e. potential profits lost, or cost of unemployment were not included. The cost per kg reduced emissions of decaBDE was estimated to 484 €/kg (508 €/kg when uplifted to 2020). For RO1 and RO2, the cost-effectiveness of restricting DP is considerably higher, but the cost-effectiveness is lower than decaBDE for RO3. However, if the economic impacts of restricting DP were estimated using the same approach as was used for decaBDE, the assessment would result in cost savings.

While there is greater uncertainty about the availability of alternatives to DP (i.e. profit loss is more likely than for decaBDE), when all cost elements are considered for both substances, the cost-effectiveness of restricting DP is not unlikely to be in the same order of magnitude as that of decaBDE. Since the costs of the decaBDE restriction were deemed acceptable by the European Commission, this could be a supporting argument for similar acceptance of the costs associated with a restriction on DP.

Based on the above analysis it is challenging to reach a firm conclusion on proportionality for all the restriction options. It is likely that the costs of RO3 will be acceptable to decision makers and the EU society, as the cost-effectiveness is below the 'low-cost' benchmark and in the same order of magnitude as was derived for the restriction on decaBDE. RO2 and RO1, on the other hand, are in the middle of the so-called 'grey zone', and without more data on the time and cost of transitioning to alternatives, a robust conclusion on proportionality of these restriction options cannot be drawn. However, if no new information is provided by industry to justify the impacts on their company/sector in the public consultation, this could indicate that the costs are manageable for industry and that the actual costs of RO1 and RO2 may be acceptable for society as a whole.

Annex F: Assumptions, uncertainties and sensitivities

This annex sets out the key variables and assumptions used in the analysis (Section F.1. Input parameters and assumptions) and identifies uncertainties induced by uncertainty in the input parameters used (Section. F.2 Uncertainty).

F.1. Input parameters and assumptions

A large number of input parameters and assumptions has been used to derive the quantitative results in the socio-economic analysis.

Table 116 shows the input factors used in the exposure assessment.

Table 116: Input factors used in the Exposure Assessment, see Annex B.9.

Input factor / Assumption	**Value**	**Unit**	**Comment**
Use 1: Formulation of sealants and adhesives			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of total volume - sealants and adhesives	5%		See Table 12.
Total tonnage in sealants and adhesives	5 - 12	tonnes/year	
Number of days of formulation	225	days/year	Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Daily amount of DP formulated at a site (local scenario)	0.022 - 0.053	tonnes/day	Estimate – assumes all of the tonnage is formulated at one site as a worst case
Fraction released to air	0.0008 – solvent-borne 0.000097 – water-borne		Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction released to wastewater	0.0002 – solvent-borne 0.00505 – water-borne		Default from FEICA SPERC 2.1a.v3 and 2.2b.v3
Fraction release 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)
Use 2: Industrial use of sealants and adhesives			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of total volume - sealants and adhesives	5%		See Table 12.
Total tonnage in sealants and adhesives	5 - 12	tonnes/year	

Input factor / Assumption	**Value**	**Unit**	**Comment**
Number of days of use	225	days/year	Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Daily amount used (local scenario)	0.0022 - 0.0053	tonnes/day	Estimate – assumes 10% of the total use occurs at a large site
Fraction released to air	0.017		Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction released to wastewater	0 – solvent-borne 0.003 – water-borne		Default from FEICA SPERC 5.1a.v3 and 5.1c.v3
Fraction release 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)
Use 3: Industrial use in polymers			
Total volume used in the EU	90 - 230		See Table 12.
Share of volume used in polymers	93%		See Table 12.
Total tonnage in polymers	84 - 214	tonnes/year	
Number of days of use	20	days/year	Default from ECHA (2016a)
Daily amount of used (local scenario)	0.42 - 1.07	tonnes/day	Estimate – assumes 10% of the total use occurs at a large site
Fraction released to air	0.00002 – closed processes 0.00004 – partially open processes 0.00006 – open processes		For powders <40 µm - OECD (2009)
Fraction released to wastewater	0.00652 – closed processes 0.00654 – partially open processes 0.00656 – open processes		For powders <40 µm - OECD (2009)
Fraction release to industrial soil	0		OECD (2009)
Fraction to solid waste	0.01		For powders <40 µm - OECD (2009)
Use 4: Formulation of greases			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of total volume - greases	2%		See Table 12.

Input factor / Assumption	**Value**	**Unit**	**Comment**
Total tonnage in greases	2 - 5	tonnes/year	
Number of days of formulation	10	days/year	Default from ECHA (2016a)
Daily amount of formulated (local scenario)	0.2 - 0.5	tonnes/day	Estimate – assumes that all of the formulation occurs at 1 site as a worst case
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 release to industrial soil	0		Losses to soil expected to be low.
Fraction to solid waste	0.015		Based on OECD (2004)
Use 5: Indoor use of articles containing Dechlorane Plus over their service life			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume used in articles that are used indoors	90%		Assumption
Total tonnage - indoor use of articles	79.2 - 203	tonnes/year	
Number of days of use	365	days/year	Default from ECHA (2016a)
Daily amount used (local scenario)	4.34E-05 - 1.11E-04	tonnes/day	Estimated using ECHA (2016a)
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 release 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).

Input factor / Assumption	Value	Unit	Comment
Use 6: Outdoor use of articles containing Dechlorane Plus over their service life			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of volume used outdoors	10%		
Total tonnage - outdoor use of articles	8.8 - 22.5	tonnes/year	
Number of days of use	365	days/year	Default from ECHA (2016a)
Daily amount used	4.82E-6 - 1.23E-5	tonnes/day	Estimated using ECHA (2016a)
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 release to industrial soil	0		Default for ERC 10a (ECHA, 2016a) and OECD (2009)
Fraction to solid waste/recycling	1		Default from ECHA (2012).
Use 7: Dismantling and recycling of waste/articles containing Dechlorane Plus			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume of articles undergoing shredding	65% - 85%		
Total tonnage undergoing shredding	57 – 191	tonnes/year	
Number of days of use	330	days/year	Default from ECHA (2012)
Daily amount used (local scenario)	0.00321 - 0.0107	tonnes/day	Estimated using ECHA (2012)
Fraction released to air	0.1		Default from ECHA (2012)
Fraction released to wastewater	0		Default from ECHA (2012)

Input factor / Assumption	**Value**	**Unit**	**Comment**
Fraction release to industrial soil	0		Default from ECHA (2012)
Fraction to solid waste/recycling	0		Default from ECHA (2012)
Use 8: Disposal of waste/articles containing Dechlorane Plus by incineration			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume in articles ending up being incinerated	50%		
Total tonnage incinerated	45 - 115	tonnes/year	
Number of days of use	330	days/year	Default from ECHA (2012)
Daily amount used (local scenario)	0.00109 - 0.00279	tonnes/day	Estimated using ECHA (2012)
Fraction released to air	0.0001		Default from ECHA (2012)
Fraction released to wastewater	0.0001		Default from ECHA (2012)
Fraction release to industrial soil	0		Default from ECHA (2012)
Fraction to solid waste/recycling	0		Default from ECHA (2012)
Use 9: Disposal of waste/articles containing Dechlorane Plus by landfill			
Total volume used in the EU	90 - 230	tonnes/year	See Table 12.
Share of volume used in articles	98%		Sum of shares used in polymers and adhesives. See Table 12.
Total volume used in articles	88 - 225	tonnes/year	
Share of total volume in articles ending up in landfill	50%		
Total tonnage landfilled	45 - 115	tonnes/year	
Number of days of formulation	365	days/year	Default from ECHA (2012)
Daily amount of formulated	5.87E-05 – 1.50E-04	tonnes/day	Estimated using ECHA (2012)
Fraction released to air	0		Default from ECHA (2012)

Input factor / Assumption	**Value**	**Unit**	**Comment**
Fraction released to wastewater	0.016		Default from ECHA (2012). Assumes a release fraction of 0.0016/year, 20-year lifetime of the landfill, removal fraction of 0.5 for on-site treatment.
Fraction release to industrial soil	0.0016		Default from ECHA (2012)
Fraction to solid waste	0		Default from ECHA (2012)

Table 117 sets out all key variables and assumptions used in the quantitative analysis and corresponding sources.

Table 117: Input factors used in the socio-economic analysis

Input factor	**Details/comments**	**Original year for input factor**	**Value – uplifted to 2020 when needed**	**Unit used in the analysis**	**Source**
GENERAL					
Analytical period	Period analysis is carried out for	n.d.	20	years	
Monetary base year		2020	2020		
Source for GDP deflator		2000 - 2020	-		OECD and European Central Bank (2020)[46]
Exchange rate € / $	Time when affected actors starts substitution process	2019-2020	1.1		European Central Bank (2020)
Exchange rate € / $	Time needed before successful substitution is achieved for most of the market. Further details in E.3.	2015	1.1		European Central Bank (2020)
Entry into force	Typical rate used in restriction proposals.	2020	Jan-25		Assumption
Start of substitution process, if no alternatives currently exists	Average from Aug 2019 to Aug 202	2020	Jan-23		Assumption
Discount rate		n.d.	4%	yearly rate	(EC, 2017)
Population EU 2025		2030	449,121,599	people	Eurostat (2020c)
Population EU 2040		2040	446,754,877	people	Eurostat (2020c)
Population growth 2025-2040		2025-2040	-0.05%	% per year	Calculated based on Eurostat (2020c)

