

**Guidance on best available
techniques and best
environmental practices
relevant to short chain
chlorinated paraffins listed
under the Stockholm
Convention on Persistent
Organic Pollutants**

December 2024



Disclaimer

In the event of any inconsistency or conflict between the information contained in this non-binding guidance document and the Stockholm Convention on Persistent Organic Pollutants (POPs), the text of the Convention takes precedence, taking into account that the interpretation of the Stockholm Convention remains the prerogative of the Parties.

The designations employed and the presentations in this guidance document are possible options, based on expert judgment, to provide assistance to Parties to develop, revise and update national implementation plans or national reports under the Stockholm Convention. The Stockholm Convention Secretariat, UNEP or contributory organizations or individuals cannot be liable for misuse of the information contained in it.

While reasonable efforts have been made to ensure that the content of this publication is factually correct and properly referenced, the Secretariats of the Basel, Rotterdam and Stockholm Conventions, UNEP, FAO or the UN do not accept responsibility for the accuracy or completeness of the contents and shall not be liable for any loss or damage that may be occasioned, directly or indirectly, through the use of, or reliance on, the contents of this publication, including its translation into languages other than English.

Acknowledgements

The work to review and update the guidelines and guidance on best available techniques and best environmental practices is conducted by the experts on best available techniques and best environmental practices in accordance with the terms of reference set out in annex to decision SC-8/6, through the in-kind contributions of the nominated experts. The valuable input of the experts nominated by Parties and others to be consulted in the process for review and update of the guidelines and guidance is highly acknowledged. The experts' names are listed in the joint Toolkit and BAT and BEP expert roster, accessible on the Stockholm Convention's website (<https://chm.pops.int/tabid/9650>).

Table of Contents

Acknowledgements	3
Abbreviations and acronyms.....	8
Units	9
Executive Summary	10
1. Introduction.....	12
1.1 Purpose	12
1.2 Structure and use of the guidance.....	12
2. Substances covered under this document	13
2.1 Chlorinated paraffins.....	13
2.2. Short-Chain Chlorinated Paraffins (C10-C13).....	14
2.3. SCCPs physical and chemical properties	15
2.4 Production.....	16
2.5 Different categories of chlorinated paraffins.....	17
2.6 Regulations concerning production, use, and trade of CPs	18
2.6.1 Stockholm Convention on Persistent Organic Pollutants.....	18
2.6.2 Basel Convention and SCCPs	19
2.6.3 Other Regulations.....	20
2.6.4 Analysis and Characterization of Chlorinated Paraffins	21
2.6.5 Standards for SCCPs analysis in some matrices.....	22
2.6.6 Worldwide Production of CPs and SCCPs	23
2.6.7 Products containing SCCPs	24
3. Uses of chlorinated paraffins	25
3.1 Use of SCCPs in Metalworking	26
3.1.1 Lubrication in Metalworking.....	26
3.1.2 Cooling in Metalworking Processes.....	26
3.1.3 Corrosion Protection in Welding	26
3.1.4 Metal Forming	26
3.1.5 Deburring.....	27
3.1.6 Drawbacks of SCCPs in metalworking.....	27
3.1.7 Alternatives to SCCPs in metalworking.....	27
3.1.8 Considerations for Selection of Alternatives to SCCP in Metalworking	29
3.2 Use of SCCPs in PVC.....	29
3.2.1 Purpose.....	29
3.2.2 Alternative substances	29
3.3 SCCPs as Flame-Retardant	30
3.3.1 Purpose.....	30

3.3.2 Alternatives to SCCPs used as Flame Retardants	30
3.4 SCCPs in Paints, Adhesive, and Sealants used in manufactured products.....	31
3.5 SCCPs in Textile Finishing	31
3.5.1 Purpose.....	31
3.5.2 Alternatives for the Textile Sector.....	31
3.6 SCCPs in Leather Finishing.....	32
3.6.1 Purpose.....	32
3.6.2 Alternatives to SCCPs in Leather Manufacturing.....	32
3.7 SCCPs in Adhesives	32
3.7.1 Purpose.....	32
3.7.2 Alternatives of SCCP in adhesives.....	32
3.8 Waterproofing and Fire-Retardant Paints.....	33
3.8.1 Purpose.....	33
3.8.2 Alternatives of SCCPs in Paints	33
4. Best Available Techniques (BAT) and Best Environmental Practices (BEP).....	33
4.1 General BAT and BEPs in chemical manufactures	33
4.2 Measures to protect health of workers	34
4.2.1 Use of Personal Protective Equipment (PPE)	35
4.2.2 Work conditions.....	35
4.2.3 Contingency plan	35
4.2.4 Monitoring and Health Surveillance.....	35
4.3 Waste Management.....	35
4.3.1 General considerations.....	35
4.3.2 Waste elimination.....	36
4.3.3 Training and Information.....	37
4.4 Summary of BAT and BEP for chlorinated paraffins production and use	37
5. Stakeholders and their role in phasing-out SCCPs	41
5.1 Industries and Trading Companies.....	41
5.1.1 Compliance and Innovation.....	41
5.1.2 Supply Chain Management.....	41
5.1.3 Environmental Responsibility	42
5.2 Government and Regulatory Bodies	42
5.3 Scientists and Academic Institutions.....	43
5.4 Non-Governmental Organizations (NGOs).....	43
5.5 International Organizations	43
5.6 Consumers.....	44
Annex to the guidance:	45
References.....	46

List of Figures

Figure 1. Examples of chlorinated paraffins formulas.	13
Figure 2: Temporal trends of global annual production of CPs and the distribution of CP usage.....	23
Figure 3. SCCP life cycle (UNEP/POPS/POPRC.12/INF/7)	25

List of Tables

Table 1. Specific exemptions for the production and use of SCCPs.	14
Table 2. Main Physico.chemical properties of SCCPs.....	15
Table 3. Summary of BAT and BEP applicable to manufacture using chemicals.	33
Table 4. Summary of BAT and BEP for chlorinated paraffins production and use.....	37

Preface

This document was developed in 2024 by the Toolkit and best available techniques (BAT) and best environmental practices (BEP) experts working in collaboration with the Secretariat of the Stockholm Convention, and taking into account comments received from Parties and others, further to the request by the Conference of the Parties (COP) to the Stockholm Convention in 2023 (decision 11/5) as part of the ongoing review and update of the Toolkit and the guidelines and guidance on BAT and BEP.

Abbreviations and acronyms

ATBC	Acetyl Tributyl Citrate
BAT	Best available techniques
BEP	Best environmental practices
BCD	Base Catalyst Decomposition
CAS	Chemical Abstract Service
CD	Catalyst Dechlorination
CPs	Chlorinated paraffins
COP	Conference of the Parties
DNA	Deoxyribonucleic Acid
DOS	Dioctyl Succinate
EC	European Community
ECNI	Electro Capture Negative Ionization
EEC	European Economic Community
EMS	Environmental management system
FAO	Food and Agriculture Organization
FR	Flame retardant
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
GC-ECD	Gas chromatography with Electron Capture Detector
GHG	Greenhouse gas
HCD	Hydro Dechlorination
ISO	International Organization for Standardization
kt	Kilo Tons
LCCPs	Long Chain Chlorinated Paraffins (C18+)
LDAR	Leak Detection and Repair
LEV	Local Exhaust Ventilation
LC	Liquid Chromatography
MCCP	Medium Chain Chlorinated Paraffins (C14-C17)
MS	Mass Spectrometry
MSW	Municipal solid waste
NMR	Nuclear Magnetic Resonance
NGOs	Non-Governmental Agencies
PAG	Poly Alkyl Glycol
PCDD/PCDF	Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans
PCB	Polychlorinated biphenyl(s)
PCD	Photochemical Dechlorination
PPE	Personal Protective Equipment
POPs	Persistent organic pollutants
POPRC	Persistent Organic Pollutants Review Committee
PVC	Polyvinylchloride
SC	Stockholm Convention
SCC	Stress Corrosion Cracking
SDS	Safety Data Sheet
SCCPs	Short-chain chlorinated paraffins
UNEP	United Nations Environmental Program
USEPA	United States Environmental Agency
VOC	Volatile organic compound
XRF	X-ray fluorescence

Units

t	Metric tons
kt	Kilo metric tons
kt/y	Kilo metric tons per year

Executive Summary

Short-Chain Chlorinated Paraffins (SCCPs) have been extensively utilized across various industries, including but not limited to manufacturing, metalworking, leather processing, and as additives in consumer products as rubber and plastics, due to their chemical properties as flame retardants and plasticizers. Recognizing the environmental and health risks posed by SCCPs, their production, use, and disposal have come under scrutiny, leading to regulatory actions under international conventions such as the Stockholm Convention.

Acknowledging the persistent, bioaccumulative, and toxic nature of SCCPs, these chemicals were listed in Annex A to the Stockholm Convention with specific exemptions. This document outlines the Best Available Techniques and Best Available Practices for exempted uses of SCCPs, which as of December 2023 are no longer allowed¹.

For substances listed in Annex A, Article 3 requires Parties to take measures to eliminate the production and use of the chemicals, subject to any specific exemptions listed in the Annex. It specifies that each Party must:

- Prohibit and/or take the legal and administrative measures necessary to eliminate the production and use of the chemicals listed in Annex A;
- The import and export of these chemicals, except for the purposes of environmentally sound disposal as set forth in paragraph 1(b) of Article 6 (Management of POPs Waste);
- Allow specific exemptions for the production and use of the chemicals listed in Annex A, or for specific uses of chemicals listed in Annex B, under the conditions agreed upon by the Conference of the Parties (COP) and listed in the relevant Annex.

Specific exemptions for certain uses or production of a listed chemical for the registered Parties are time-bound and subject to review. When a chemical is listed in Annex A with specific exemptions, the Convention allows Parties to register for these exemptions if they cannot immediately eliminate the production and use of the substance. These exemptions provide a transition period during which Parties can work towards alternatives or phase out the substance's use and production entirely.

Despite the restrictions, the legacy use of SCCPs in products and industrial applications presents ongoing challenges. These substances are found in long-lasting products and assets, which means they will persist in the environment and continue to enter waste streams for years to come. The document emphasizes the importance of managing these legacy uses and the waste generated from SCCP-containing products to prevent further environmental contamination.

Key milestones in the global effort to manage SCCPs include listing specific compounds under the Stockholm Convention, reflecting a global commitment to reducing the environmental and health impacts of these chemicals. The document highlights the necessity of applying Best Available Techniques (BAT) and Best Environmental Practices (BEP) to minimize releases of SCCPs during their production, use, and disposal phases.

Alternatives to SCCPs are discussed, focusing on identifying safer substitutes for various applications. The document underscores the importance of innovation and research in developing non-hazardous alternatives that meet the technical requirements of industries previously reliant on SCCPs.

Waste management and recycling practices are critical in the context of SCCPs, given their presence in a wide range of consumer and industrial products. The document outlines strategies for the identification,

¹ See Decision SC-11/1.

separation, and safe disposal of SCCPs-containing materials, advocating for recycling and recovery processes that prevent environmental release. It also discusses the role of stakeholders, including industry, regulators, and the public, in ensuring the effective management of SCCPs throughout their lifecycle.

In conclusion, the guidance document on SCCPs aims to assist in the management of risks associated with these chemicals. It calls for coordinated international action, the adoption of safer alternatives, and the implementation of stringent waste management practices to protect human health and the environment from the adverse effects of SCCPs.

1. Introduction

This document is the first draft guidance on best available techniques and best environmental practices for the production and use of Short-Chain Chlorinated Paraffins listed in Annex A to the Stockholm Convention, as per Decision SC-8/11 adopted in May 2017, with specific exemptions.

1.1 Purpose

The purpose of this document is to provide Parties with guidance on Best Available Techniques (BAT) and Best Environmental Practices (BEP) for the production, use, recycling, disposal, and management of stockpiles and waste containing Short-Chain Chlorinated Paraffins (SCCPs) listed under Annex A to the Stockholm Convention (Decision SC-8/11), including specific exemptions for production and use.

BAT and BEP are fundamental in environmental management and policy. They aim to minimize or prevent pollution and reduce environmental impacts from various industrial and agricultural processes. They are often used in environmental regulation and policy to set standards and guidelines for industries to follow, encouraging continuous improvement in environmental performance.

BAT is not aimed at the prescription of any specific technique or technology; BAT means the most effective and advanced activities, methods of operation, and techniques for providing the basis for release limitations designed to prevent and, generally, reduce releases of chemicals and their impact on the environment (Article 5 of the Stockholm Convention).