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[46] Price index:

https://data.oecd.org/price/price-level-indices.htm#indicator-chart

https://sdw.ecb.europa.eu/reports.do?node=10000051

Input factor	**Details/comments**	**Original year for input factor**	**Value – uplifted to 2020 when needed**	**Unit used in the analysis**	**Source**
Average EU hourly gross earnings		2018	13.7	€ per hour	(Eurostat, 2018a)
Average hours worked per week		2018	40.3	hours per week	Eurostat (2018b)
Average number of holidays per year	25 days + 8 bank holidays	2018	33	days per year	Eurostat (2018b)
Average annual gross salary	Calculated based on earnings and average work hours per year	2018	25,065	€ per year	Calculated based on Eurostat (2018a) and Eurostat (2018b)
Societal value of one job lost	~2.7 x gross annual salary	2018	67,675	€	Calculated based on ECHA (2016d), Eurostat (2018a) and Eurostat (2018b)
OVERALL MARKET FOR DP AND ALTERNATIVES					
DP volume replacing decaBDE by 2020	Due to recent implementation of restrictions on decaBDE under REACH and the Stockholm Convention. Corresponds to around 5% of use of decaBDE in plastics	2020	0	tonnes	Assumption
Real growth rate 2020 - 2030 - Use of DP in the EU	Assuming a growth equal to growth in the automotive sector. This can be changed for the sensitivity analysis, to account for restriction on DecaBDE	2020-2025	2.2%	% per year	Assumption based on PwC (2017)
Real growth rate 2030 - 2042 - Use of DP in the EU	Assuming a growth equal to the population growth	2025-2040	-0.05%	% per year	Assumption based on Eurostat (2020c)
Share of DP volume transitioning to Ammonium polyphosphate		2020	30%	% of DP substituted	Assumption
Share of DP volume transitioning to EBP		2020	30%	% of DP substituted	Assumption

Input factor	**Details/comments**	**Original year for input factor**	**Value – uplifted to 2020 when needed**	**Unit used in the analysis**	**Source**
Share of DP volume transitioning to Aluminium hydroxide		2020	40%	% of DP substituted	Assumption
Average concentration of DP when used as a flame retardant	Weighted average based on application and corresponding concentrations reported by stakeholders	2020	17%	%ww	See Annex A and Annex E.2. Alternatives
Average concentration of DP when used as an extreme pressure agent	Weighted average based on application and corresponding concentrations reported by stakeholders	2020	23%	%ww	See Annex A and Annex E.2. Alternatives
Price of Dechlorane Plus	9-10 $/kg stated by ADAMA	2020	6-10	€/kg	ADAMA (stakeholder consultation). See Annex H for exact estimate.
Average concentration of Ammonium polyphosphate when used as a flame retardant		2020	31%	% w/w	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
Price of Ammonium polyphosphate	Converted from € to $	2020	2.7	€/kg	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
Average concentration of EBP when used as a flame retardant		2020	17%	% w/w	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
Price of EBP	Converted from € to $	2020	5.8	€/kg	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives

Input factor	Details/comments	Original year for input factor	Value – uplifted to 2020 when needed	Unit used in the analysis	Source
Average concentration of Aluminium hydroxide when used as a flame retardant		2020	65%	% w/w	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
Price of Aluminium hydroxide	Converted from € to $	2020	1.1	€/kg	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
Price of LCCPs	Converted from € to $	2020	1	€/kg	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
Price of TCP	Converted from € to $	2020	7.8	€/kg	See Annex A.2.3. Information from stakeholders and Annex E.2. Alternatives
AUTOMOTIVE INDUSTRY					
EU vehicle sales 2017		2017	18	million vehicles	PwC (2017)
EU vehicle sales 2030		2030	24	million vehicles	PwC (2017)
EU vehicle sales growth rate 2017-2030	CAGR	2017-2030	2.2%	% per year	PwC (2017)
Lifespan cars EU		2015	14	years	Ricardo-AEA (2015)
Time to reduce need of DP for spare parts to zero after manufacture stops - average	Assumed half of the total lifetime of a car	n.d.	7	years	Assumption based on Ricardo-AEA (2015)
Share of volume used for spare parts - automotive		n.d.	10%		Assumption
Time to substitute	Assumed 95% of the market	n.d.	5	years	See Annex A.2.3. Information from stakeholders

Input factor	Details/comments	Original year for input factor	Value – uplifted to 2020 when needed	Unit used in the analysis	Source
Total turnover linked to plastics and wiring used in the automotive sector	Prodcom codes: 22299160 and 80% of 29311000	2015 - 2019	31521	€ million	(PRODCOM, 2019)
Profit margin manufacture of vehicles	Assumed constant profit margin	2003-2007	9.1%	% of revenue	(Eurostat, 2020d)
Total number employed in Manufacturing of motor vehicles (EU 2018)		2018	2686	thousand	ACEA (2020) and Eurostat (2020d)
Share of jobs at risks	Used ratio of total turnover in the sector (NACE 29) and total turnover linked to relevant prodcom codes (22299160 and 80% of 29311000)	2018	3.0%		Assumption based on PRODCOM (2019) and Eurostat (2020d)
AEROSPACE & DEFENCE INDUSTRY					
Lifespan aircrafts	15 to 35 years	2018	25	years	Boeing (2013)
Time to reduce need of DP for spare parts to zero after manufacture stops - average	Assumed half of the total lifetime of an aircraft	2013	12.5	years	Assumption based on Boeing (2013)
Share of DP volume used for spare parts - aircrafts		2020	20%		Assumption
Time to substitute - aerospace	Assumed 70% of the market	2020	5	years	Stakeholder consultation
Total turnover linked to plastics and wiring used in the aircraft sector	Turnover linked to relevant prodcom codes 22299180 and 10% of 29311000	2015 - 2019	2577	€ million	Eurostat (2020d)
Profit margin manufacture of aircrafts	Assumed constant profit margin	2003-2007	10.1%	% of revenue	PRODCOM (2019)
Total number employed in Aerospace and Defence H30		2019	870	thousand	ASD (2019)
Share of jobs at risks	Used ratio of total turnover in the sector and total turnover linked to relevant prodcom codes (22299180 and 10% of 29311000)	2018	1.1%		Assumption based on PRODCOM (2019) and Eurostat (2020d)

F.2 Uncertainty

Use volumes

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 highlighted in Section A.2. Uses and Section D.3. Use of Dechlorane Plus, only a few uses of DP were verified in the stakeholder consultation. It may therefore be the case that there are additional uses of DP than reported by stakeholders, which means that the volume associated with the identified uses are also highly uncertain. Without further information from stakeholders on these uses - if any, 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.

Exposure assessment

Owing to a lack of site-specific exposure information for the EU, 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, a realistic worst-case approach has been chosen in line with ECHA Guidance R16.

Uncertainties in the use volumes, both at a given site (local scale) and EU-wide, is a driving factor for 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. Details of the specific factors used are given for each life cycle stage in Section B.9. Exposure assessment and summarised in Table 116.

The Predicted environmental concentrations (PECs) have been estimated using the EUSES model (v.2.2.0). This model uses basic information on the properties of DP and, combined with estimates of the amounts of DP released, calculates the resulting concentrations in the environment using standard models. The approach used is generic and uncertainties arise in modelled outputs from a number of sources. In particular, the validity of some of the estimation methods within EUSES, particularly related to exposure in the food chain and exposure via earthworms, are uncertain for DP. For example, for some scenarios, high concentrations in human diet are predicted, resulting from high predicted concentrations in root crops and the reliability of these values are unclear.

Further uncertainties are introduced when dynamics is introduced to the modelling developing the baseline emissions. As mentioned in D.3.4. Baseline emissions of Dechlorane Plus, it has not been possible to capture continued emissions from articles already in use, nor the continued emissions after the end of the analytical period. These exclusions will, to some extent, balance each other out, so it is not expected that this will have a large impact on the overall results.

Costs and cost-effectiveness

The estimated costs for the restriction options 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. 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 were estimated based on Eurostat and PRODCOM data, but they also rely on a number of assumptions on behavioural responses, which are intrinsically uncertain.

The cost-effectiveness incorporates both emissions and costs, so the same uncertainties described above will apply to the cost-effectiveness estimates as well.

It is not possible to reduce these uncertainties any further without more information from stakeholders.

F.3. Sensitivity analysis

As highlighted in Section F.2 Uncertainty, there are uncertainties associated with many of the input factors and consequently results of the analyses. Input variables that were considered highly uncertain and / or potentially impactful on the final conclusions were, as far as practically feasible, tested in a quantitative sensitivity analysis. The use volumes were identified as a key uncertainty, but these have not been tested in the sensitivity analysis as the uncertainty is already reflected in the broad tonnage band used throughout the analyses.

Table 118 presents a simple one-parameter sensitivity analysis. It provides the assumptions used in the calculations, the ranges tested and shows the resulting percentage change in the cost-effectiveness values. It should be noted that the percentage variation presented is not exact due to rounding as well as confidentiality issues associated with some of the input parameters. The results from the sensitivity analysis are presented in full, including more precise cost-effectiveness estimates in €/kg, in Table H17 in Annex H: Confidential information.

The sensitivity analysis showed that only a few of the tested parameters have a significant (here “significant” is defined as an absolute value higher than 10%) effect on the cost-effectiveness of the restriction options. The input factor with the highest impact on the cost-effectiveness estimates is the overall sales value associated with manufacture of plastics and wiring for the automotive sector, where percentage variation in the sales value translate almost one for one in the cost-effectiveness estimates. The second largest driver is the corresponding profit margin for the automotive sector. Considering the dominance of the automotive sector in the market for DP, this is not surprising. These results also highlight the uncertainties introduced when using profits as the primary cost component. If only substitution costs are estimated, the primary cost drivers would be price and loading of alternatives as compared to DP. Potential profit losses are associated with a higher degree of uncertainty as they will rely heavily on assumptions and modelling choices such as affected products, behavioural responses and inclusion or exclusion of knock-on effects.

Although large uncertainties are induced by the inclusion of potential profits lost in the cost estimates, the overall conclusions did not change throughout the sensitivity analysis where a change in profit lost of +- 50% was tested. The large interval for the use and emission volumes included in the core analysis encompasses most of the variation seen in the central value in the sensitivity analysis, i.e. most of the sensitivity values falls within the range estimated in the core analysis – see Table H17 in Annex H: Confidential information for more details. As such, it is concluded that uncertainties induced by single input factors are not likely to change the overall conclusions.

Table 118: Sensitivity analysis with key input factors

Parameter	Value used in the analysis	Values tested	Resulting cost-effectiveness		
			RO1	RO2	RO3
			Central value ~ 20 000 €/kg	Central value ~ 10 000 €/kg	Central value ~ 500 €/kg
MARKET FOR DECHLORANE PLUS					
DP volume replacing decaBDE by 2020	0 tonnes	0 - 100 tonnes	0% - -1%	0% - 0%	0% - -20%
Real growth rate 2020 - 2030 - Use of DP in the EU	2.2%	0% - 4%	22% - -14%	23% - -15%	20% - -20%
Real growth rate 2020 - 2030 - Use of DP in the EU	-0.1%	-1% - 1% per year	22% - -14%	23% - -15%	20% - -20%
AUTOMOTIVE INDUSTRY					
Time to reduce need of DP for spare parts to zero after manufacture stops - average	7 years	4 - 10 years	-6% - 5%	-1% - 0%	0% - 0%
Share of volume used for spare parts - automotive	10.0%	5% - 20%	-2% - 7%	4% - -19%	0% - -20%
Total turnover linked to plastics and wiring used in the automotive sector	€31 521 million/year	€15 000 – €45 000 million/year	-42% - 34%	-47% - 38%	-40% - 20%
Profit margin manufacture of vehicles	9.1%	7% - 11%	-19% - 16%	-20% - 19%	-20% - 0%
AEROSPACE & DEFENSE INDUSTRY					
Time to reduce need of DP for spare parts to zero after manufacture stops - average	12.5 years	10 - 15 years	-1% - 1%	0% - 0%	0% - 0%

Parameter	**Value used in the analysis**	**Values tested**	**Resulting cost-effectiveness**		
			RO1	**RO2**	**RO3**
			Central value ~ 20 000 €/kg	**Central value ~ 10 000 €/kg**	**Central value ~ 500 €/kg**
Share of DP volume used for spare parts - aircrafts	20.0%	10% -30%	-1% - 1%	0% - -1%	0% - -20%
Total turnover linked to plastics and wiring used in the aircraft sector	€2 577 million / year	€1 000 - €4 000 million / year	-8% - 7%	-3% - 3%	-20% - 0%
Profit margin manufacture of aircrafts	10.1%	8% - 12%	-3% - 2%	-1% - 1%	-20% - 0%
Total variation in <u>central</u> value (% change)			**-42% - 34%**	**-47% - 38%**	**-40% - 20%**
Total variation in <u>central value</u> (€/kg)			**~ 10 000 – 25 000**	**~ 5 000 – 15 000**	**~ 0 – 1 000**
Range from the core analysis (<u>Low, High</u>)			**~ 13 000 – 39 000**	**~ 8 000 – 23 000**	**~ 0 – 1 000**

Note:

- Total variation in RO1 and RO2 variation is rounded to nearest 5000 €/kg DP, and RO3 to nearest 500 €/kg DP.
- As a result of rounding and confidentiality of input factors, the percentage values are not exact and should only be viewed as an indicator for order of magnitude.

Annex G: Stakeholder information

A total of 16 stakeholders, most of which are industry associations, have provided information via the online survey, the Call for Evidence (CfE), participated in an interview and/or other input by email. In total, seven sectors were covered by the stakeholder engagements:

- Manufacture of chemicals;
- Cable and wire;
- Automotive;
- Aviation;
- Consumer electronics;
- Recycling; and
- Explosives.

G.1. Call for Evidence (CfE)

ECHA launched a CfE which was open on the ECHA website from 01/04/2020 to 15/06/2020 (ECHA, 2020a). The aim of the CfE was to gain information on uses of DP in the EU as well as gauging the impacts to relevant industries if a restriction was put in place. The CfE was split into four questions depending on which stakeholders should answer: question 1 was for all stakeholders to answer, while questions 2, 3 and 4 were for suppliers, downstream users and recyclers of DP, respectively. The questions followed a similar format and primarily focussed on the following topics:

- Tonnage data of DP (as a substance or in articles) and the DP market;
- Potential alternatives and information on the technical difficulties and economic impacts of switching to these; and,
- Time needed to adapt the processes/make the substitution.

In total, five responses were received, all of which were non-confidential. Respondents included a company (aviation industry), three industry associations (automotive, aviation and motorcycle industries) and one non-governmental organisation who provided information on environmental contamination, exposure and effects of DP.

The background note for the CfE gives more information:
https://echa.europa.eu/documents/10162/724b8c08-98fc-a992-49fd-aa329de4437d

G.2. Stakeholder surveys

In parallel with the CfE, eftec, on behalf of the Dossier Submitter, produced and launched three online stakeholder surveys for manufacturers and/or importers, downstream users, and recyclers of DP / articles containing DP. All three stakeholder online surveys followed a similar structure and asked questions within the following sections:

- Manufacture and use of DP / articles (and recycled articles) containing DP;

- Releases of DP into the environment (and for recyclers: separation technologies);

- Substance function;

- Alternatives and substitution process; and
- Response and impacts of restriction DP (and for recyclers: disposal routes of DP).

The aim of the online surveys was to complement information gathered by the CfE with a greater focus on quantitative (tonnage) data throughout the DP supply chain. The stakeholder surveys were available to answer through an online platform (SmartSurvey) and were provided to stakeholders through URL weblinks and PDF copies. On behalf of the Dossier Submitter, the consultant eftec contacted approximately 100 stakeholders who were identified as potentially being impacted by the restriction of DP. All were sent emails detailing the potential REACH and Stockholm Convention restrictions and were directed to complete and return the most appropriate of the three surveys (depending on their position in the DP supply chain) by 15/05/20. Due to the unprecedented challenge of COVID19, the stakeholder survey deadline was extended by 1-month to align with the CfE deadline. In mid-April 2020 'email reminders' were sent to all stakeholders who received the initial email to inform them of the extended deadline.

Although 30 stakeholders interacted with the survey, only 5 surveys were submitted by the deadline. Clarifications (or, follow-up questions) were sent to 3 out of the 5 survey responses that were returned, as one submission had no contact information and another submission included 'dummy responses' (e.g. answers were '123' for multiple questions), so could not be included in the data analysis. Thus, one manufacturer and/or importer and two downstream user surveys were analysed and included in the report.

G.3. Stakeholder interviews

Two associations (automotive and wiring and cables) and one company (electronics and electrical equipment) agreed to interview. Although the Dossier Submitter repeatedly reached out to a European recycling association, it was not possible to undertake an interview.

An interview script was sent to each of the interviewees before the interview took place so that the stakeholder(s) could gather the relevant information and prepare submissions if required. Some specific clarifications (or, follow-up questions) were added dependent on the previous CfE or stakeholder survey submission. The interview script mirrored the structure of the stakeholder surveys, see Section G.2. Stakeholder surveys.

After the interview, an interview report was written and sent to the interviewee so that any misinterpretations could be corrected, any clarifications could be resolved, and any further follow-up questions could be asked. This was edited and sent back to the stakeholder as a record of the information that the Dossier Submitter had gained from the interview.

G.4. Other communications with stakeholders

In addition to the survey and interviews, some stakeholders, provided information per email. Where email correspondence was unsuccessful, the Dossier Submitter made approximately 30 additional phone calls to gather additional information and promote greater engagement with the restriction process. Engagement was encouraged through inviting them to fill in the stakeholder survey or attempting to arrange an interview.

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Appendix 1: Environmental and human monitoring data

Table 119: (Copy of Table 4 in UNEP/POPS/POPRC.16/INF/14.)[47] *Detection in wastewater treatment, sludge and matrix from impacted sites and from manufacture/recycling sites*

Matrix	**Country /Region /Area**	**Year**	**Study site Type of location**		**Concentration**			**Comments**	**Reference**
Wastewater treatment, sludge, impacted sites and from manufacture etc					***syn***	***anti***	***tot*DP**		
Wastewater	China	2010-2011	WWTP, Shanghai				50-1400 pg/L		Xiang et al., 2014
Soil	China	2009	E-waste recycling site				0.17-1990 ng/g dw		Xiao et al., 2013
Soil	China	2009	Near manufacturing plant				0.83-1200 ng/g		Wang et al., 2010b
Soil	China	2009	Manufacturing facility in Huai'an				5.11-13400 ng/g dw		Wang et al., 2010a
Soil	China	2011	Manufacturing facility in Huai'an				0.50–2315 ng/g		Zhang et al., 2015
Soil	China	-	E-waste disposal area in Guiyu		0.14–38 ng/g	0.42–107 ng/g	0.57–146 ng/g		Xu et al., 2017
Soil	China		E-waste recycling site		1081 ng/g	2246 ng/g	3327 ng/g		Yu et al., 2010
Soil	China		Areas surrounding the e-waste recycling sites		n.d. - 12.2 ng/g	n.d. - 36.3 ng/g	n.d. - 47.4 ng/g		Yu et al., 2010

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[47] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx – note that a new version of this document is in preparation under the Stockholm Convention; UNEP/POPS/POPRC.17/INF/xx