BEP are focused on the operational or management aspects, emphasizing the application of the most appropriate combination of environmental control measures and strategies. BEP aim to prevent or minimize emissions and waste through measures such as material substitution, process modification, good housekeeping, recycling and reuse, product design, and changes in consumption patterns.

According to Article 3, Paragraph 6 of the Stockholm Convention, if a Party has a specific exemption or acceptable purpose for a chemical listed in Annex A or Annex B of the Convention, they must take measures to ensure that any production or use under such exemption, or purpose, is carried out in a way that prevents or minimizes human exposure and releases to the environment. To put it simply, the BAT and BEP should be applied for chemicals that have a specific exemption(s) or an acceptable purpose, as is the case for SCCPs. This approach helps ensure appropriate methods are used to protect the environment and human health while considering economic feasibility and technological viability.

1.2 Structure and use of the guidance

This document is structured as follows:

Chapter 1 outlines the purpose and structure of this document.

Chapter 2 provides information on the substances covered by this document, including the relevant provisions under the Stockholm Convention and the Basel Convention.

Chapter 3 addresses general BAT and BEP principles for general chemical management and general guidance for the management of SCCPs. Further relevant details are included in the annex to this guidance.

Chapter 4 addresses BAT and BEP for uses of SCCPs benefiting from a specific exemption in metalworking, lubricants in engines, additives in polymer/plastic, waterproofing and fire retardant paints, and leather applications listed as specific exemptions under the Convention. Each section provides a general description of the process/application in which SCCPs is exempted for use, and specific BAT and BEP guidance for management of this substance, including information on available alternatives for that use.

Chapter 5 addresses BAT and BEP for the life cycle management of SCCPs containing articles, energy/material recovery and recycling considerations, focusing on the key material recycling flows – namely plastics and rubbers, mechanical parts and electronic products.

2. Substances covered under this document

This document focuses on SCCPs, a complex mixture of polychlorinated N-alkanes (straight chain alkanes) ranging from C10 to C13.

2.1 Chlorinated paraffins

Chlorinated paraffins (CPs) are widely produced chemicals, with certain CP subgroups (SCCPs) facing global restrictions due to their environmental dispersion, persistence, bioaccumulation, and toxicity. Chlorinated paraffins, also called chlorinated alkanes, are complex mixtures of substances having the molecular formula pattern $C_nH_{2n+(2-x)Cl_x}$ in common. According to their chain length, CPs are subdivided into short-chain CPs (SCCPs, C10–C13), medium-chain CPs (MCCPs, C14–C17) and long-chain CPs (LCCPs, C18–C30). Examples of CP formulas are given in Figure 1, noting that this document will only address short-chain paraffins (C10 to C13). In some regions CPs are characterized by their chlorination by percent chlorination by weight e.g (CP-42, CP-52 and CP-70). According to Gao et al. the SCCP mass fractions in CP-42, CP-52 and CP-70 were determined to be 3.7%, 24.9% and 0.5%, respectively (Gao et al. 2012).

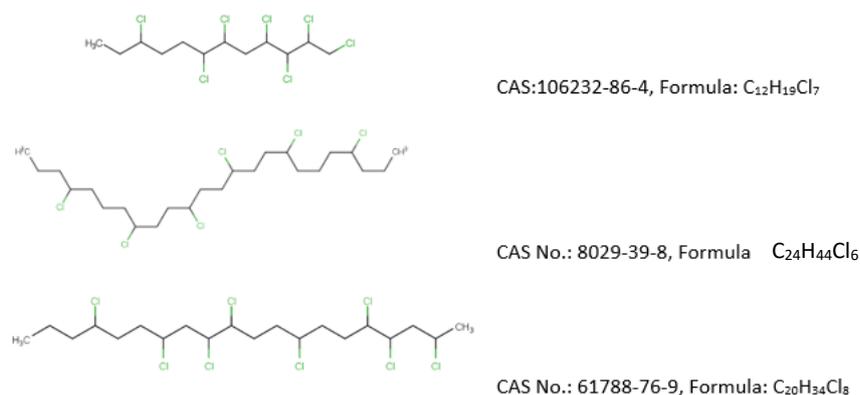


Figure 1. Examples of chlorinated paraffins formulas.

Chlorinated paraffins are produced with different chlorination degrees varying from 30% to 70% in weight. Due to their complexity and variability, SCCPs are regulated as a group of substances instead of individual chemicals. Commercial CP products are classified as substances as "Unknown or Variable composition, Complex reaction products or Biological materials (UVCB)"². This designation is used for substances whose exact chemical composition is unknown and may vary. Specifically, SCCPs can be produced as an unintentional by-product in processes intended to produce medium- or long-chain chlorinated paraffins via complex reaction products resulting from the manufacturing process.

The variation in chain lengths and chlorination degrees makes them versatile, and more than 200 commercial CP formulations are in use worldwide. Different grades and purities are produced according to needs but generally, industrial products are technical mixtures of different CPs. Assessment of the

² Health Canada defines gives the following definition to UVCBs: "These substances cannot be identified sufficiently by their chemical composition because the number of constituents is relatively large; the composition is, to a significant degree, unknown; and/or the variability of composition is relatively large or poorly predictable."

homologue composition of 36 CPs used worldwide has shown that SCCPs are present in almost all the technical CP mixtures³.

According to GuideChem, a chemical trading guide⁴, there are at least 12 CP producers in China, India, France, Japan and the USA.

2.2. Short-Chain Chlorinated Paraffins (C10-C13)

The eighth meeting of the Conference of the Parties to the Stockholm Convention⁵ decided to amend part I of Annex A to the Stockholm Convention to list “short-chain chlorinated paraffins” therein, with specific exemptions. The decision defines the listed substance as follows: Short-chain chlorinated paraffins, C10-13, chloro: straight-chain chlorinated hydrocarbons with chain lengths ranging from C10 to C13 and content of chlorine covered by the Stockholm Convention listing of greater than 48 percent by weight.

According to IUPAC, SCCPs, otherwise known as short chain chlorinated alkanes, are highly complex mixtures of polychlorinated n-alkanes with a chlorination degree between 30 and 70 % by weight, constituted by thousands of homologs, diastereomers, and enantiomers. The following congeners may fall under the definition of SCCPs $C_xH_{(2x-y+2)}Cl_y$, where $X=10-13$ and $y \geq 4$.

For this reason, the Convention listing covers chemicals that may contain small amounts of short-chain chlorinated paraffins as for example:

- Alkanes, C6-18, chloro (CAS No. 68920-70-7);
- Alkanes C12-13, chloro (CAS No. 71011-12-6);
- Alkanes, C12-14, chloro (CAS No. 85536-22-7);
- Alkanes, C10-14, chloro (CAS No. 85681-73-8);
- Alkanes, C14-C17, chloro (CAS N°85535-84-8);
- Paraffin waxes, chlorinated (C12, 60% chlorine) (CAS No. 108171-26-2).

As stated in the decision, the list provided is not exhaustive, this is because any industrial chlorinated alkane has the potential to contain some SCCPs, they can be found as unintentional by-products in CP-substances and formulations even when the goal is producing longer chain length CPs. Therefore, the Convention stated that any mixture that contains more than 1% by weight of SCCPs with 48% chlorine, even if it has a low chlorination level, is considered a Persistent Organic Pollutant (POP).

The annex to this guidance provides a list of trade names of chlorinated paraffins potentially containing SCCPs.

The specific exemptions for the production and use of SCCPs are, as of 2017, described in Table 1.

Table 1. Specific exemptions for the production and use of SCCPs.

Activity	Specific exemptions
Production	As allowed for the Parties listed in the Register
Use	<ul style="list-style-type: none"> • Additives in the production of transmission belts in the natural and synthetic rubber industry • Spare parts of rubber conveyor belts in the mining and forestry industries

³ Yago Guida, Hidenori Matsukami, Gabriel Oliveira de Carvalho, Roland Weber, Walter Vetter, and Natsuko Kajiwara. Environmental Science & Technology 2023 57 (35), 13136-13147 (DOI: 10.1021/acs.est.3c02243).

⁴ www.guidechem.com.

⁵ See decision SC-8/11.

Activity	Specific exemptions
	<ul style="list-style-type: none"> • Leather industry, in particular, fatliquoring in leather • Lubricant additives, in particular : <ul style="list-style-type: none"> ○ for engines of automobiles, ○ electric generators and wind power facilities, and for ○ drilling in oil and gas exploration and petroleum refining to produce diesel oil. • Tubes for outdoor decoration bulbs • Waterproofing and fire-retardant paints • Adhesives • Metal processing • Secondary plasticizers in flexible polyvinyl chloride, except in toys and children's products.

Specific exemptions are granted to registered Parties for a period of five years, unless otherwise indicated. In accordance with decision 8/14, the Conference of the Parties invites each Party listed in the register of specific exemptions for short-chain chlorinated paraffins to report to the Secretariat, by December 2019, justifying its need for the registration of that exemption and informing on production, uses, national control actions taken, and progress made in building capacity on safe alternatives.

2.3. SCCPs physical and chemical properties

As SCCPs are complex mixture of chlorinated paraffins, their properties vary according to many factors (UNEP, 2016):

1-Carbon Chain Length: The alkanes in SCCPs have carbon chain lengths primarily in the C10 to C13 range. The longer the n-alkane chain is the higher boiling point.

2-Chlorine Content: SCCPs are chlorinated to varying degrees. The chlorine content, according to IUPAC, ranging from 45% to 70% by weight. This variation in chlorine content affects their physical and chemical properties, such as viscosity and solubility.

3-Physical Form: The physical state of SCCPs can vary from oily liquids to waxy solids, depending on the chain length and chlorine content. Higher chlorine content makes them more solid, whereas lower chlorine content results in a more liquid form.

4-Chemical Properties: The specific composition of SCCPs, including the exact distribution of chain lengths and chlorine content, influences their chemical properties, such as stability, reactivity, and ability to act as flame-retardants or plasticizers.

From Decision POPRC-12/4, Table 2 gives the main physico-chemical properties.

Table 2. Main Physico.chemical properties of SCCPs.

Property	Value	Reference
Vapour pressure (Pa)	Range from 2.8 to 0.028×10^{-7} Pa	Drouillard et al. 1998, BUA 1992
	SCCP with 50% chlorine by weight is 0.021 Pa at 40 °C	EC 2000
	SCCP products with 50-60% chlorine are predicted to have subcooled liquid VPs ranging from 1.4×10^{-5} to 0.066 Pa at 25°C	Tomy et al. 1998

Property	Value	Reference
Henry's Law Constant (Pa·m ³ /mol)	0.7 - 18 Pa x m ³ /mol	Drouillard et al. 1998
Water solubility (µg/L)	C ₁₀₋₁₂ chlorinated alkanes ranged from 400 - 960 µg/L	Drouillard et al. 1998
	C ₁₀ and C ₁₃ chlorinated alkane mixtures ranged from 6.4 – 2370 µg/L	BUA 1992
	SCCPs containing 59% chlorine content at 20°C range from 150 to 470 µg/L	EC 2000
log K _{ow}	4.48 – 8.69	UNEP/POPS/POPRC.11/10/Add.2
	SCCPs with chlorine content ranging from 49-71% range from 4.39-5.37	EC 2000
log K _{OA}	4.07 to 12.55 for a chlorination content of 30-70% (modeled values)	Gawor & Wania 2013

2.4 Production

The manufacturing process for CPs involves the direct chlorination of n-alkane feedstock, which is also known as normal alkanes or straight-chain alkanes. Alkanes are saturated hydrocarbons consisting only of carbon (C) and hydrogen (H) atoms with single bonds between the carbon atoms; their general formula is C_nH_{2n+2}. They can be obtained through several methods, primarily from natural sources and processes.

The primary source of alkanes is petroleum refining. Alkanes are major constituents of crude oil. Through the process of refining, crude oil is separated into its component fractions, each containing alkanes of different chain lengths. This separation is primarily achieved through distillation in a fractionating column, where the crude oil is heated, and its components are separated based on their boiling points. The fractions obtained can range from gases (e.g., methane, ethane) to light liquids (e.g., naphtha, gasoline) to heavier liquids and waxes (e.g., diesel, lubricating oils, paraffin wax). Further processing of these fractions can isolate or produce alkanes of specific chain lengths.

Other processes exist for obtaining alkanes of different lengths, such as the Fischer-Tropsch process that allows the synthesis of alkanes from carbon monoxide (CO) and hydrogen (H₂) gas under high pressure and temperature in the presence of a catalyst typically based on Iron (Fe) or Cobalt (Co).