Matrix	**Country /Region /Area**	**Year**	**Study site Type of location**		**Concentration**			**Comments**	**Reference**
Wastewater treatment, sludge, impacted sites and from manufacture etc					***syn***	***anti***	***tot*DP**		
Soil	China		Industrial areas		n.d. - 1.18 ng/g	0.03 - 3.47 ng/g	0.03 - 4.65 ng/g		Yu et al., 2010
Soil	China		Manufacturing areas				0.50–2,315 pg/g		Zhang et al., 2015
Sediment	Lake Ontario	2004	Near manufacturing plant				<310 ng/g dw		(Qiu et al., 2007)
Sediment core	Lakes Erie	1997-1998	Near manufacturing plant				0.061-8.62 ng/g dw		Sverko et al., 2008
Sediment core	Lake Ontario	1997-1998	Near manufacturing plant				2.23-586 ng/g dw		Sverko et al., 2008
Surficial sediments	Great Lakes, Canadian site	2002-2006	Near manufacturing plant				0.035-310 ng/g dw		Shen et al., 2011b
Suspended sediment	Niagara river	1980-2007	Near manufacturing plant				2.5-62 ng/g dw		Shen et al., 2011a
Sediment core	Lake Ontario		Near manufacturing plant				0.061-160 ng/g dw		Shen et al., 2011a
Surficial sediment core	Lake Ontario	2007	Near manufacturing plant				73-140		Yang et al., 2011
Sediment core	Lake Ontario	2006-2007	Near manufacturing plant				0.85-96		Shen et al., 2010
Sediment	China		Manufacturing facility in Huai'an				1.86-8.00 ng/g dw		Wang et al., 2010a
Sediment	China	2009	e-waste recycling site		520-1630 ng/g	1860-6630 ng/g			Zhang et al., 2011b
Riverine surface sediments	China	2013	e-waste recycling region in Taizhou		27 – 14280 pg/g dw	81 – 13410 pg/g dw	108 – 55270 pg/g dw	*anti*-Cl_{10}: nd - 2580 *anti*-Cl_{11}: 2 - 580	Zhou et al., 2017

Matrix	**Country /Region /Area**	**Year**	**Study site Type of location**		**Concentration**			**Comments**	**Reference**
Wastewater treatment, sludge, impacted sites and from manufacture etc					***syn***	***anti***	***tot*DP**		
Suspended sediment	China	-	e-waste recycling site		*13130 ± 2885 ng/g OC*	*65660 ± 11440 ng/g OC*		ng/g Organic Carbon	Wu et al., 2010
Surficial sediment	China	-	e-waste recycling site		*21820 ± 2160 ng/g OC*	*55320 ± 7140 ng/g OC*		ng/g Organic Carbon	Wu et al., 2010
Sediment	China		Manufacturing areas				0.32–20.5 ng/g dw		Zhang et al., 2015
Sewage sludge	Norway	2017	WWTP		2.1 ng/g	7.4 ng/g			Norwegian Environment Agency, 2018b
Sewage sludge	Norway	2018	WWTP		2.5 ng/g	11.8 ng/g			Norwegian Environment Agency, (2019a)
Sewage sludge	Spain		WWTP				2.58-18.8 ng/g d.w.		Barón et al. (2012)
Sludge	Spain	2010	Ebro and Llobregat river basins,				<0.06-18.8		(Barón et al., 2014)
Sewage sludge, biosolids	United States of America	2006-2010	Municipal, North Carolina		2-24 ng/g d.w	5-29 ng/g d.w			Davis et al., 2012
Sewage sludge	Spain	2006	WWTP				2.45-93.8 ng/g d.w.		de la Torre et al. (2011a)
Sludge	China	2013-2014	Sewage treatment plants (STP)		8.6 – 16 ng/g d.w	7.2 – 19.2 ng/g d.w			Wu et al. (2017)
Air	Canada	2017-2018	e-waste recycling site, small facility		2–5.8 ng/m3	2.3–5.4 ng/m3	4.4–11 ng/m3		Gravel et al. (2019)

Matrix	**Country /Region /Area**	**Year**	**Study site** **Type of location**		**Concentration**			**Comments**	**Reference**
Wastewater treatment, sludge, impacted sites and from manufacture etc					***syn***	***anti***	***tot*DP**		
Air	Canada	2017-2018	e-waste recycling site, medium facility		4.7–9.3 ng/m3	7.3–15 ng/m3	12–24 ng/m3		(Gravel et al., 2019)
Air	Canada	2017-2018	e-waste recycling site, large facility		12–18 ng/m3	22–34 ng/m3	34–53 ng/m3		(Gravel et al., 2019)

Table 120 (Copy of Table 6 in UNEP/POPS/POPRC.16/INF/14.) [48] *Abiotic monitoring data for Dechlorane Plus in remote locations (adopted from ECHA (2017d) and added new literature)*

Matrix	**Country/Region/Area**	**Year**	**Study site/ type of location**	**Concentration**			***f*anti**	**Detection frequency %, syn; anti-DP**	**Comment**	**Reference**
				syn	*anti*	*tot*DP				
Atmosphere	Canada	2006 - 2007?	Alert, High Arctic			<0.05 - 2.1 pg/m^3			Primarily associated with particles	Xiao *et al.*, 2012
	Tibet, China	2006 - 2008	Tibetan Plateau (Nam Co), Remote Mountain Area			ND			ND in pre-screening suggested to be due to fewer particulates reaching the station	
Atmosphere	Greenland	2009	Transect in East Greenland Sea			0.05 - 4 pg/m^3			- Mainly detected in the particulate phase - In the Atlantic, the highest concentration was observed in the English Channel originating from continental air passing Western Europe - The fractional abundance of syn-DP	Möller *et al.*, 2010
	Atlantic	2008	Transect in northern and southern Atlantic Ocean							

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[48] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx – note that a new version of this document is in preparation under the Stockholm Convention; UNEP/POPS/POPRC.17/INF/xx

Matrix	**Country/Region/Area**	**Year**	**Study site/ type of location**	**Concentration**			***ƒ*anti**	**Detection frequency %, syn; anti-DP**	**Comment**	**Reference**
				syn	*anti*	*tot*DP				
									increased with decreasing northern latitude from 0.37 to ca. 0.67, showing a stereoselective depletion of anti-DP	
Atmosphere	China	2010	Transect from East China Sea to Arctic			0.01 - 1.4 pg/m^3			Mainly detected in the particulate phase	Möller *et al.*, 2011
		2010 - 2011	Transect in Pacific Ocean			1.7 - 11 pg/m^3				Möller et al. (2012)
			Transect in Indian Ocean			0.26 - 2.1 pg/m^3				
			Transect in Southern Ocean			0.31 pg/m^3				
Atmosphere	Arctic	2012 - 2013	Arctic (78.22°N 15.65°E)	Mean 0.29 (±0.04) pg/m3	Mean 1.1 (±0.19) pg/m3	0.05 - 5 pg/m^3	0.43 - 0.9 (mean 0.75)	91; 91	The samples represent the atmospheric particulate fraction collected on quartz fibre filters (2.2 µm cut-off)	Salamova et al. (2014)
Atmosphere	Sweden	2009 - 2010	Råö			0.18 - 0.52 pg/m^3				Kaj et al. (2010)

Matrix	**Country/Region/Area**	**Year**	**Study site/ type of location**	**Concentration**			**ƒanti**	**Detection frequency %, syn; anti-DP**	**Comment**	**Reference**
				syn	*anti*	*tot*DP				
			Aspvreten			0.12 - 0.23 pg/m^3				
	Northern Finland		Pallas, Arctic			0.016 - 0.047 pg/m^3				
Atmosphere	Arctic								It does not cite articles beyond the ones already summarised here	Vorkamp et al., (2014)
Atmosphere	Northeast Greenland	2012	Station Nord	Mean 2.32 (<1 - 9.0) pg/m^3	Mean 5.24 (<1 - 33.1) pg/m^3					Vorkamp et al. (2015)
Atmosphere	Greenland, Arctic	2014-2016	Villum Research Station			Mean 4.2 pg/m^3 Max. 31.7 pg/m^3				Vorkamp et al. (2019)
		2014				Mean 0.64 pg/m^3 Max. 5.5 pg/m^3				

Matrix	**Country/Region/Area**	**Year**	**Study site/ type of location**	**Concentration**			***f*anti**	**Detection frequency %, syn; anti-DP**	**Comment**	**Reference**
				syn	*anti*	*tot*DP				
Atmosphere	Northern Sweden	2009 - 2010	Abisko in the Arctic			Max. 5.7 ng per sample	Mean 0.25		- The higher flux was found at the more remote site - It suggests isomer-selective degradation or isomerization during long range transport to the more remote site - The *f*anti at the sub-Arctic site was similar to that in commercial products, which may indicate proximity to a local source	Newton et al. (2014)
			Krycklan in the sub-Arctic			Max. 0.16 ng per sample	Mean 0.62			
Atmosphere	All continents except Antarctica	2005 (also 2006?)	25 sites			ND - 348 pg/m^3			- The highest level being for Cape Grim, Tasmania where population density is very low - Also detected in north Alaska and Svalbard	Sverko *et al.*, 2010
Seawater	Greenland	2009	Transect in East Greenland Sea			< LOD - 1.3 pg/L			Mainly detected in the particulate phase	Möller *et al.*, 2010
	Atlantic	2008	Transect in northern and							

Matrix	**Country/Region/Area**	**Year**	**Study site/ type of location**	**Concentration**			***ƒ*anti**	**Detection frequency %, syn; anti-DP**	**Comment**	**Reference**
				syn	*anti*	*tot*DP				
			southern Atlantic Ocean							
Seawater	China	2010	Transect from East China Sea to Arctic			0.006 - 0.4 pg/L				Mőller *et al.*, 2011
Soil	Norway	-	Ny-Ålesund, Svalbard, Arctic	Mean 0.284 (0.094 - 1.01) µg/kg dw	Mean 0.042 (0.012 - 0.105) µg/kg dw		0.18		Low *f*anti values found in water, sediment, soil may reflect degradation of anti-DP during long-range transport, possibly by UV	(Na et al., 2015)
Seawater				Mean 61 (22 - 116) pg/L	Mean 32 (85 - 648) pg/L		0.36			
Sediment				Mean 0.270 (0.085 - 0.648) µg/kg dw	Mean 0.073 (0.023 - 0.228) µg/kg dw		0.21			
Sediment	Norway	2009	Kongsfjorden, Svalbard, Norwegian Arctic	ND - 5.4 pg/g dw (mean 1.4 ±	ND - 15.9 pg/g dw (mean 4.5 ±			78; 94	- No clear spatial trend between the outer and inner fjord - Plausible that both glacial runoff and oceanic currents play a	Ma et al. (2015)