The second phase of the process consists of selecting the alkane feedstock: paraffin wax or liquid paraffin with carbon chain lengths predominantly in the desired range. The feedstock's purity and composition significantly affects the final product's properties.

The selected n-alkane feedstock is subjected to chlorination, where chlorine gas is introduced into the feedstock. This reaction is conducted in the presence of a catalyst (usually iron or aluminum chloride) at temperatures ranging from 80°C to 100°C. Unbranched paraffin fractions (<2 % isoparaffins, <100 ppm aromatics) are used (Kellersohn, 1998), and the chemical reaction is as follows:



The chlorination process is controlled by temperature to achieve the desired degree of chlorination. Higher temperatures generally increase the chlorination rate but can also lead to the formation of unwanted by-products. UV light may promote radical substitution.

After chlorination, the reaction mixture undergoes several post-processing steps, including neutralizing any acid formed during the reaction (e.g., hydrochloric acid), evacuation of non-reacted chlorine, and fractionation or distillation to separate the chlorinated paraffins based on their carbon chain lengths and degree of chlorination if specific fractions are desired. Finally, purification steps, such as washing and filtering, help remove catalyst residues and other impurities.

The final product is then submitted to quality control tests and analysis to determine its chlorine content, carbon chain length distribution, color, density, and other physical and chemical properties relevant to its intended use.

Packaging: Once approved through quality control, the SCCPs are packaged accordingly for distribution and use in various applications, such as plasticizers in PVC, additives in lubricants, flame-retardants, and more.

2.5 Different categories of chlorinated paraffins

While the basic chemical process of CPs is similar across SCCPs, and other CP-substances and formulations, differences in the feedstock chain length and the specific conditions used in the production process result in products with distinct physical and chemical properties, as well as different environmental and health profiles.

The production of chlorinated paraffins involves the chlorination of a mixture of n-alkanes, and achieving a perfect separation of chain lengths during the manufacturing process, especially when preparing the alkane feedstock, is technically challenging. This can result in CP-substances and formulations containing small amounts of SCCPs.

The presence of short-chain chlorinated paraffins (SCCPs) in chlorinated paraffin (CP) mixtures, at concentrations greater or equal to 1% per weight are also considered to be listed in Annex A and needs to be assessed for several important reasons:

- **Toxicity and Environmental Persistence:** SCCPs are known for their toxicity to aquatic organisms, as well as their persistence and bioaccumulative properties in the environment. Their potential to remain in ecosystems for extended periods without breaking down increases the risk of long-term environmental damage;
- **Human Health Risks and consumer information:** SCCPs can pose health risks to humans, particularly due to their classification as potential carcinogens. They may enter the human body through various exposure routes, including ingestion, inhalation, or skin contact;
- **Product Safety:** Many industries, including plastics, paints, and lubricants, use CP mixtures in manufacturing processes. The presence of SCCPs in these products may render them unsafe, particularly if they exceed regulated thresholds, thus necessitating regular assessments;
- **Potential for Contamination:** CP mixtures can often be contaminated with SCCPs during production, making it important to monitor and assess the presence of these compounds to avoid unintentional environmental release or exposure.

Manufacturers and regulatory bodies should employ strict controls and analytical testing to minimize the presence of SCCPs in CP-substances, especially for products intended for use in sensitive applications, such as metal working fluids, lubricants, coolants or additives in consumer goods, where the main concern is direct human exposures or leakage or leaching of CPs into the environment during use or disposal (UNEP 2019, Yuan et al. 2017; Gallistl et al. 2018; Guida et al. 2020). Despite these efforts, the potential for SCCP contamination highlights the importance of careful product selection, regulatory compliance,

and risk assessment in using chlorinated paraffins. Some countries have developed unintentional trace contaminant limits for SCCPs in products (European Parliament 2019).

2.6 Regulations concerning production, use, and trade of CPs

Due to the potential presence of SCCPs with a high chlorine content (>48%) in some products and some processes, and the associated health risks, many countries and international organizations have imposed restrictions on the free trade of chlorinated paraffins (CPs). There are no specific Harmonized System (HS) codes for SCCPs. HS codes can provide indicative information that could be used to identify SCCPs trade. Experience has shown that chlorinated paraffins are imported under different HS codes. These are mainly:

- HS Code 27122010 Synthetic paraffin wax of a molecular weight of 460 or more but not exceeding 1560;
- HS Code 27129090 (paraffin waxes);
- HS Code 38122090 Plasticisers, compound; for rubber or plastics;
- HS Code 38249090 Chemical products and preparations of the chemical or allied industries, not elsewhere specified or included.

Those codes are not specific to SCCPs nor chlorinated paraffins. However, in some countries additional information may be included in the import documents which can inform if individual imports/exports under these HS categories are chlorinated paraffins (UNEP, 2019).

Starting in the 1990s, limits for trading chlorinated paraffins were imposed, leading to restrictions and regulations under various international and national frameworks. Below is an overview of key regulations affecting the production, use, and trade of chlorinated paraffins.

2.6.1 Stockholm Convention on Persistent Organic Pollutants

International considerations for SCCPs include the Stockholm Convention, which listed SCCPs and mixtures containing more than 1% w/w of highly chlorinated SCCPs (>48% w/w of chlorine) to the Convention's Annex A with some specific production and use exemptions.

The listing of a product in Annex A to the Stockholm Convention has significant implications for the Parties (countries that have ratified or acceded to the Convention) but also for non-Parties that intend to trade a listed substance with a Party.

Article 3, titled "Measures to Reduce or Eliminate Releases from Intentional Production and Use," outlines the Parties' obligations regarding the prohibition, elimination, or restriction of the production and use of chemicals listed in Annexes A, B, and C.

The duration of specific exemptions is usually determined at the time of listing and is specified in the relevant Annex for each chemical. Typically, exemptions might last for a specific number of years, and they can be subject to review, modification, or extension by the COP. These specific exemptions have a limited timeframe and shall expire five (5) years after the date of entry into force of the Convention with respect to that particular chemical (paragraph 4 of Article 4). Unless an earlier date is indicated in the Register by the Party benefiting of the exemption, or an extension is granted by the Conference of the Parties (maximum five years under Article 4 paragraph 7).

As from 18 December 2023, there are no longer any Parties registered for specific exemptions for the production and use of SCCPs, and thus no new registrations may be made with respect thereto as of that date⁶.

⁶ See decision SC-11/1.

Restriction on Trade

The listing restricts international trade of the substance between Parties and non-Parties. Parties must ensure that exports of a listed chemical to non-Parties are only allowed for environmentally sound disposal or if the importing non-Party has provided an annual certification that the import is for allowable purposes under the Convention (Article 3 Paragraph 2).

Waste Management

Parties must manage waste containing listed chemicals in an environmentally sound manner, minimizing its impact. In summary, the listing of a chemical in Annex A to the Stockholm Convention signifies a global consensus on the need to eliminate that substance to protect human health and the environment from its harmful impacts. It imposes legal obligations on Parties to take concrete steps towards this goal, involving measures related to production, use, import, export, waste management, and reporting.

2.6.2 Basel Convention and SCCPs

In addition to the provisions of the Stockholm Convention, the provisions of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal are directly relevant to the application of BAT and BEP to address releases of SCCPs from waste. Considering that several waste streams, including waste from electrical and electronic equipment (WEEE), plastic waste and others are major potential SCCPs-containing material flows, synergies between the Stockholm Convention and Basel Convention are of high importance.

The Basel Convention places obligations on countries that are Parties to, inter alia: minimize generation of hazardous waste; ensure that adequate disposal facilities are available; and ensure environmentally sound management of waste.

Under the Stockholm Convention, POP-containing wastes are, in accordance with Article 6, paragraph 1 (d) (ii), to 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, they may be disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, as well as relevant global and regional regimes governing the management of hazardous waste.

Paragraph 2 of Article 6 of the Stockholm Convention, which addresses measures to reduce or eliminate releases from stockpiles and waste, contains the following provisions:

“The Conference of the Parties shall cooperate closely with the appropriate bodies of the Basel Convention on the Control of Transboundary Movements of Hazardous Waste and Their Disposal to, inter alia:

- (a) Establish levels of destruction and irreversible transformation necessary to ensure that the characteristics of persistent organic pollutants are not exhibited;*
- (b) Determine what they consider to be the methods that constitute environmentally sound disposal referred to above; and*
- (c) Work to establish, as appropriate, the concentration levels of the chemicals listed in Annexes A, B and C in order to define the low persistent organic pollutant content referred to in paragraph 1 (d) (ii).”*

The Conference of the Parties to the Basel Convention adopted:

- The guidelines for the environmentally sound management of waste consisting of, containing or contaminated with short-chain chlorinated paraffins (UNEP/CHW.14/7/Add.2/Rev.1) (UNEP 2019);

- The general technical guidelines for the environmentally sound management of waste consisting of, containing or contaminated with persistent organic pollutants (UNEP/CHW.16/6/Add.1/Rev.1) (UNEP 2023a).

The general technical guidelines developed under the Basel Convention address matters related to all three of the provisions outstanding definitional issues raised in Section 2 of Article 6 of the Stockholm Convention. These documents provide the framework for the environmentally sound management (ESM) of SCCPs waste. The provisional definition of low POP content limit (LPCL) values for SCCPs under the Basel Convention is [100 mg/kg][1500 mg/kg][10,000 mg/kg] (UNEP 2023a). As of May 2023, the Conference of the Parties to the Basel Convention has not adopted a value for the LPCL of SCCPs.

Further guidance relevant to matters under Article 6 of the Stockholm Convention is contained in Basel Convention technical guidelines⁷ and Guidance documents elaborated by other bodies (Partnerships)⁸ for:

- Plastic waste:
 - Technical guidelines for the environmentally sound management of plastic waste and for their disposal (UNEP/CHW.16/6/Add.3/Rev.1) (UNEP 2023b).
- WEEE:
 - Guidance document on environmentally sound management of used and end-of-life computing equipment (UNEP/CHW.13/INF/31/Rev.1) (UNEP 2017a);
 - Technical guidelines on transboundary movements of electrical and electronic waste and used electrical and electronic equipment, in particular regarding the distinction between waste and non-waste under the Basel Convention (UNEP/CHW.16/INF/10/Rev.1) (UNEP 2023c). These technical guidelines were adopted on an interim basis.
- Co-processing of hazardous wastes in cement kilns:
 - Technical guidelines on the environmentally sound co-processing of hazardous wastes in cement kilns (UNEP/CHW.10/6/Add/3/Rev.1) (UNEP 2011).
- Landfills:
 - Technical guidelines on the environmentally sound disposal of hazardous wastes and other wastes in specially engineered landfill (D5) (UNEP/CHW.15/6/Add.5/Rev.1) (UNEP 2022a).
- Incineration:
 - Technical guidelines on the environmentally sound incineration of hazardous wastes and other wastes as covered by disposal operations D10 and R1 (UNEP/CHW.15/6/Add.4/Rev.1) (UNEP 2022b)

2.6.3 Other Regulations

Many countries and regional organizations have their regulations aligned with international conventions or have established specific limits and restrictions on the use and trade of CPs, including SCCPs. It is crucial for manufacturers, importers, exporters, waste handlers, and users of chlorinated paraffins to be aware of and comply with the regulations applicable in their countries and in the countries with which they trade.

⁷ The guidelines can be accessed on the Basel Convention website: <https://www.basel.int/tabid/8025>.

Europe: SCCPs were added to Annex I of the EU POP Regulation (Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants), extending the scope of the original regulations to prohibit the production, placing on the market and use of SCCPs or preparations containing SCCPs in concentrations greater than 1% by weight or articles containing SCCPs in concentrations greater than 0.15% by weight. Some exemptions were allowed at the publishing of this rule, but since 2015 all uses of SCCPs are prohibited above the previously mentioned limit values.

REACH Regulation (Europe): SCCPs are also identified as Substances of Very High Concern (SVHCs) under REACH.

United States: The Environmental Protection Agency (EPA) has taken action under the Toxic Substances Control Act (TSCA) to assess and manage risks from SCCPs. It has evaluated and regulated the use of chlorinated paraffins, including SCCPs, and imposed specific rules and consent orders to restrict the use of SCCPs in certain applications. The EPA has also proposed a Significant New Use Rule (SNUR) for certain chlorinated paraffins, including SCCPs, requiring notification to the EPA before they can be used in new applications.