Matrix	**Country/Region/Area**	**Year**	**Study site/ type of location**	**Concentration**			**ƒanti**	**Detection frequency %, syn; anti-DP**	**Comment**	**Reference**
				syn	*anti*	*tot*DP				
				1.5 pg/g dw)	4.3 pg/g dw)				role in introducing DP to the fjord sediments - Relatively low fractional abundance of the syn-DP isomer indicates the long-range transport of this chemical to this Arctic site	

Table 121 (Copy of Table 10 in UNEP/POPS/POPRC.16/INF/14.) [49] *Measured concentrations in aquatic biota*

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
Invertebrates										
Mussel (species not specified) (n=2)	Soft parts	Canada	-	Niagara River area	Affected	Site 1 ~2 µg/kg ww Site 2 ~0.8 µg/kg ww	Site 1 ~2 µg/kg ww Site 2 ~1 µg/kg ww	Site 1 ~4 µg/kg ww Site 2 ~1.8 µg/kg ww	- Analysis by GC-HRMS - Not known if mussels were depurated prior to analysis - Values read from a graph - It appears that two different locations were involved, with one mussel representing each site	Kolic *et al.* (2009)
Blue Mussel (*Mytilus edulis*) (n unknown)	Soft parts	Iceland	2011	Fossá river estuary, Hvalfjörður	Remote	< LOD	< LOD		- Analysis by GC-MS - LOD: presumably 0.003/4 µg/kg ww for both isomers - Not known if mussels were depurated prior to analysis	(Schlabach, 2011)
		Norway	-	Receiving water from Åse WWTP, Ålesund	Affected	0.017-0.023 µg/kg ww	0.018-0.019 µg/kg ww	0.035-0.042 µg/kg ww		
Fish										
Barbel (*Barbus barbus*) Wels Catfish (*Silurus glanis*)	Not stated	Spain	-	Ebro river basin	Affected			Median 0.88 µg/kg lw	- Analysis by GC-NCI-MS-MS - LOD (µg/kg lw):	(Barón et al., 2012)

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[49] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx – note that a new version of this document is in preparation under the Stockholm Convention; UNEP/POPS/POPRC.17/INF/xx

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
Common Carp (*Cyprinus carpio*) (n unknown)								Range <LOD-2.24 µg/kg lw	Anti-DP: 0.0023 Syn-DP: 0.0055 - Presumably a subset of the data reported by Santín *et al*. (2013)	
Fish (various species) (n=48)	Whole body	Spain	2010	Llobregat river basin	Affected			0.57-4.86 µg/kg lw	- Analysis by GC-MS - LOD (µg/kg lw): Anti-DP: 0.0023 Syn-DP: 0.0055 - The study included four Wels Catfish (*Silurus glanis*) caught in the Ebro river basin	Santín *et al*. (2013)
				Júcar river basin				<LOD-0.59 µg/kg lw		
				Ebro river basin				0.11-1.28 µg/kg lw		
				Guadalquivir river basin				0.06-1.91 µg/kg lw		
Lake Trout (*Salvelinus namaycush*) (from Lake Superior (n=3), Lake Huron (n=5), Lake Ontario (n=5)) Whitefish (*Coregonus clupeaformis*) (from Lake Erie (n=5), Lake Ontario (n=5))	Dorsal muscle	Canada	1999-2002	Lake Superior, Lake Huron, Lake Ontario, Lake Erie	Affected			Range 0.061-2.600 µg/kg lw	- Analysis by GC-HRMS - Detected in all samples - Fish from Lake Ontario had higher concentrations compared to those from the other lakes - Most fish samples had *f*anti values below the highest value of technical products (no difference was observed between the two fish species)	(Shen et al., 2010)
Walleye (*Stizostedion vitreum)*	-	United States of America (USA)	1980-2000	Lake Erie	Affected			Range 0.14-0.91 µg/kg lw	- Analysis by GC-MS - LOQ (µg/kg lw): Anti-DP: 0.05 Syn-DP: 0.12 - Most of the muskelunge samples were >7 years old	Hoh et al. (2006); Houde et al. (2014)
Yellow Perch (*Perca flavescens*) (n=29)	Whole body							ND		
Northern Pike (*Esox lucius*) (n=11)	Liver					Range ND-9.1 µg/kg lw	Range ND-2 µg/kg lw			

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
						(Detected in 45% of samples)	(Detected in 45% of samples)			
Muskellunge (*Esox muskellunge*) (n=10)	Liver							Mean 6.2±3.6 µg/kg lw (one fish contained 37.4 µg/kg lw) (Detected in at least 90% of samples)		
Lake Trout (*Salvelinus namaycush*) (n=5 per year)	Whole body	Canada	1979 1983 1988 1993 1998 2004	Lake Ontario (north of Main Duck Island)	Affected			Mean per year 0.31±0.07 to 0.85±0.20 µg/kg ww (2.3±0.6 to 7.2±1.3 µg/kg lw)	- Analysis by GC-MS - LOQ 0.01 µg/kg ww - Sampled fish were four to five years old - Stable isotope analysis showed that trophic status and food sources were highly variable over time	Ismail *et al.* (2009)
European Eel (*Anguilla anguilla*) Glass eels (n=100, split into 10 samples)	Whole body or muscle	France	-	The French Atlantic coast	Affected			Glass eels: <0.02-0.32 µg/kg ww (LOD-31.8 µg/kg lw)	- Analysis by GC-MS - LOD (µg/kg ww): Anti-DP: 0.017 Syn-DP: 0.0053 - Levels were similar to American Eels, and probably reflect diffuse exposure - The isomer ratio changes over the life cycle: The syn-isomer predominates (>80%) in glass, elvers and yellow eels, but its contribution drops to 40% in silver (fully adult) eels that have stopped feeding	Sühring *et al.* (2013 and 2014)
European Eel (*Anguilla anguilla*) Elvers (n=30), yellow (n=30), silver eels (n=12)		Germany	-	River Vidå, River Elbe and Rivers Elbe and Rhine	Affected			Elvers: <0.02-0.46 µg/kg ww (<LOD-33.8 µg/kg lw) Yellow eels: 0.013-0.50 µg/kg ww (0.14±0.008 µg/kg lw) Silver eels: 0.017-0.38 µg/kg ww (0.17±0.19 µg/kg lw)		

Organism		**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
							syn	*anti*	*tot*DP		
American Eel (*Anguilla rostrata*)	Glass eels (n=37, pooled into three samples)	Whole body or muscle	Canada	2007-2008	Baie des Sables, Matane, Quebec	Affected			<0.02 µg/kg ww	- Analysis by GC-MS - LOD (µg/kg ww): Anti-DP: 0.017 Syn-DP: 0.0053 - Levels were similar to European Eels and probably reflect point source as well as diffuse exposure - The isomer ratio changes over the life cycle: The syn-isomer predominates (>70%) in yellow eels, but its contribution drops to 44% in silver (fully adult) eels that have stopped feeding - DPMA was detected in yellow and silver eels from the same area	Sühring *et al*. (2014); Byer *et al*. (2013)
	Young yellow eels (n=10)				The Saint Lawrence River				0.10-0.69 µg/kg ww (1.7 ± 0.92 µg/kg lw)		
	Yellow eels (n=15, muscle)				Lake Ontario and the upper Saint Lawrence River				0.19±0.086 to 0.29±0.20 µg/kg ww (0.90 ± 0.41 to 0.17±0.19 µg/kg lw)		
	Silver eels				Lake Ontario				0.067±0.048 µg/kg lw		
Arctic Char (*Salvelinus alpinus*) (12 fish analysed as a pooled sample)		Muscle	Faroe Islands	-	á Mýranar lake	Remote	< LOD	< LOD		- Analysis by GC-MS - LOD (µg/kg ww): Presumably 0.003/4 for both isomers	(Schlabach, 2011)
Perch (*Perca fluviatili*)	n=1 from Helsinki and n=5 Pyhäjärvi	Muscle	Finland	-	Helsinki (Old City Bay) and Pyhäjärvi, Tampere	Affected	0.0038 µg/kg ww in one composite sample, all others < LOD	0.0011 and 0.0030 µg/kg ww in two composite samples, all others < LOD		- Analysis by GC-MS - LOD (µg/kg ww): Anti-DP: 0.001-0.003 Syn-DP: 0.002-0.004 - Composite sample	
	n unknown		Sweden		Riddarfjärden and Stora Essingen at Lake		< LOD	< LOD		- Analysis by GC-MS - LOD (µg/kg ww): Anti-DP: 0.001-0.003 Syn-DP: 0.002-0.004	

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
				Mälaren, Stockholm					- 6-10 individuals per composite sample	
Striped Bass (*Morone saxatilis*) (n=1) Tilapia (*Oreochromis mossambicus*) (n=1) Cod (*Gadus morhua*) (n=1) Atlantic Salmon (*Salmo salar*)] (n=1)	Muscle	Taiwan, Province of China	-	Two Super-markets in Chung-Li city	Affected	Range 0.038-0.273 µg/kg lw	Range 0.034-0.300 µg/kg lw		- Analysis by GC-MS - LOD: 0.0003 µg/g lw for both isomers - Cod and salmon were imported while the other two species were locally caught - The highest concentrations occurred in the bass	Chen *et al.* (2014)
Fish (15 marine species) (n=20)	Muscle	Japan	2011	Super-markets in Osaka	Affected			Up to 0.0142 µg/g ww	- Analysis by GC-MS - LOD 0.0002 µg/kg ww - Detected in 18 out of 20 samples	Kakimoto et al. (2012)
Common Mullet Oriental Goby Steed Barbel Temperate Sea Bass Crucian Carp (Latin names not provided)	Muscle	Republic of Korea	2008	22 rivers across South Korea	Overall	Range 0.17 – 30 µg/kg lw	Range 0.44 – 97 µg/kg lw	Average 24.5 (range 0.61-126) µg/kg lw	- Analysis by GC- high resolution MS - Fish were sampled twice at each site and several individual fish carcasses were combined and homogenized to provide a pooled sample - Both isomers were consistently detected in all fish samples regardless of sampling sites and fish species - Mean concentrations at the urban sites were around 25 times greater than those at the rural sites - The anti-DP isomer was dominant in all samples - The mean *f*anti value (0.67 ±0.060) was significantly	Kang *et al.* (2010); Kang *et al.* (2009) [ABST]
					Rural-industrial (3 sites) and Rural (4 sites)			1.4±1.0 µg/kg lw		
					Urban-industrial (15 sites)			36.1±35.3 ng/g lw		