Canada: Canada has concluded SCCPs are toxic under the Canadian Environmental Protection Act, 1999 (CEPA) and prohibited their manufacture, use, sale, and import under the Prohibition of Certain Toxic Substances Regulations, 2012. Regarding incidental presence of SCCPs, the regulations require annual reporting if the total annual quantity of SCCPs contained in a product, such as MCCPs, that is manufactured in Canada or imported into Canada exceeds 1 kg, and its annual weighted average concentration in the product is equal to or greater than 0.5% (w/w) (UNEP, 2016). On May 14, 2022, proposed amendments to the Regulations were published which would remove the above-mentioned annual reporting requirements.

Asia: Regulatory actions in Asia vary by country, with some countries implementing restrictions in line with the Stockholm Convention. For instance: China has been working on measures to control and reduce the production and use of SCCPs, including issuing risk assessment reports and environmental management actions. Noting that China and Vietnam were registered as Parties benefiting from specific exemptions allowed by the Stockholm Convention⁸.

2.6.4 Analysis and Characterization of Chlorinated Paraffins

Analyzing CPs to determine their composition is very important, especially to determine the proportion of the mixture composed of SCCPs congeners and the level of the chlorine content; this is the only way to know if a CPs mixture is to be classified as POP. As technical CP mixtures are complex and may contain thousands of congeners and isomers, it is a challenging task to reach high levels of determination. Several analytical techniques are used together to characterize the carbon chain length distribution of CP-substances and chlorine content. Some of the techniques used are summarized below.

Gas Chromatography (GC):

GC-ECD is sensitive to chlorinated compounds, making it suitable for detecting CPs, but it does not effectively resolve complex mixtures of CPs (and electron-capturing analytes) and is entirely dependent on chromatographic resolution.

Gas Chromatography-Mass Spectrometry (GC-MS):

When GC is coupled with a mass spectrometer (MS) more detailed information can be obtained, including mass resolution of chromatographically co-eluting CPs, and thus can more effectively identify specific chlorination patterns and chain lengths. GC-MS combines chromatographic separation of analytes from the GC with the mass resolution and detection by MS. The GC-MS can provide detailed information on the molecular weights and structural characteristics of CPs, allowing for more extensive (but not complete)

⁸ <https://chm.pops.int/tabid/7595>.

identification of individual CP congeners within a mixture. However, the complexity of CP mixtures can make complete resolution and identification challenging.

Liquid Chromatography-Mass Spectrometry (LC-MS):

Liquid chromatography (LC) coupled with mass spectrometry is particularly useful for analyzing CPs with higher molecular weights and those that are difficult to volatilize for GC analysis. LC-MS can analyse CP mixtures, without the need for derivatization, and can provide detailed information on the chain length distribution and degree of chlorination.

Fourier Transform Infrared Spectroscopy (FTIR):

FTIR spectroscopy is used to identify functional groups in molecules based on their infrared absorption characteristics. It can provide information on the presence of C-H and C-Cl bonds, indicating chlorinated paraffins. Still, it is less effective for detailed compositional analysis or for distinguishing between CPs of different chain lengths and chlorination levels.

Nuclear Magnetic Resonance Spectroscopy (NMR):

NMR spectroscopy can offer detailed structural information about CPs, including insights into the carbon chain length and degree of chlorination. H-NMR and C-NMR are particularly useful for elucidating the structure of CPs. However, the technique requires relatively large sample amounts and may be less sensitive compared to mass spectrometry-based methods.

X-ray Fluorescence Spectroscopy (XRF):

XRF can be used to quantify the total chlorine content in CP samples, providing an indication of the degree of chlorination. While XRF offers rapid and non-destructive analysis, it does not provide detailed information on chain length distribution or specific congener identification.

Analytical strategies for CPs often involve the use of multiple techniques in combination to achieve a comprehensive characterization of the sample. The choice of method depends on the specific requirements of the analysis, including the type of CPs being analyzed, the complexity of the mixture, the desired level of detail, and the available instrumentation.

Currently, the determination of SCCPs is mostly performed by mass spectrometry (MS) in the Electron Capture Negative Ionisation (ECNI) mode. This approach is prone to interferences from other chlorinated compounds and medium-chain chlorinated paraffins, leading to errors in the quantification of SCCPs.

Alternative approaches for SCCP determination have been developed, for example, carbon skeleton gas chromatography (GC-MS) in which chlorinated paraffins are catalytically hydrodechlorinated to the corresponding n-alkanes and analyzed. Information on the chlorination degree is lost, but accurate quantification of paraffins is possible.

The National Institute for Environmental Studies, Japan, has developed a new method based on LC-MS/MS to screen wastes and consumer products containing CPs (Matsukami et al., 2020).

2.6.5 Standards for SCCPs analysis in some matrices

International norms and standards have been developed to standardize CP analysis in different matrices; some of them are presented below:

- ISO 18219-1: Leather - Determination of chlorinated hydrocarbons in leather - Part 1: chromatographic method for short-chain chlorinated paraffins (SCCPs). This document specifies a chromatographic method to determine the amount of short-chain chlorinated paraffins (SCCPs) C10 to C13 in processed and unprocessed leathers;
- ISO 22818: Textiles - Determination of short-chain chlorinated paraffins (SCCP) and middle-chain chlorinated paraffins (MCCP) in textile products out of different matrices by use of gas chromatography negative ion chemical ionization mass spectrometry (GC-NCI-MS). This

document specifies a chromatographic method to determine the amount of short-chain chlorinated paraffins (SCCPs: C10-C13) and middle-chain chlorinated paraffins (MCCPs: C14-C17) in textile articles, especially in polymer of the coated fabrics, prints made of polymer and buttons made of polymer (e.g. polyvinylchloride) using solvent extraction and gas chromatography negative ion chemical ionization mass spectrometry (GC-NCI-MS);

- ISO 12010: Water quality - Determination of short-chain polychlorinated alkanes (SCCP) in water - Method using gas chromatography-mass spectrometry (GC-MS) and negative-ion chemical ionization (NCI). This standard specifies a method for the quantitative determination of the sum of short-chain polychlorinated n-alkanes, also known as short-chain polychlorinated paraffins (SCCPs) in the carbon bond range n-C10 to n-C13 inclusive, in mixtures with chlorine mass fractions ("contents") between 50 % and 67 %, including approximately 6 000 of approximately 8 000 congeners. This method applies to determining the sum of SCCPs in unfiltered surface water, groundwater, drinking water and wastewater using gas chromatography-mass spectrometry with electron capture negative ionization (GC-ECNI-MS).

2.6.6 Worldwide Production of CPs and SCCPs

Chlorinated paraffins are produced in various regions worldwide (Figure 2(b)), reflecting its widespread use in numerous industrial applications. The production and use patterns can vary due to regional regulations, economic factors, and demand in specific sectors such as metalworking fluids, plastics, paints, and flame retardants.

The production of CPs can be divided into three time periods:

- 1935–1974: the production volumes were below 35,000 t/year;
- 1975–2005: the sum of worldwide CP production increased from 60,000 to 350,000 t/year;
- 2006–2012: the sum of worldwide CP production increased much more rapidly than before and went up to 1,100,000 t/year (Glüge et al., 2016).

The actual global production capacity was estimated to be around two million metric tons (t) per year (Guida et al., 2022; SETAC SciCon, 2021). Even if the global production landscape for CPs has shifted due to changes in regulations, market demand, and technological advancements in alternatives, SCCPs are still produced, frequently in mixtures with MCCPs and LCCPs in proportion reaching 20%. The SCCP mass fractions in three CP brands produced in China (CP-42, CP-52, and CP-70) were determined to be 3.7%, 24.9%, and 0.5%, respectively (Gao et al., 2012). China, the only country registered for a specific exemption for the production of SCCPs, is actually the largest producer of CPs worldwide; its production increased from 600 kt in 2007 (Fiedler, 2010) to 1,000 kt/year in 2009 (Chen et al., 2011). In 2020, the

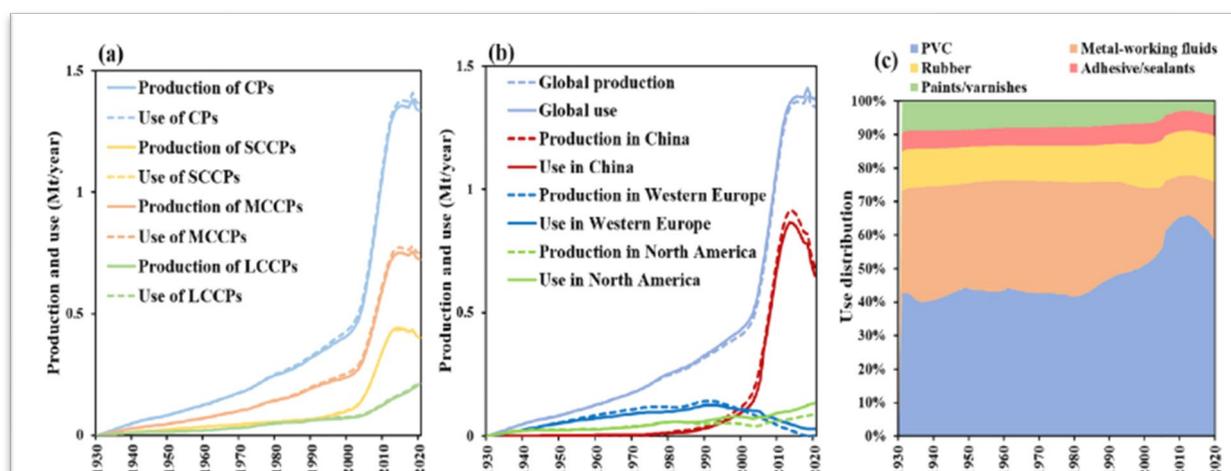


Figure 2: Temporal trends of global annual production of CPs and the distribution of CP usage

production ceased in Europe but it is still ongoing in China and North America with SCCPs, MCCPs, and LCCPs accounting for ~30, 55, and 15%, respectively. Figure 2 shows the temporal evolution of global annual production of the different CPs (a), their production and use (b), and the distribution of CP use among major end-use applications. (Chen et al. 2022).

2.6.7 Products containing SCCPs

SCCPs were and continue to be used primarily as extreme pressure additives (i.e., lubricants and coolants) in metalworking applications and polyvinyl chloride (PVC) plastics. Other uses include in paints, adhesives and sealants, leather fat liquors, and as flame retardants in rubber, textiles, and polymeric materials (UNEP/POPS/POPRC.11/10/Add.2).

As reported in UNEP/POPS/POPRC.12/4, SCCPs are still used in everyday products such as microwave dishes, lamps, electronic items such as cables, adapters, keyboards, memory media, photo frames, headphones, and also in detergent. Inspection and enforcement activities carried out in Norway, Germany, Austria, and Sweden, where SCCPs are banned, have found the continued presence of SCCPs in articles:

In Norway (Annex F submission -2015), products were found to contain SCCPs above permitted levels ranging from 0.16 to 10.7 %.

In Germany (Annex F submission 2015), the City of Hamburg found that 19 of 84 plastic products sampled contained SCCPs, including electronics, toys, household articles, tools, swimming gadgets, bicycle pants and sports articles.

In Austria (Annex F submission 2016), SCCP concentrations exceeding permitted levels in mats, ranging from 0.4% to 6.9%, were detected.

The Swedish Chemicals Agency (Sweden Annex F 2015 submission) has also carried out tests on 62 articles and found that 16 contained SCCPs in high concentrations; furthermore, 11 different articles were found to have low concentrations of SCCPs. The low concentrations could have been caused by contamination during the manufacturing or delivery process. SCCPs were detected in various products such as electrical items, toys, childcare articles, exercise gloves, plastic bags, bathroom accessories, sports equipment, garden tools and office supplies.

These findings demonstrate that new products continue to be a source of SCCPs and contribute to human and environmental exposure. In Europe, it was estimated that releases during the service life of products and articles contributed 0.6 – 1.7 t/year to air, 7.4 – 19.6 t/year to wastewater, 4.7-9.5 t/year to surface water and 8.7-13.9 t/year to industrial soil (BRE 2008).

Figure 3 below summarize the full life cycle of SCCPs from production to release in the environment.