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
									lower than that of the technical product (0.75) (p = 0.032) suggesting that the syn-isomer may be more bioaccumulative There is no manufacturing facility in South Korea	
Mud Carp (*Cirrhinus molitorella*) (n=10) Northern Snakehead (*Channa argus*) (n=10)	Muscle, liver & brain	China	2009	Natural pond at an e-waste recycling site, South China	Affected		Anti-DP-1Cl Median 0.01-5.63 µg/kg ww Anti-DP-2Cl 0.01 µg/kg ww	Mud Carp (median) Muscle: 0.38 µg/kg ww Liver: 9.55 µg/kg ww Brain: 18.26 µg/kg ww Northern Snakehead (median) Muscle: 0.76 µg/kg ww Liver: 92.0 µg/kg ww Brain: 11.8 µg/kg ww	- Analysis by GC-MS - LOD (µg/kg ww): Anti-DP: 0.00052 (muscle) to 0.024 (brain) Syn-DP: 0.0012 (muscle) to 0.055 (brain) - Both species are associated with benthic environments - Both isomers were detected in all samples - The median sediment concentration (total isomers) was above 3,000 µg/kg dw - Higher levels of the anti-isomer were detected in the brain than liver or muscle for Mud Carp whereas liver accumulated more of both isomers in Northern Snakehead - Lipid-normalized concentrations indicated preferential distribution to liver in both species, suggesting that hepatic proteins might be important in	Zhang *et al.* (2011a)

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
									the accumulation of this substance - It appeared that there was enrichment of the syn- isomer in all tissues (except Northern Snakehead brain) compared to levels in sediment and the technical product - The study shows that both isomers can cross the blood-brain barrier in fish - Anti-DP-1Cl was detected in 100% of liver and 80% of muscle samples - Anti-DP-2Cl was detected in one muscle sample of Mud Carp - Both anti-DP-1Cl and anti-DP-2Cl were detected in all five sediment samples collected at the same time (range 6.32-25.0 µg/kg dw, median 12.0 µg/kg dw for anti-DP-1Cl and range 0.42-0.83 µg/kg dw and median 0.64 µg/kg dw for anti-DP-2Cl)	
Mud Carp (*Cirrhinus molitorella*) (n=3) Northern Snakehead (*Ophicephalus argus*) (n=3)	Blood serum	China	2010	Electronics waste recycling site in South China	Affected			Mud Carp Mean 0.3 µg/kg ww Mean *f*anti = 0.44 Northern Snakehead	- Analysis by GC-MS - LOD: 0.009-0.026 µg/kg ww - Six individuals per pooled sample - Each pooled sample was divided into 2 subsamples for analysis	Zeng *et al.* (2014b)

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
								Mean 4.6 µg/kg ww Mean *f*anti = 0.56 Both species Range 0.3-5.1 µg/kg ww (47-727 µg/kg lw)	- The fanti in both species was significantly lower (*p*<0.001) than that in sediments from the area (*f*anti=0.755) - Detected in all pooled samples	
Crucian Carp (*Carassius carassius*) Common Carp (*Cyprinus carpio*) Grass Carp (*Ctenopharyngodon idellus*) Sharpbelly (*Hemiculter leucisculus*) Pond Loach (*Misgurnus anguillicaudatus*) (n=18, pooled samples)	Muscle	China	2010	Liaohe River, Liaoning province (6 sites)	Affected			Mean 223 ng/kg lw Median 215 ng/kg lw Range ND-470 ng/kg lw	- Analysis by GC-MS - Detected in 17 out of 18 pooled samples	(Ren et al., 2013)
Bleeker (*Pseudolaubuca sinensis*) (n=12) Loach (*Misgurnus anguillicaudatus*) (n=7) Crucian Carp (*Carassius auratus*) (n=9) Common Carp (*Cyprinus carpio*) (n=8) Northern Snakehead (*Channa argus*) (n=3)	Muscle	China	2010	Beijing-Hangzhou Grand Canal (downstream of the discharge point of the Chinese manufacturing facility), Huai'an,	Affected			Mean 764 (range of mean for each species: 56.8-1110) µg/kg ww Mean 67500 (range of mean for each species: 2760-96800) µg/kg lw	- Analysis by GC- high resolution MS - LOD (µg/kg ww): Anti-DP: 0.135 Syn-DP: 0.120 - Five fish were pooled into composite sample for each species (except Northern Snakehead) - The highest mean concentrations were 1.1 mg/kg ww in Common Carp and 97 mg/kg lw in Bleeker	Wang et al, 2013

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
				Jiangsu province						
Mosquito Fish (*Gambusia affinis*) (n=11) Paradise Fish (*Macropodus opercularis*) (n=9) Chinese Hooksnout Carp (*Opsariichthys bidens*) (n=18). Chinese False Gudgeon (*Abbottina rivularis*) (n=10) Nichols' Minnow (*Nicholsicypris normalis*) (n=6) Chinese Bitterling (*Rhodeinae*) (n=9)	Whole fish	China	2010	Dinghu Mountain (reference site)	Rural		Anti-DP-1Cl < LOD (0.09 µg/kg lw)	34 fish, 12 composites Medians per species 1.7-8.4 µg/kg lw Overall range 0.96-8.8 µg/kg lw	- Analysis by GC-MS - LOD (µg/kg lw): Anti-DP: 0.59 Syn-DP: 0.14 - Fish were pooled into composite sample for each species at each site - The e-waste site is in a heavily industrialized area - The reference site is in a relatively non-contaminated agricultural area - Anti-DP-2Cl was not detected in any sample (LOD: 0.01 µg/kg lw)	(Mo et al., 2013)
				E-waste recycling site in the Pearl River Delta, Guangdong Province	Affected		Anti-DP-1Cl Range 2.4-14 µg/kg lw	29 fish, 9 composites Medians per species 79-410 µg/kg lw Overall range 60-420 µg/kg lw		
Greenland Shark (*Somniosus microcephalus*) (n=15)	Liver	Iceland	2001-2003	Female sharks caught in a commercial fishery in the waters around Northeast Atlantic	Remote				- The paper provides quantitative data on three target compounds that were "routinely" detected in the liver samples, but does not comment on the concentrations or detection frequencies of the other substances that were included in the analysis (including Dechlorane Plus) - In summarising this study, Vorkamp & Rigét (2014) stated that Dechlorane Plus was "not detected", but this might be misleading	Strid *et al.* (2013)

Organism	**Tissue**	**Country /Region/ Area**	**Year**	**Study site**	**Type of location**	**Concentration**			**Comment**	**Reference**
						syn	*anti*	*tot*DP		
Brown trout (*Salmo trutta*)	Fillet	Norway	2017	Lake Mjøsa	Urban	4.5 µg/kg ww 530 µg/kg lw	4.9 µg/kg ww 580 µg/kg lw			Norwegian Environment Agency (2018b).
Smelt	Fillet	Norway	2017	Lake Mjøsa	Urban	6.8 µg/kg ww 660 µg/kg lw	9.6 µg/kg ww 940 µg/kg lw			Norwegian Environment Agency (2018b)
Brown trout (*Salmo trutta*)	Fillet	Norway	2017	Eikdalsvatnet	Rural	17.8 µg/kg ww 1800 µg/kg lw	47 µg/kg ww 4880 µg/kg lw			Norwegian Environment Agency (2018b).
Brown trout (*Salmo trutta*)	Fillet	Norway	2017	Femunden	Rural	4.5 µg/kg ww 530 µg/kg lw	4.9 µg/kg ww 580 µg/kg lw			Norwegian Environment Agency (2018b).

Table 122 (Copy of Table 11 in UNEP/POPS/POPRC.16/INF/14.) [50] *Detection of Dechlorane monoadduct (DPMA) in environmental samples*

Matrix		**Country/Region/Area**	**Year**	**n**	**Concentration**			**Comment**	**Reference**
					1,5-DPMA	**1,3-DPMA**	**ΣDP**		
Lake trout		Canada, Lake Ontario	2000-2003	4	nd	34 ± 43 ng/g lw			Sverko *et al.*, 2010
Plankton		Canada, Lake Ontario	2000-2003	1	nd	199 ng/g lw	2.05 ng/g lw		Tomy *et al.*, 2013
Diporeia				1	nd	56.1 ng/g lw	5.87 ng/g lw		
Alewife				2	7.9, 15.1 ng/g lw	3.40, nd ng/g lw	0.102, 0.082 ng/g lw		
Smelt				2	nd	5.9, 7.8 ng/g lw	0.01, 0.026 ng/g lw		
Sculpin				3	25.8, 22.2, 21.7 ng/g lw	16.4, 24.3, 101 ng/g lw	1.36, 2.91, 0.502 ng/g lw		
Trout				4	nd	0.50, 0.12, 0.22, 0.41 ng/g lw	0.107, 0.062, 0.076, 0.576 ng/g lw		
European eels	Glass eels	France, the French Atlantic coast	-	10 (pooled samples)	< LOD		<LOD - 0.32 ng/g ww <LOD - 31.8 ng/g lw	100 European glass eels were purchased from a glass eel distributer and combined into ten samples	Sühring *et al.*, 2014
	Elvers	Germany, the river Vidå	-	10 (pooled samples)	< LOD		<LOD - 0.46 ng/g ww <LOD–33.8 ng/g lw	Data for elvers and adult European eels were previously published in Sühring *et al.* (2013)	
	Yellow eels	Germany, the river Elbe	-	30	< LOD		0.041 ± 0.027 ng/g ww 0.14 ± 0.085 ng/g lw		