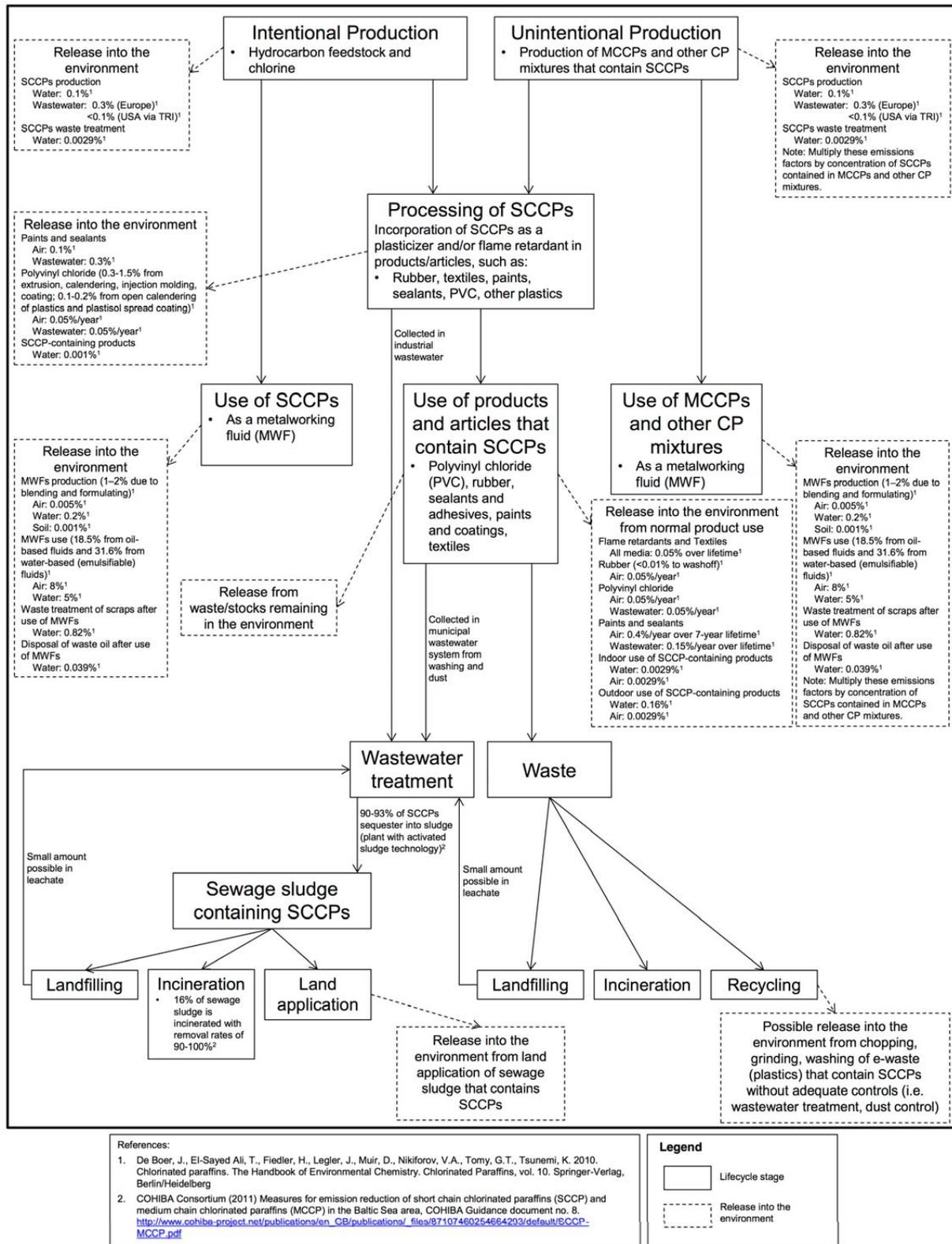


Figure 3. SCCP life cycle (UNEP/POPS/POPRC.12/INF/7)

3. Uses of chlorinated paraffins

CPs with different carbon lengths and degrees of chlorination have different properties and, because of their versatility, they are used for a wide range of applications. Uses have varied among countries and over time, but the main applications of SCCPs have been as plasticizer for the production of products in

polyvinylchloride (PVC) metalworking fluids, paints, coatings, sealants, rubber and textiles, as a flame retardant, and in leather fat liquoring or as water repellent (UNEP/CHW.14/7/Add.2/Rev.1).

In this chapter, most important uses of SCCPs are presented along with some alternative substances that could be used instead. This is to help countries, industries and users to make better choices than SCCPs, noting that, as per Article 9 par.1 (b), each Party shall facilitate or undertake the exchange of information relevant to alternatives to POPs, including information relating to their risks as well as to their economic and social costs.

3.1 Use of SCCPs in Metalworking

SCCPs are used in metalworking for several key purposes, leveraging their properties to enhance the performance and longevity of metal components and tools. SCCPs are valuable in metalworking for their multifunctional properties that enhance lubrication, cooling, corrosion protection, and metal forming. These benefits contribute to more efficient manufacturing processes, higher quality metal components, and extended tool life. The main properties of SCCPs in metalworking are described below.

3.1.1 Lubrication in Metalworking

One of the primary uses of SCCPs in metalworking is as a lubricant. Due to their chlorine content, SCCPs are highly effective in reducing friction between metal surfaces. This lubrication is crucial during processes such as machining, drilling, and stamping, where metal parts move against each other or cutting tools. The lubricating properties of SCCPs help in extending the life of cutting tools by reducing wear and tear, and they also improve the finish of the machined parts by minimizing scratches and other surface imperfections.

3.1.2 Cooling in Metalworking Processes

In addition to lubrication, SCCPs also serve as coolants in metalworking processes. The heat generated from metal-on-metal contact can lead to deformation of the parts being machined and can degrade the cutting tools. SCCPs help in dissipating this heat, maintaining the temperature at a level that is safe for both the machinery and the workpiece. This cooling effect further contributes to the precision of the machining process and the quality of the finished product.

3.1.3 Corrosion Protection in Welding

SCCPs have excellent corrosion-inhibiting properties, which is another reason for their use in metalworking. They form a protective layer on the surface of metals, shielding them from the corrosive effects of moisture, oxygen, and other environmental factors. This protective layer helps prevent rust and other forms of corrosion, thereby prolonging the life of metal parts and tools.

In metalworking, SCCP prevents stress corrosion cracking (SCC) in welded joints. Failure often occurs due to void formation and residual stresses, especially when exposed to corrosive environments. This is particularly important in industries where metal components are exposed to harsh conditions and must maintain their integrity over long periods, like supercritical water-cooled nuclear Reactors (SCWR), which work in temperatures over 600°C and 25 Atm.

3.1.4 Metal Forming

In metal forming processes such as extrusion, rolling, and forging, SCCPs facilitate the shaping of metal workpieces. They provide a lubricating film that reduces the force required to shape the metal, improving process efficiency and preventing sticking or seizing of parts. This not only helps achieve the desired shape and dimensions more easily but also ensures a better surface finish on the final product.

3.1.5 Deburring

The removal of burrs (sharp, unwanted pieces of metal) from machined parts is an essential finishing process in metalworking. SCCPs are used in deburring to lubricate the parts and the tools used for burr removal. This lubrication helps achieve a smoother finish and prevents damage to the delicate surfaces of the machined parts.

3.1.6 Drawbacks of SCCPs in metalworking

While SCCPs offer several advantages in metalworking, their use also comes with notable drawbacks, primarily related to the SCCPs' properties which classify them as POPs. Currently “safe” concentration in the environment cannot be established using the risk assessment methods available with sufficient reliability (ECHA, 2023). But there are also direct health hazards for metalworkers, and pose difficulty in eliminating waste containing SCCPs, and economical issues:

Workers in facilities that use SCCPs in metalworking processes might be exposed to these chemicals through inhalation or skin contact, posing occupational health risks:

- Direct skin contact may irritate, leading to discomfort and potentially more severe dermatological conditions with prolonged exposure. Eye contact may potentially damage irreversibly the eyes;
- Inhalation of fumes or mists containing SCCPs during metalworking processes can lead to respiratory issues, including irritation of the respiratory tract, difficulty breathing, and potentially long-term lung problems;
- There is also evidence to suggest that SCCPs may have carcinogenic effects and can interfere with hormonal functions, potentially leading to reproductive issues, endocrine disruption, and other systemic health effects.

Materials contaminated with SCCPs, such as cutting fluids or metal shavings, require careful handling to avoid environmental contamination. This can increase the complexity and cost of waste management processes for companies involved in metalworking as these wastes are to be eliminated according to the guidelines of the Basel Convention.

The regulatory restrictions and potential future ban on SCCPs after the exemption period may lead to increased costs for industries that rely on these chemicals. Companies might need to invest in research and development to find suitable, environmentally friendly alternatives or face increased costs associated with compliance and waste disposal. Additionally, the potential health risks associated with SCCP exposure can lead to higher insurance premiums and business liabilities.

As regulations on SCCPs become more stringent, metalworkers and their employers may be forced to seek alternative substances or processes. This transition can involve significant research, investment, and training to ensure that alternatives are effective and compliant with new regulations.

3.1.7 Alternatives to SCCPs in metalworking

Using alternatives to SCCPs in metalworking is essential due to their environmental and health impacts, along with increasing regulatory restrictions. Alternatives are required across various applications, including lubricants, coolants, and anti-corrosion treatments, focusing on providing similar benefits without the associated drawbacks. Alternatives to SCCPs in metalworking include:

Lubricants and Coolants in metalworking

Alternatives to SCCPs as coolants and lubricants exist, and many of them have no known drawbacks; here are some examples:

- **Vegetable-Based Oils:** Natural vegetable-based oils are increasingly popular as lubricants and coolants due to their biodegradability and lower toxicity. Modifications and additives

can enhance their performance, making them suitable for a wide range of metalworking processes;

- **Polyalphaolefins (PAOs):** Synthetic hydrocarbons like PAOs offer thermal stability and lubrication properties, making them suitable alternatives to SCCPs in applications requiring high-performance lubricants. J. Carpenter (1995), in a study published in the *Journal of Synthetic Lubrication*, discussed the biodegradability and toxicity of polyalphaolefin base and concluded that they have low eco-toxicity, with minimal impact on aquatic life compared to many other types of oils and lubricants. PAOs are generally considered to have low acute toxicity to humans. They are less likely to cause skin irritation or sensitization compared to many other types of oils and lubricants, including some mineral oils and chlorinated paraffins. Their low volatility also reduces the risk of inhalation exposure during use. Moreover, their lower eco-toxicity makes them a preferable option in applications where potential leaks or spills could affect water bodies. However, like with any chemical substances, appropriate handling measures and personal protective equipment (PPE) are recommended to minimize exposure risks in occupational settings;
- **Ester-Based Lubricants:** Synthetic esters, derived from organic acids and alcohols, provide good lubricity and biodegradability and are less toxic than SCCPs. They are used in various metalworking fluids for their excellent lubricating properties;
- **Water-Based Fluids:** Water-based or water-soluble metalworking fluids, which can be supplemented with corrosion inhibitors and extreme pressure additives, provide an alternative that significantly reduces health and environmental risks associated with oil-based products.

Anti-Corrosion Treatments

Following are some alternatives of SCCPs as anti-corrosion fluids:

- **Phosphate Esters:** Phosphate esters are used as fire-resistant hydraulic fluids and as additives in other metalworking fluids offering good anti-wear and anti-corrosion properties;
- **Inorganic Corrosion Inhibitors:** Compounds like sodium nitrite, molybdates, and borates can be used in cooling systems and metalworking fluids to provide corrosion protection without the environmental persistence of SCCPs;
- **Ceramic Coatings:** Instead of using fluids to inhibit corrosion, ceramic coatings can provide excellent corrosion resistance and surface hardness, reducing the need for chemical corrosion inhibitors in certain applications;
- **Barrier Coatings:** Non-toxic barrier coatings made from polymers or natural wax-based products can prevent metal corrosion by physically isolating the metal surface from corrosive agents.

Metal forming

Alternatives to SCCPs in metal forming have to offer similar benefits—lubrication, cooling, and reduced tool wear—without the associated environmental and health risks. Some substances are the same as those already identified above with regards to their properties for use as coolants and anti-corrosives for metalworking purposes, such as vegetable-based oils, synthetic esters, and water-based fluids, and here are others suitable for metal forming:

- **Polyalkylene Glycols (PAGs):** PAGs are synthetic lubricants known for their excellent lubrication properties and stability across a wide range of temperatures. Their advantages include water-solubility, which can aid in cleaning and reducing residues on metal parts, low

toxicity, and a good environmental profile. They are suitable for various metalworking applications, including metal forming.

3.1.8 Considerations for Selection of Alternatives to SCCP in Metalworking

Transitioning to these alternatives requires carefully evaluating their performance in specific applications. Pilot testing and consultation with lubricant suppliers can help identify the best option for a given metalworking process.

Here are some criteria to consider substances as alternatives to SCCP in metalworking:

- **Compatibility with Metals:** the chosen alternative should not cause corrosion or staining of workpieces;
- **To be viable in demanding metalworking applications,** alternatives should match or exceed the performance of SCCPs regarding lubrication, cooling, and corrosion protection;
- **Process Requirements:** the lubricant must meet the specific needs of the metalworking process, whether it requires high pressure, temperature, or specific surface finish qualities;
- **Environmental and health Impact:** ideally, alternatives should have a lower impact on workers' health and the environment, including considerations for biodegradability and toxicity. Lower volatility and reduced skin, and respiratory irritation (avoiding toxicological risks to workers is paramount);
- **Regulatory compliance:** it is essential to ensure that the alternative lubricants comply with local and international regulations to avoid potential legal and financial implications;
- **Cost-effectiveness:** while some alternatives may be more expensive than SCCPs, their use can be justified by improved worker safety, environmental compliance, and potential savings from regulatory compliance.

3.2 Use of SCCPs in PVC

3.2.1 Purpose

SCCPs were used as plasticizers in PVC due to their ability to impart flexibility, flame retardancy, and chemical stability to the final products. The incorporation of SCCPs into PVC formulations helps in achieving the desired material characteristics essential for a wide range of consumer, industrial, and construction products.

SCCPs enhance the properties of PVC products, such as vinyl flooring and synthetic leather, by improving flexibility. This is critical for the performance and durability of these products, particularly relevant in applications requiring high elasticity and resilience against physical stress.

3.2.2 Alternative substances

Many SCCPs alternatives as plasticizers in PVC exist, offering similar functionalities while mitigating environmental and health concerns associated with SCCPs:

- **Phthalate esters, adipate esters, and citrate esters:** recognized as potential alternatives, these esters can serve similar plasticizing functions in PVC (Guida et al., 2022);
- **Plasticizer composition containing epoxidized fatty acid monoester and epoxy ester:** demonstrated to reduce the extraction of halogenated polymers and exhibit less volatility, offering an alternative plasticizing option (Peter Frenkel et al., 2012);
- **Bio-based and phthalate-free plasticizers:** these alternatives are derived from renewable resources or non-chlorinated paraffins, designed to replace SCCPs in PVC applications (Hogue, 2013);

- Di(2-ethylhexyl) terephthalate (DEHT) and dibutyl phthalate (DBP): mentioned as compatible and performance-enhancing in PVC, indicating the viability of these plasticizing options (Kobetičová et al., 2018);
- CP-substances and formulations are often used in PVC industry as plasticizers: some research suggests these compounds offer potentially lower health risks and better environmental profiles only when compared to SCCPs. MCCPs may still present risks that warrant further investigation (South et al., 2022). Chlorinated paraffins with carbon chain lengths in the range C14–17 and chlorination levels at or exceeding 45 per cent chlorine by weight were assessed by the POPRC and were recommended to be listed to the Stockholm Convention under Annex A with specific exemptions (Decision POPRC-20/2).

3.3 SCCPs as Flame-Retardant

3.3.1 Purpose

SCCPs are used as flame retardants due to their ability to enhance the fire-resistant properties of various materials. The mechanism behind their flame-retardant action is primarily physical and chemical in nature. When materials treated with SCCPs are exposed to high temperatures or flames, the chlorine present in SCCPs releases hydrogen chloride (HCl) gas. This release of HCl helps to quench the flame by inhibiting the radical chain reaction that sustains combustion. There is also a physical mechanism; SCCPs can also promote the formation of a char layer on the material's surface when exposed to fire. This char layer acts as a barrier, reducing heat transfer to the underlying material and slowing down the material's contribution to the fire.

3.3.2 Alternatives to SCCPs used as Flame Retardants

Some alternatives for SCCPs as flame retardants exist:

- Aluminum hydroxide (aluminum trihydrate, ATH): a widely used flame retardant that releases water when heated, helping to cool the material and reduce the temperature below the combustion point. ATH is non-toxic and does not produce hazardous decomposition products just water and aluminium hydroxide;
- Magnesium hydroxide: works similarly to ATH by releasing water when heated, thus cooling the material and acting as a flame retardant. Magnesium hydroxide also offers the advantage of higher thermal stability compared to ATH;
- Phosphorus-based flame retardants: these include red phosphorus, ammonium polyphosphate, and organophosphorus compounds. They act mainly by promoting char formation and inhibiting the combustion process;
- Inorganic flame retardants: materials like zinc borate and expandable graphite are used as flame retardants in various applications. They can act by promoting char formation, diluting flammable gases, and absorbing heat;
- Intumescent coatings: these coatings expand when exposed to heat, forming an insulating char layer that protects the material underneath from fire. Intumescent systems often contain a combination of acid, carbon, and blowing agents;
- Bio-based flame retardants research is ongoing with the aim of creating bio-based flame retardants derived from natural or renewable sources. These include flame retardants based on lignin, DNA, and other natural polymers, which offer the potential for lower toxicity and environmental impact;

- Other alternatives for flame retardants have been extensively documented in other documents: Guidance on PBDEs and DP's BAT BEP and all PBDEs, DP, SCCP's risk evaluations.

When selecting an alternative flame retardant, it is important to consider the specific requirements of the application, including thermal stability, mechanical properties, and compatibility with the host material, in addition to the ecological and health impacts, while avoiding regrettable substitution.

3.4 SCCPs in Paints, Adhesive, and Sealants used in manufactured products

Open applications of SCCPs include their incorporation in paints, adhesives, and sealants.

3.5 SCCPs in Textile Finishing

3.5.1 Purpose

SCCPs are used in some textiles primarily for their flame-retardant and plasticizing properties. These chemicals are added to textiles to enhance fire resistance, reduce flammability, and improve the durability and flexibility of materials. Their application in this sector include clothing, drapery, and furniture covering, especially those that could be exposed to open flame or high heat sources. Another reason for using these substances is their relatively low cost compared to some alternative chemicals that offer similar properties. However, due to environmental and health concerns associated with SCCPs, there is a growing interest in finding safer alternatives.

3.5.2 Alternatives for the Textile Sector

Due to the importance of this sector in today's economy, textile and chemical sectors developed many alternatives including the following⁹:

- Phosphorus-based flame retardants: these compounds offer good flame retardancy. They can be used in various textile applications;
- Inorganic flame retardants: compounds like aluminum hydroxide and magnesium hydroxide act as flame retardants by releasing water when heated, which helps to cool the material and reduce flammability;
- Halogen-free flame retardants: these include a variety of chemicals, such as expandable graphite and certain nitrogen-based compounds, which may be less harmful than chlorinated and brominated flame retardants;
- Intumescent coatings: These coatings expand when heat exposure, forming a protective char layer that insulates the underlying material from fire. Intumescent systems are increasingly used in textiles for their effective flame-retardant properties;
- Bio-based flame retardants: research is ongoing into natural and bio-based compounds that offer flame retardancy. These include DNA, lignin, and certain plant-derived compounds that can impart flame-retardant properties to textiles in a potentially environmentally friendly manner (Sonnier et al., 2018);
- Boron compounds: Borates and other boron-based compounds are used for their flame-retardant properties. They are effective and are used in various applications, including textiles.

⁹ Sourced from many Internet sites and documents.

3.6 SCCPs in Leather Finishing

3.6.1 Purpose

Fat liquoring is a critical step in leather processing that introduces oils, fats, or other substances to enhance the leather's softness, flexibility, and water resistance. Fat liquoring with SCCPs is not a common practice, according to manufacturers, and products or mixtures containing this substance are not well known. Developing standards to analyze the presence of SCCPs in leather may bring some transparency in this sector.

3.6.2 Alternatives to SCCPs in Leather Manufacturing

Many manufacturers have shifted to using more ecological alternatives. Such alternatives like sulfated fat liquor from sheep-limed fleshing waste show comparable quality to commercial fish oil-based fat liquors, suggesting the importance of choosing effective fat liquoring agents for desired leather qualities (A. Nasr et al.). Besides these natural products others chemical substances may be used (Aguado, Angel, et al.; Manich et al., 2005) :

- Polymeric fat liquors: these are modern alternatives based on polymers that can impart excellent softness and fullness to the leather. Polymeric fat liquors can often provide superior performance regarding the leather's physical properties;
- Esterquats: they are used as cationic surfactants in fat-liquoring formulations and represent another innovative approach. They can contribute to the softening process while being more biodegradable than traditional materials containing SCCPs;
- Amidated and phosphorylated vegetable oils: these chemically modified vegetable oils offer an efficient fat-liquoring alternative, improving leather properties such as softness, lightness, and waterproofing.

3.7 SCCPs in Adhesives

3.7.1 Purpose

SCCPs are used in adhesives for several reasons, primarily because they can act as plasticizers and secondary flame retardants. SCCPs help to enhance flexibility, durability, and flame-retardant properties, making the adhesive formulations more effective for various applications, including in the automotive, construction, and textile industries. There is a growing demand for safer and more sustainable alternatives.

3.7.2 Alternatives of SCCP in adhesives

Alternatives to SCCPs in adhesive include the following substances:

- Phthalate-free plasticizers: alternatives like dioctyl terephthalate (DOTP), dioctyl succinate (DOS), and bio-based plasticizers offer similar plasticizing effects as SCCPs. These are becoming increasingly popular in the adhesive industry;
- Phosphorus-based flame retardants: phosphorus-based compounds, including red phosphorus, ammonium polyphosphate, and phosphonates, are effective flame-retardants that can be used in adhesives;
- Boron compounds: borates and other boron-based compounds have been used for their flame retardant properties and represent an alternative to SCCPs in adhesives.

3.8 Waterproofing and Fire-Retardant Paints

3.8.1 Purpose

SCCPs are used in the production of waterproof paints for several key reasons, including their ability to act as secondary plasticizers, flame retardants, and to enhance the durability of paint coatings. SCCPs help to improve the flexibility of paint films, making them less brittle and more resistant to cracking or chipping. By adding flame-retardant properties to paints, SCCPs contribute to reducing the flammability of coated surfaces, which is particularly important in certain industrial and residential applications.

However, due to the environmental and health risks associated with SCCPs, there's a growing interest in identifying safer and more sustainable alternatives for use in paint formulations.

3.8.2 Alternatives of SCCPs in Paints

Some alternatives to SCCPs are presented below:

- Water-based formulations: Increasingly, paint formulations are moving towards water-based systems, which reduce the need for plasticizers and flame retardants;
- Bio-based and renewable plasticizers: research into sustainable alternatives has led to the development of plasticizers derived from vegetable oils (e.g., epoxidized soybean oil) and other renewable resources;
- Phthalate-free plasticizers: alternatives such as dioctyl terephthalate (DOTP) and acetyl tributyl citrate (ATBC) have been developed to provide the necessary plasticizing effects.

UNEP/POPS/POPRC.12/INF/7 contains an extensive list of SCCP alternatives for different uses. This document also includes information on Environmental and health properties, Regulatory status, Load in% w/w, Price, Economic feasibility, availability and accessibility, and references.

4. Best Available Techniques (BAT) and Best Environmental Practices (BEP)

4.1 General BAT and BEPs in chemical manufactures

Table 3 below summarizes information on BAT and BEP applicable in industry in general.

Table 3. Summary of BAT and BEP applicable to manufacture using chemicals.