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[50] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx – note that a new version of this document is in preparation under the Stockholm Convention; UNEP/POPS/POPRC.17/INF/xx

Matrix		Country/Region/Area	Year	n	Concentration			Comment	Reference
					1,5-DPMA	1,3-DPMA	ΣDP		
	Silver eels	Germany, the river Elbe and Rhine	-	20	< LOD		0.043 ± 0.048 ng/g ww 0.17 ± 0.19 ng/g lw		
American eels	Glass eels	Canada, Baie des Sables	-	3 (pooled samples)	< LOD		< LOD	37 American glass eels were pooled into 3 samples	
	Young yellow eels	Canada, the Saint Lawrence River	-	20	<LOD–0.037 ng/g ww <LOD–0.37 ng/g lw		0.17 ± 0.092 ng/g ww 1.7 ± 0.92 ng/g lw		
	Yellow eels	Canada, Lake Ontario	-	7	0.070 ± 0.019 ng/g ww 0.33 ± 0.090 ng/g lw		0.19 ± 0.086 ng/g ww 0.90 ± 0.41 ng/g lw		
	Yellow eels	Canada, the Saint Lawrence River	-	6	0.10 ± 0.016 ng/g ww 0.48 ± 0.076 ng/g lw		0.29 ± 0.20 ng/g ww 1.4 ± 0.95 ng/g lw		
	Silver eels	Canada, Lake Ontario	2007-2008	10	n.a.		n.a.	Data for American silver eels were previously published in Byer *et al.* (2013)	
	Silver eels	Canada, Lake Ontario	2007-2008	10	n.a. 0.37 ± 0.57 pg/g lw		n.a. 66.9 ± 48.1 pg/g lw		
Common carp		China, the Beijing-Hangzhou Grand Canal	2010	7	14.2 ± 3.1 ng/g lw		85700 ± 3300 ng/g lw	Not specified whether 1,5-DPMA or 1,3-DPMA (or both) were measured	Wang *et al.*, 2015
Snakehead				2	65.5 ± 14.8 ng/g lw		92600 ± 1600 ng/g lw		
Crucian carp				6	29.2 ± 4.5 ng/g lw		64400 ± 3700 ng/g lw		
River snail				25	31.4 ± 7.8 ng/g lw		10500 ± 2600 ng/g lw		
Bleeker				7	43.6 ± 9.7 ng/g lw		93000 ± 5600 ng/g lw		
Shrimp				14	17.3 ± 5.8 ng/g lw		19300 ± 500 ng/g lw		

Matrix		**Country/Region/Area**	**Year**	**n**	**Concentration**			**Comment**	**Reference**
					1,5-DPMA	**1,3-DPMA**	**ΣDP**		
Loach				5	13.3 ± 4.9 ng/g lw		3010 ± 330 ng/g lw		
Antarctic rock cod		Antarctica, King George Island	2010-2011	1 from each tissue		<LOD in all tissues		Samples include muscle, liver, spleen, stomach, stomach contents, blood, egg, and gallbladder	Wolsche *et al.*, 2015
Gentoo penguin				1 from each tissue		<LOD in all tissues		Samples include muscle, liver, spleen, stomach, stomach contents, lung, intestinal, intestinal contents, heart, gallbladder, genital, yolk, and egg white	
Brown Skua	Muscle			1		79.2 pg/g dw			
	Liver			1		53.6 pg/g dw			
	Spleen			1		52.8 pg/g dw			
	Stomach			1		55.7 pg/g dw			
	Blood			1		<LOD			
	Ovarian			1		92.8 pg/g dw			
	Gallbladder			1		136 pg/g dw			
Baltic wild salmon		Latvia, the Daugava and Venta rivers	2012	25		Min 311 pg/g fw (8760 pg/g dw) Max 2169 pg/g fw (44,594 pg/g dw) Mean 969 ± 490 pg/g fw (22,571 ± 8747 pg/g dw) Median 861 pg/g fw (22,383 pg/g dw)		1,3-DPMA was the predominant DRC (Dechlorane-Related Compound) contributing up to 70% to the ∑DRC	Rajabova *et al.*, 2016
	Overall	Canada, the Canadian Great Lakes Basin	2007-2009	**12**	Geometric mean 30.2 ng/g lw		Geometric mean 36.4 ng/g lw		(Guerra et al., 2011)

Matrix		**Country/Region/Area**	**Year**	**n**	**Concentration**			**Comment**	**Reference**
					1,5-DPMA	**1,3-DPMA**	**ΣDP**		
Peregrine falcon egg	Terrestrial			10	Geometric mean 30.5 ng/g lw Range 1.2 - 1660 ng/g lw Median 62 ng/g lw		Geometric mean 38.4 ng/g lw Range 7.5 - 209 ng/g lw Median 43 ng/g lw	Not specified whether 1,5-DPMA or 1,3-DPMA (or both) were measured	
	Aquatic			2	Geometric mean 28. 8 ng/g lw Range 3.8 - 218 ng/g lw Median 111 ng/g lw		Geometric mean 27.7 ng/g lw Range 6.3 - 122 ng/g lw Median 64 ng/g lw		
Peregrine falcon egg	**Overall**	Spain, Guadalajara in Central Spain and Bilbao on the North-Cantabric Coast of Spain	2003-2006	**13**	Geometric mean 21.1 ng/g lw		Geometric mean 1.78 ng/g lw	Not specified whether 1,5-DPMA or 1,3-DPMA (or both) were measured	
	Terrestrial			5	Geometric mean 2.19 ng/g lw Range 1.7 - 37 ng/g lw Median 2.5 ng/g lw		Geometric mean 0.6 ng/g lw Range 0.3 - 3.6 ng/g lw Median 0.6 ng/g lw		
	Aquatic			8	Geometric mean 71.2 ng/g lw Range n.d. - 469 ng/g lw Median 51 ng/g lw		Geometric mean 2.81 ng/g lw Range 0.4 - 17 ng/g lw Median 2.3 ng/g lw		

Table 123 (Copy of Table 12 in UNEP/POPS/POPRC.16/INF/14.)[51] Indoor air and dust

Matrix	**Country/ Region/Area**	**Year**	**N**	**Study site Type of location**	**Mean (range) in ng/g, *air concentrations in pg/m3* detection frequency %**			**Comment**	**References**
					***Syn*-DP**	***Anti*-DP**	**Mean ΣDP**		
Indoor air	Norway	2012	47	Residential living rooms	0.18 (<MLD-7.39) 2%	0.28 (<MLD-7.61) 4%	0.457		Cequier et. al., 2014
Indoor air	Norway	2012	6	School classrooms	<MLD 0%	<MLD 0%	-		Cequier et. al., 2014
Indoor air	Norway	2013-14	60	Residential living rooms	<1.2 (<1.2-150) 25%	<1.3 (<1.3-47) 15%			Tay et al., 2017
Indoor air	United Kingdom of Great Britain and Northern Ireland (UK)	2013-1015	20	Office	1.3 (<2.0-7.7) 5%	1.8 (<1.2-24) 5%			Tao et al., 2016
Indoor air	UK	2013-1015	15	Residential houses	<2.0 (<2.0-4.6, 7%	2.2 (<1.2-20) 20%			Tao et al., 2016
Indoor air	United States of America (USA)			Residential houses	0.37 (nd-4.0)	4.1(nd-23)			Venier et al., 2016
Indoor air	Canada			Residential houses	23 (nd-76)	25 (nd-243)			Venier et al., 2016
Indoor air	Czechia			Residential houses	-	65 (nd-65)			Venier et al., 2016
Dust	Norway	2012	48	Residential living rooms	9.07 (max 311) 92%	18.9 (max 590) 92%	27.97	Concentration of DP was negatively correlated with number of "Picture tube TVs",	Cequier et. al., 2014

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[51] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx – note that a new version of this document is in preparation under the Stockholm Convention; UNEP/POPS/POPRC.17/INF/xx

Matrix	**Country/ Region/Area**	**Year**	**N**	**Study site Type of location**	**Mean (range) in ng/g, *air concentrations in pg/m3* detection frequency %**			**Comment**	**References**
					***Syn*-DP**	***Anti*-DP**	**Mean ΣDP**		
								p= 0.018 and 0.04, for syn and anti-DP, respectively, and positive correlated with age of the woman (p=0.000)	
Dust	Norway	2012	6	School classrooms	1.31 (max 3.13) 83%	3.68 (max 9.25) 100%	4.99		Cequier et. al., 2014
Dust	Norway	2013-14	61	Settled dust, residential homes	2.3 (<0.51-62) 48%	8.3 (<0.34-120) 72%			Tay et al., 2017
Dust	UK	2013-1015	42	Office	60 (<0.26-640), 98%	210 (<0.15-2100) 98%	270		Tao et al., 2016
Dust	UK	2013-1015	30	Residential houses	3.6 (<0.26-28) 63%	21 (<0.15-170) 84%	24.6		Tao et al., 2016
Dust	Egypt, Cairo	2013	17	Residential houses	0.63 (<0.02-2.28) 71%	0.39 (<0.01-1.70) 47%			Hassan and Shoeib (2015)
Dust	Egypt, Cairo	2013	5	Workplaces	1.42 (0.02-2.88) 100%	0.37 (0.01-0.95) 80%			Hassan and Shoeib (2015)
Dust	Egypt, Cairo	2013	9	Cars	2.10 (<0.02-4.94) 100%	1.65 (0.01-0.95) 100%			Hassan and Shoeib (2015)
Dust	Canada, Vancouver	2007-2008	116	Residential houses	7.5 (<0.70-170) 99%	11 (<0.70-170) 99%		Whole vacuum cleaner bag	Shoeib et al., 2012
Dust	USA, Massachusetts	2002-2003	38	Residential houses	3.16 (max 43.1) 89%	9.60 (max 68.4), 100%		Whole vacuum cleaner bag	Johnson et al., 2013
Dust	Australia (A), United Kingdom *of Great Britain*	A: 2014, UK: 2008-2009, CA: 2014,	A=4, UK=4 ,	A: Office, UK: house bedroom, CA, S, CH: office	0.04 (0.018-0.19) 100%	0.04 (0.013-0.15) 100%	0.079, (0.032-0.31)		Wong et al., 2017