Process steps	BAT	BEP
General measures for manufactures using SCCPs or related substances	<ul style="list-style-type: none"> • Regular inspection and maintenance of plant and equipment • Monitoring of emissions/releases • Substitution of harmful/hazardous substances • Limiting the number of emission points 	<ul style="list-style-type: none"> • Implementation and adherence to an internationally accepted EMS, such as ISO 9001 and ISO 14001 • Establishment, maintenance and regular review of a channeled and diffuse emissions to air inventory
Measures for the reduction of channeled emissions	<ul style="list-style-type: none"> • Use of the following techniques to reduce channeled emission to air of organic compounds: adsorption, absorption, catalytic oxidation condensation, thermal oxidation • Use of the following techniques to reduce channeled emissions to air using optimized catalytic or thermal oxidation, rapid waste-gas cooling, adsorption using activated carbon 	

Process steps	BAT	BEP
	<ul style="list-style-type: none"> The use of an absolute filter, absorption, fabric filter, and/or high-efficiency air filter to reduce channeled emissions to air of dust and particulate-bound metals 	
Measure for the reduction of diffuse emissions	<ul style="list-style-type: none"> Limiting the number of emission sources (e.g. minimizing pipe lengths, reducing the number of pipe connectors and valves, using welded fittings and connections, using compressed air or gravity for material transfer) Collection of diffuse emissions and treating off-gases Facilitating access to potentially leaky equipment (installing platforms, using drones for monitoring) Use of high-integrity equipment: valves with bellow or double packing seals or equally efficient equipment, magnetically driven or canned pumps/compressors/ agitators, or pumps/compressors/ agitators using double seals and liquid barrier, certified high-quality gaskets, corrosion-resistant equipment 	<ul style="list-style-type: none"> Establishing and implementing a leak detection and repair (LDAR) program for fugitive emissions and reviewing and updating the program Establishing and implementing a detection and reduction program for non-fugitive emissions and reviewing and updating this program Estimation of diffuse and fugitive emissions to air using a combination of different techniques (such as emission factors, mass balance, thermodynamic models) Review and update of operating conditions (e.g. frequency and duration of reactor opening, preventing corrosion)
Measures referring to emissions from storage	<ul style="list-style-type: none"> Using advanced instrumentation and control systems to achieve precise level control in the tank Minimization of level fluctuations Gas balance lines Floating roofs (large tanks only) Installed condensers Vent recovery to treatment 	
Measures referring to water emissions	<ul style="list-style-type: none"> Use of an integrated wastewater management and treatment strategy that includes a combination of the following techniques: process-integrated techniques, recovery of pollutants at the source, wastewater pre-treatment, final wastewater treatment 	<ul style="list-style-type: none"> Establishment and maintenance of an inventory of wastewater and waste gas streams as part of the environmental management system Monitoring of emissions to water using European (E), national standards (D, BS, NS etc.) or international standards (ISO), with a minimum frequency

4.2 Measures to protect health of workers

It is important to apply specific protective measures to safeguard workers' health in countries that still use SCCPs or substances that potentially contain them, such as mixtures of CPs. It is important to introduce a hierarchy of prevention and control measures e.g. that follow the STOP principle: substitution, technological measures, organizational and as a last resort personal protective equipment.

When working with SCCPs in metalworking processes, it is crucial to implement precautions to mitigate potential health and environmental risks. SCCPs have been associated with various environmental and health concerns due to their persistence, bioaccumulation potential, and possible toxic effects. Key precautions to consider are presented in the following sections.

4.2.1 Use of Personal Protective Equipment (PPE)

Skin protection: wear protective gloves resistant to chemicals to prevent skin contact with SCCPs. Long-sleeved clothing and aprons can protect against splashes.

Eye protection: use safety goggles to guard against splashes and vapors that could irritate or damage the eyes.

Respiratory protection: In areas with poor ventilation or where aerosols, mists, or vapors of SCCPs may be present, wear appropriate respiratory protection, such as masks or respirators.

4.2.2 Work conditions

An adequate working environment is also essential. The following measures should be taken to minimize hazards from dangerous substances as SCCPs:

- Ensure adequate ventilation: work in well-ventilated areas to minimize inhalation exposure to fumes or vapors from SCCPs. Use local exhaust ventilation (LEV) systems at points of emission to capture contaminants;
- Handle and safely store all SCCP substances (including CP mixtures). Containers of SCCPs (bottles, flasks, dishes, barrels...) should be clearly labeled and tightly sealed in a cool, well-ventilated area away from direct sunlight and incompatible substances;
- Avoid eating, drinking, or smoking in areas where SCCPs are handled to prevent ingestion.

4.2.3 Contingency plan

The development of a contingency plan is essential to protect workers during an emergency:

- Develop and implement a spill response plan;
- Equip the workplace with spill cleanup materials;
- Ensure that all employees are trained in spill response procedures;
- Spill containment measures and secondary containment systems to prevent environmental contamination in case of leaks or spills exist in the workshop where SCCPs might be present to avoid any contamination of the environment and wastewater sewage.

4.2.4 Monitoring and Health Surveillance

In places where SCCPs are used, in considerable amounts, it is important to conduct regular monitoring of SCCP concentrations or, when not possible, regularly sample and analyze the air to ensure compliance with occupational exposure limits.

In addition, it is important to implement health surveillance programs for workers regularly exposed to SCCPs to detect any adverse health effects early.

4.3 Waste Management

4.3.1 General considerations

Disposal of SCCP-containing waste, including used metalworking fluids and contaminated materials, must be conducted according to local environmental regulations and Basel Convention guidelines for POP-

containing waste. This may involve sending the contaminated waste to approved hazardous waste treatment, storage, and disposal facilities (TSDFs).

For developing countries that might not have dedicated facilities for dangerous waste treatment, it is important to consider the possibility of exporting those wastes to countries where such possibilities exist, in compliance with their domestic laws and rules and Basel and Rotterdam Convention provisions.

4.3.2 Waste elimination

According to the Basel Convention General Technical Guidelines on the Environmentally Sound Management (ESM) of Waste consisting of, containing, or contaminated with POPs (UNEP 2023a), waste with LPCL for SCCPs at or above [100 mg/kg] [1500 mg/kg][10,000 mg/kg]¹⁰ must be disposed of in such a way that the POP content is destroyed or irreversibly transformed.

Pre-treatment may be required for the proper and safe operation of disposal technologies. Pre-treatment operations before disposal should be performed only if the POPs that are separated from the waste during pre-treatment are subsequently and properly disposed.

Appropriate methods are described in the Basel Convention general technical guidelines on POPs waste and may include mechanical separation size reduction, dewatering, absorption or adsorption, thermal desorption, oil-water separation, solvent washing, pH adjustment, etc.

The destruction and irreversible transformation methods to be used are fully described in the Basel Convention general technical guidelines on POPs waste, as well as the commercially available operations for the environmentally sound destruction and the irreversible transformation of the POP content in waste. The methods applicable to SCCP waste are described extensively in the cited guidelines and include the following processes:

- Advanced solid waste incineration (ASWI);
- Cement kilns co-incineration;
- Gas-phase chemical reduction (GPCR);
- Supercritical water oxidation (SCWO) and subcritical water oxidation;
- Hazardous waste incineration;
- Thermal and metallurgical production of metals.

Where neither destruction nor irreversible transformation is the environmentally preferable option, for waste with a POP content at or above the LPCL, countries may allow such waste to be disposed of by other methods than the methods presented in subsection IV.G.2 of the general technical guidelines for the ESM of waste containing POPs. In all cases they should be disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option.

Waste with a SCCP content below [100 mg/kg] [1500 mg/kg] [10,000 mg/kg]¹¹ should be disposed of in accordance with the methods referred to in subsection IV.G.4 of the general technical guidelines of the Basel Convention (outlining disposal methods when POP content is low), taking into account subsection IV.I.1 of the present guidelines (pertinent to higher-risk situations).

¹⁰ As of May 2023, there is no consensus concerning this value among experts.

¹¹ As of May 2023, there is no consensus concerning this value among experts.

4.3.3 Training and Information

Preventing contamination and health problems due to SCCP manipulation is paramount. Companies using this substance must provide training for all personnel handling SCCPs on the potential health risks, safe handling procedures, and emergency response actions.

It is also important to keep a record of Safety Data Sheets (SDS) for SCCP-containing products and ensure that SDS are accessible to all employees.

4.4 Summary of BAT and BEP for chlorinated paraffins production and use

Table 4 presents a summary of the BAT and BEP to reduce and/or eliminate releases of chlorinated paraffins during its production and use.

Table 4. Summary of BAT and BEP for chlorinated paraffins production and use.

Application	BAT	BEP
SCCP production	<ul style="list-style-type: none"> Implementing closed-loop systems to minimize SCCP emissions during the production process. This involves capturing and recycling process gases and wastewater containing SCCPs to prevent their release into the environment. Employing advanced process design and engineering techniques to minimize SCCP waste generation and maximize production efficiency, optimizing reaction conditions, catalysts, and raw material inputs to reduce SCCP by-products and improve process yields. Utilizing efficient waste treatment technologies to treat SCCP-containing waste streams generated during production. This may include processes such as distillation, solvent extraction, or chemical treatment to remove or neutralize SCCPs before discharge. Implementing measures to prevent spills, leaks, and releases of SCCPs into the environment. This includes proper handling, storage, and transportation practices. Conducting regular maintenance and inspection of production equipment to identify and address potential sources of SCCP emissions. 	<ul style="list-style-type: none"> Complying with relevant regulations and standards governing the production and handling of SCCPs. This may include obtaining permits, conducting environmental impact assessments, and adhering to emission limits and reporting requirements. Conducting comprehensive risk assessments to identify potential environmental and health hazards associated with SCCP production. Implementing risk management strategies to mitigate these risks, such as implementing engineering controls, providing personal protective equipment, and establishing emergency response protocols. Engaging with local communities, environmental organizations, and regulatory agencies to promote transparency and accountability in SCCP production operations. Establishing communication channels for sharing information, addressing concerns, and soliciting feedback from stakeholders.
Chlorinated Paraffins production	<ul style="list-style-type: none"> Employ advanced process control and engineering techniques to optimize reaction conditions, such as temperature, pressure, and reaction time, to minimize the formation of SCCPs. Select feedstocks with higher molecular weights and longer carbon chains to minimize the formation of short-chain chlorinated paraffins. 	<ul style="list-style-type: none"> Ensuring compliance with relevant regulations and standards governing the production and use of chlorinated paraffins, including restrictions on SCCPs (<1% w/w SCCPs containing >48% w/w chlorine). Maintain accurate records of production processes, emissions, and waste management activities, and submit required reports to regulatory agencies as per regulations.

Application	BAT	BEP
	<ul style="list-style-type: none"> • Use whenever possible feedstock (paraffins) certified with low, or zero, content of C10-13 carbon chains. • Ensure raw materials are free from impurities that can catalyze the formation of SCCPs during chlorination processes. 	
Metalworking	<ul style="list-style-type: none"> • Substituting SCCPs with less harmful alternatives wherever possible. Depending on the metalworking process the alternatives might be: <ul style="list-style-type: none"> ➤ Lubricants : Vegetable base oils, Polyalphaolephins (PAOs), Ester based lubricants ➤ Anti-corrosion: Phosphate esters, inorganic corrosion inhibitors ➤ Metal forming: Polyalkylen glycols (PAGs) ➤ Synthetic esters • Implementing closed-loop systems to minimize SCCP emissions during metalworking processes¹². • Employing advanced filtration and treatment systems to capture and treat SCCP-containing wastewater and emissions. • Optimizing process efficiency to reduce SCCP usage and waste generation. • Implementing proper storage and handling procedures to prevent spills and releases of SCCPs into the environment. • Installing closed-loop systems to capture and recycle process gases and wastewater containing chlorinated paraffin by-products, reducing the likelihood of SCCP emissions. • Utilizing efficient waste treatment technologies to treat waste streams generated during production, minimizing the release of SCCPs into the environment. • Implementing spill prevention measures, such as proper handling and storage procedures for raw materials 	<ul style="list-style-type: none"> • Regular monitoring and testing of SCCP levels in air, water, and soil to ensure compliance with regulatory limits. • Training employees on safe handling practices and emergency response procedures to prevent accidental releases of SCCPs. • Proper labeling and storage of mixtures possibly containing SCCPs. • Developing and implementing spill prevention and response plans to minimize the environmental impact of accidental releases. • Engaging in continuous improvement efforts to identify opportunities for further reducing SCCP usage and environmental impact.

¹² In the context of industrial processes, a closed system refers to a manufacturing setup where materials, for example water or lubricant in our case, are recycled and reused within the system, minimizing or eliminating waste discharge. This approach not only conserves water and lubricant but reduces environmental impact by preventing pollutants from entering the environment or impacting the workers. Such systems are integral to sustainable manufacturing practices, promoting resource efficiency and reducing operational costs.