Matrix	**Country/ Region/Area**	**Year**	**N**	**Study site Type of location**	**Mean (range) in ng/g, *air concentrations in pg/m3* detection frequency %**			**Comment**	**References**
					***Syn*-DP**	***Anti*-DP**	**Mean ΣDP**		
	and Northern Ireland (UK), Canada (CA), Sweden (S), China (CH)	S: 2014, CH: 2012	CA=6 , S= 5, CH=5						
Dust	USA	2015	12	Student campus, common area. Furniture flammability standard TB133			340, (max 2800), 100%	Campus purchased institutional furniture to meet California's TB133 (which requires furniture to withstand a much larger and longer test flame than TB117)	Dodson et al., 2017
Dust	USA	2015	42	Student campus, dormitory. Furniture flammability standard TB133			140, (max 1900), 100%	Campus purchased institutional furniture to meet California's TB133 (which requires furniture to withstand a much larger and longer test flame than TB117)	Dodson et al., 2017
Dust	USA	2015	15	Student campus common area. Furniture flammability standard TB117			15, (max 38), 100%	Campus purchased institutional furniture to meet California's TB117 (The other standard, TB133 requires furniture to withstand a much larger and longer test flame than TB117)	Dodson et al., 2017

Matrix	**Country/ Region/Area**	**Year**	**N**	**Study site Type of location**	**Mean (range) in ng/g, *air concentrations in pg/m3* detection frequency %**			**Comment**	**References**
					***Syn*-DP**	***Anti*-DP**	**Mean ΣDP**		
Dust	USA	2015	26	Student campus, dormitory. Furniture flammability standard TB117			19, (max 130), 100%	Campus purchased institutional furniture to meet California's TB117 (The other standard, TB133 requires furniture to withstand a much larger and longer test flame than TB117)	Dodson et al., 2017
Dust	USA	2010	19 air-planes, 40 samples	Airplane	110 (40-9500) 100%	330 (92-4200) 100%		Carpet dust. Airplanes represented a wide range of manufacturing dates (1986 – 2008) from five manufacturers (Boeing, Airbus, Canadair Regional, McDonnell Douglas and Embraer).	Allen et al., 2013
Dust	USA	2010	19 airplanes, 40 samples	Airplane	160 (34-2200) 100%	300 (31-9600) 100%		Air return grills. Airplanes represented a wide range of manufacturing dates (1986 – 2008) from five manufacturers (Boeing, Airbus, Canadair Regional, McDonnell Douglas and Embraer).	Allen et al., 2013

Matrix	**Country/ Region/Area**	**Year**	**N**	**Study site** **Type of location**	**Mean (range) in ng/g,** ***air concentrations in pg/m3*** **detection frequency %**			**Comment**	**References**
					***Syn*-DP**	***Anti*-DP**	**Mean ΣDP**		
Dust	China, Beijing	2012	3	Hotels	-	-	124,000	Highest level of DP in small particles, 7-20 µm	Cao et al., 2014
Dust	China, Beijing	2012	2	Kindergarten	-	-	231	Highest level of DP in small particles, 7-20 µm	Cao et al., 2014
Dust	China, Beijing	2012	2	Kindergarten	-	-	1,350	12± 10 µm, dust particle fraction	Cao et al., 2014
Dust	China, Beijing	2012	2	Kindergarten	-	-	1,530	7± 7 µm, dust particle fraction	Cao et al., 2014
Dust	China, Beijing	2012	40	Dormitories	-	-	14,200	Carpeted, Highest level of DP in small particles, 7-20 µm	Cao et al., 2014
Dust,	China, Dongguan	2013	102	Indoor	-	-	68.5 (nd-622)	Highest level of DP in small particles, 7-20 µm	Chen et al., 2014
Dust	China, Dongguan	2013	20	outdoor	-	-	22.9, (1.44-93.1)		Chen et al., 2014
Dust	China, Guangzhou		51	House dust	5.3 (<LOD-216) 78%	19.4 (<LOD-834) 98%	24.5, (nd-1050)	Median. DBDPE dominated	Tang et al., 2019
Dust	China, Guangzhou		31	Children's hand wipe	0.02 (nd-0.2) 68%	0.1 (nd-1.4) 97%	0.1, (nd-15)	Median. DBDPE, DE209 and BEH-TEBP dominated	Tang et al., 2019
Dust	China, Guangzhou		51	Adults' hand wipe	0.04 (nd-1.5) 76%	0.14 (nd-5.3) 94%	0.2, (nd-5.6)	Median. DBDPE, BDE209 and BEH-TEBP dominated	Tang et al., 2019

Table 124 (Copy of Table 13 in UNEP/POPS/POPRC.16/INF/14.)[52] *Median concentration (ng/g lipid) of Dechlorane Plus and its isomers and de-chlorinated DP in human samples*

Country/Region/Area	**Matrix**	**Year**	***n***	**Detection frequency %, *syn; anti*-DP**	***Syn*-DP**	***Anti*-DP**	**ΣDP median**	**Σ DP range**	***Anti*-Cl_{11}-DP**	***f*-*anti***	**Reference**
Norway	Serum	2012	48	78; 89	0.45	0.85	1.3		-	0.67	Cequier et al., 2015
Norway	Serum	2013	61	3; 3	<0.80	<2.1					Tay et al., 2017
Germany, Red Cross donors	Serum	2013-14	42	93; 79	0.77	1.23			-	0.57	(Fromme et al., 2015)
France, people living in area of a municipal solid waste incinerator	Serum	2003-05	48	75; 94	0.22	0.89	1.20		-	0.75	(Brasseur et al., 2014)
Canada, maternal serum	Serum	2007-09	102	77; 87	0.49	1.9	2.37			0.81	Zhou et al., 2014
Republic of Korea	Serum	2013	61		0.21	0.52	0.75			0.74	Kim et al. (2016)
China, residents of Shandong Province	Serum	2014	490 in 20 pooled samples		-	-	2.1 (mean)			0.62-0.82	Ma et al. (2017)
China, residents of Shandong Province	Serum	2015	452 in 20 pooled samples		-	-	3.1 (mean)			0.62-0.82	Ma et al. (2017)
China, surplus serum from routine pathology testing, residents of Laizhou	Serum	2011	146 in 5 pooled		3.1(mean)	1.1 (mean)	4.3 (mean)				He et al. (2013); Wang et al., 2014;

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[52] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC16/Overview/tabid/8472/Default.aspx – note that a new version of this document is in preparation under the Stockholm Convention; UNEP/POPS/POPRC.17/INF/xx

Bay, within 10 km from previous production site male											
China, surplus serum from routine pathology testing residents of Laizhou Bay, within 10 km from previous production site female	Serum	2011	141 in 5 pooled		2.0(mean)	0.95(mean)	2.9 (mean)				Wang et al., 2014; He et al. (2013)
China, e-waste dismantling region	Serum	2005	20		17.10	21.20	42.6			0.53	Ren et al., 2009; 2011
China, fishing industry region	Serum	2005	20		5.10	8.60	13.7			0.64	Ren et al., 2009; 2011
China	Serum	2011	10		2.50	1.00	3.6			0.35	He et al. (2013)
China, > 20 yrs residential time in e-waste recycling region	Serum	2010-11	33		2.75	5.95	8.64			0.70	(Ben et al., 2013)
China, < 3 yrs residential time in e-waste recycling region	Serum	2010-11	16		0.95	2.71	4.09			0.75	(Ben et al., 2013)
China, > 20 yrs residential time in e-waste recycling region	Maternal serum	2010-11	48		2.40	6.16	8.43	1.28-900	0.371	0.72	(Ben et al., 2014)
China, < 3 yrs residential time in e-waste recycling region	Maternal serum	2010-11	20		0.82	2.83	3.55	1.69-11.6	0.155	0.75	(Ben et al., 2014)
China, occupational exposure DP plant	Blood	2011	23		386	471	857	89.8-2958		0.54	Zhang et al., 2013
China, workers without direct DP exposure	Blood	2011	12		143	207	350			0.60	Zhang et al., 2013
China, residents near DP manufacturing plant	Blood	2011	12		106	207	243			0.61	Zhang et al., 2013
China, > 20 yrs residential time in e-waste recycling region	Cord blood	2010-11	48		0.959	1.89	2.82	0.680-89.7		0.67	(Ben et al., 2014)
China, < 3 yrs residential time in e-waste recycling region	Cord blood	2010-11	20		0.660	1.40	1.82	0.450-27.2		0.67	Ben et al. (2014)
China, > 20 yrs residential time in e-waste recycling region	Placenta tissue	2010-11	48		0.728	2.75	3.21	0.92-197	0.0767	0.74	(Ben et al., 2014)
China, < 3 yrs residential time in e-waste recycling region	Placenta tissue	2010-11	20		0.32	0.90	1.09	0.459-2.86		0.75	(Ben et al., 2014)

Canada	Milk	2004, 2009	87	74; 85	0.27	0.71	0.98			0.67	(Siddique et al., 2012)
Canada	Milk	2007-09	105	40; 50	nd	0.02	0.02			0.80	Zhou et al., 2014
China, > 20 yrs residential time in e-waste recycling region	Milk	2010-11	33		1.33	3.32	4.46			0.71	(Ben et al., 2013)
China, < 3 yrs residential time in e-waste recycling region	Milk	2010-11	16		0.50	1.58	2.19			0.76	(Ben et al., 2013)
China, occupational exposure DP plant	Hair	2011	23					4.08-2159			Zhang et al., 2013