Application	BAT	BEP
	<p>and products, to minimize the risk of accidental releases of SCCPs.</p>	
<p>Secondary plasticizers in flexible polyvinyl chloride</p>	<ul style="list-style-type: none"> • Developing and using alternative plasticizers that do not have the same environmental and health concerns as SCCPs. Examples may include DINP (Diisononyl phthalate), DOTP (Dioctyl terephthalate), and bio-based options like those derived from vegetable oils. • Implementing closed-loop manufacturing processes to minimize leaks, spills, and emissions of SCCPs. • Checking SCCP content in PVC to be recycled, and not recycling PVC containing more than the LPCL established under the Basel Convention or other national limit values. 	<ul style="list-style-type: none"> •
<p>Additives in the production of transmission belts in the natural and synthetic rubber industry</p>	<ul style="list-style-type: none"> • Explore alternative substances, ensuring adequate health and environmental assessment prior to use. • Evaluate the technical feasibility and performance of alternative substances. • Other alternatives as plasticizers in rubber: <ul style="list-style-type: none"> ○ Long-chain chlorinated Paraffins (C18+) ○ Acrylic polymers ○ Al and Sb trioxide ○ Phosphate esters • Other alternative flame retardants in rubber: <ul style="list-style-type: none"> ○ Organophosphorus, flame retardants ○ Isopropylphenyl diphenyl phosphate (IPDPP) ○ Tricresyl phosphate • Implement measures to minimize waste generation, optimize material usage, and recycle or reuse process waste. 	<ul style="list-style-type: none"> • Implement general BEP: regulatory requirements, reporting on waste, hygienic, and safety measures, use of protective equipment. • Install and maintain effective emission control systems, such as scrubbers or filters, to capture and treat volatile organic compounds (VOCs). • Implement wastewater treatment systems to remove SCCPs and other contaminants from process wastewater before discharge.
<p>The leather industry, in particular, fat liquoring in leather</p>	<ul style="list-style-type: none"> • Some fatty chemicals can substitute SCCPs: Long-chain chlorinated paraffins (C18+), fatty acid methyl esters (FAME), polyethylene glycol (PEG) • Natural oils such as soybean oil, palm oil, rapeseed oil are alternatives in fat liquoring. • Biocompatible substances as silicone oils and emulsions that provide effective lubrication and softening of leather fibers. 	<ul style="list-style-type: none"> • Implement general BEP: regulatory requirements, reporting on waste, hygienic, and safety measures, use of protective equipment.

Application	BAT	BEP
	<ul style="list-style-type: none"> Advanced emulsion technologies can be utilized to create stable emulsions of natural oils, synthetic esters, or other fat liquoring agents. 	
Tubes for outdoor decoration bulbs	<ul style="list-style-type: none"> Use recyclable plastics or glass sourced from sustainable suppliers. Use energy-efficient manufacturing processes. Implement measures to minimize waste generation during production processes, such as optimizing material usage, reducing scrap, and reusing or recycling waste materials. Reduce GHG emissions. 	<ul style="list-style-type: none"> No specific BAT for this industry, some general principles and practices can be applied to ensure the environmentally responsible production.
Waterproofing and fire-retardant paints	<p>Waterproofing substances that can be used in place of SCCPs in paints:</p> <ul style="list-style-type: none"> Acrylic polymers: commonly used as binders in waterproofing paints (film forming). Silicone-based sealants: can be used to waterproof surfaces by creating a durable and flexible barrier that repels water and prevents moisture infiltration. Polyurethane coatings: offer excellent waterproofing properties and adhesion to various surfaces. Fluoropolymer coatings: fluorinated ethylene propylene (FEP) or polytetrafluoroethylene (PTFE), provide superior water repellency and resistance to harsh environmental conditions. <p>Fire-retardant substances:</p> <ul style="list-style-type: none"> Phosphorus-based flame retardants: ammonium polyphosphate (APP) or red phosphorus. Nitrogen-based flame retardants: melamine polyphosphate (MPP) or melamine cyanurate (MC), reducing the flammability of paints and forming a protective char layer during combustion. Intumescent coatings: contain ingredients that expand and swell when exposed to high temperatures. Mineral-based fillers: alumina trihydrate (ATH) or magnesium hydroxide (MDH), can be used as flame retardants in paints. 	<ul style="list-style-type: none"> Implement general BEP, including regulatory requirements, reporting on waste, hygienic and safety measures, and the use of protective equipment. Install and maintain effective emission control systems, such as scrubbers or filters, to capture and treat volatile organic compounds (VOCs). Install exhaust systems above workstations to reduce fugitive VOCs in workshops. Implement wastewater treatment systems to remove SCCPs and other contaminants from process wastewater before discharge.

Application	BAT	BEP
Adhesives	<ul style="list-style-type: none"> • Plasticizers: polymeric plasticizers such as phthalate-free polyesters, adipates, trimellitates, epoxidized soybean oil, or epoxidized linseed oil; polyols, such as glycerol or sorbitol, can substitute for SCCPs as plasticizers in adhesives. • Crosslinkers: such as toluene diisocyanate (TDI) or hexamethylene diisocyanate (HDI) • Takifiers: modified rosin esters, such as hydrogenated rosin esters or maleic-modified rosin esters. 	

5. Stakeholders and their role in phasing-out SCCPs

The phase-out and management of the life cycle of SCCPs, along with the protection of health and the environment, involve a collaborative effort among various stakeholders. Each group plays a unique and critical role in addressing the challenges SCCPs pose. In accordance with Decision SC-11/12, the Conference of the Parties tasked the Persistent Organic Pollutants Review Committee (POPRC) with exploring options for identifying POPs in stockpiles, products in use, and waste streams. The committee finalized a report highlighting best practices challenges and barriers for identifying persistent organic pollutants in stockpiles, products and articles in use and in wastes and issues related to the production, import and export of products and articles containing persistent organic pollutants (UNEP, 2024). Here is an overview of the roles of different stakeholders.

5.1 Industries and Trading Companies

5.1.1 Compliance and Innovation

Industries historically using SCCPs in products must comply with local, regional and international risk management measures, such as regulations and seek alternative materials or processes. They are crucial in researching and developing (R&D) safer alternatives that do not compromise product quality or safety.

Regulatory Compliance: Industries must adhere to national and international regulations concerning the production, use, and disposal of SCCPs. This may involve updating practices, processes, and products to comply with norms and standards. If the country, Party to the Convention, in which they are located is not benefiting from any specific exemption, they will have the obligation to comply with the corresponding Stockholm Convention provisions.

Industries are responsible for researching, developing, and adopting safer alternatives to SCCPs. This transition requires significant investment in R&D and may involve redesigning products or processes to accommodate new materials.

5.1.2 Supply Chain Management

It is crucial to ensure suppliers adhere to the same environmental and health standards, especially in regions with less stringent regulations. Industries should audit and work closely with their supply chains to phase out SCCPs. The term supplier covers suppliers of chemical substances used in the industry and manufacturing and suppliers of products in which SCCPs might have been used, like textiles, rubber, PVC products, etc (UNEP, 2024). The general public, consumers, media and other stakeholders require from the manufacturing and trading sector to be transparent and socially responsible for the products they put on the market.

Transparency in the trading of chemicals is paramount for ensuring environmental safety, public health, and regulatory compliance. It fosters trust among stakeholders, including consumers, businesses, and

regulatory bodies, by providing clear information about the chemical composition of products, their origins, and the safety measures taken during their production and distribution. Transparent trading practices enable better risk assessment and management, facilitating the identification and substitution of hazardous substances with safer alternatives. Moreover, transparency supports the global effort to adhere to international agreements and regulations, such as the Stockholm Convention. By promoting openness and accountability, transparency in chemical trading not only protects human health and the environment but also contributes to the sustainability and ethical integrity of global supply chains.

The social responsibility of traders and companies concerning the use and trade of dangerous chemicals is a critical aspect of global environmental and public health stewardship. These entities may consider going beyond mere legal compliance, actively ensuring their operations do not adversely affect human health or the environment. This responsibility encompasses diligently managing chemical substances throughout their lifecycle, from production to disposal, including adopting safer alternatives wherever possible. Traders and companies should also use transparent reporting and communication practices, enabling all stakeholders, including consumers, communities, and governments, to make informed decisions. By prioritizing safety, sustainability, and ethical considerations in their operations, traders and companies contribute to a safer, healthier world, demonstrating a commitment to the well-being of current and future generations.

5.1.3 Environmental Responsibility

Waste Management is part of the trading and manufacturing companies. Proper disposal of SCCP-containing products and waste is essential to prevent environmental contamination. Industries should invest in technologies and processes that minimize waste and facilitate safe disposal of hazardous materials.

Implementing BAT and BEP to minimize emissions of SCCPs during production and throughout the product lifecycle is essential for reducing the environmental and health impacts associated with these chemicals, ensuring compliance with international standards, and supporting global efforts towards sustainability and pollution prevention. This includes implementing best practices for managing existing SCCP-containing products throughout their lifecycle, including safe disposal methods to minimize environmental release.

5.2 Government and Regulatory Bodies

Government and regulatory bodies play a key role in enforcing best practices in chemicals management:

- International engagement: adhering to international conventions and frameworks, such as the Stockholm Convention, Basel Convention, Rotterdam Convention on the prior informed consent procedure for certain hazardous chemicals and pesticides in international trade, Minamata Convention on mercury, and the Global Framework on Chemicals, is the first step towards a good chemical management approach at the local level. This helps the country to align with global standards for environmental protection and public health, foster international cooperation, and access technical and financial resources necessary for effective chemical management, ultimately leading to the sustainable use and safe disposal of hazardous substances;
- Legislation and enforcement: governments enact laws and regulations to restrict and ban the use of SCCPs, oversee their phase-out, and manage exemptions for critical uses if authorized by the Convention. They are responsible for enforcing these regulations and ensuring compliance;
- Policy development: developing policies that encourage reducing SCCP use and promote the adoption of safer alternatives. This could include incentives for green chemistry and sustainable manufacturing practices;

- Standards and norms: The government, in collaboration with industrial and technical bodies, bears a shared responsibility to establish and adopt precise standards regarding the permissible use of certain chemicals, their standardization across various applications, and their allowable concentrations in products and foods. This collaborative approach ensures that chemical management policies are scientifically sound and practically enforceable, safeguarding public health and environmental integrity while supporting industry compliance and innovation.

5.3 Scientists and Academic Institutions

Scientists from universities, private and public research centers, and technical and vocational education and training (TVET) Institutions have an important role to play in the chemical management field.

- Research and development (R&D): conducting research to understand the environmental and health impacts of SCCPs, developing safer chemical alternatives, and improving detection and analysis methods for environmental monitoring. The R&D sector is pivotal in finding safe and effective alternatives to SCCPs, developing new materials, and disposal technologies to minimize environmental impact;
- Education: Educating the next generation of scientists, policymakers, and industry leaders about the risks associated with SCCPs and the importance of sustainable chemistry;
- Train future industrial and manufacturers on the safer and cleanest practices;
- Collaboration with industry: Engaging in partnerships with industries to test and scale up viable alternatives for commercial use, ensuring that new products meet safety and performance standards;
- International cooperation enables researchers, often affiliated with institutions in developed countries, to access and share knowledge, as well as benefit from technology transfers. This exchange not only enhances their personal and institutional capabilities but also significantly contributes to the development and progress of their home countries.

5.4 Non-Governmental Organizations (NGOs)

NGOs frequently emerge as formal responses to public concerns, embodying the collective aspirations and concerns of communities. Typically motivated by mission rather than profit, NGOs operate with a flexibility and agility that distinguishes them from traditional institutions like governments and universities.

This unique structure enables NGOs to undertake a wide range of activities, including advocacy, humanitarian aid, and environmental conservation, which are often beyond the scope or capacity of other stakeholders. Their ability to mobilize resources, influence policy, and implement grassroots initiatives allows them to fill crucial gaps in addressing global challenges, making them indispensable actors in pursuing social, environmental, and economic progress.

Activities they may conduct include advocacy for environmental and health protection, and awareness raising among the public, the workers, and industry. They can also monitor the use, corrupt trading practices, and poor environmental practices concerning the use of chemicals such as SCCPs. By publicly advocating for choosing products free of SCCPs and supporting companies that invest in safer alternatives, consumers NGOs can drive demand for more sustainable and less harmful products.

5.5 International Organizations

International bodies, such as the United Nations Environment Programme (UNEP), facilitate global cooperation in the management and phase-out of SCCPs. They provide platforms for sharing best practices, technical support, and funding for developing countries.

Projects aimed at delivering global environmental benefits, such as eliminating the production and use of SCCPs in specific industries like PVC and rubber manufacturing, represent a critical area for international collaboration and support. Countries can develop these initiatives with the backing of Global Environment Facility (GEF) agencies, leveraging their expertise and resources. In certain instances, these projects may also qualify for grants from the GEF, providing essential financial support to facilitate the transition towards safer, more sustainable alternatives.

This collaborative approach helps mitigate the environmental and health risks associated with hazardous chemicals and promotes technological innovation and capacity building within the targeted regions. By aligning with GEF Agencies, countries can ensure that these projects contribute effectively to broader environmental goals and sustainable development objectives, creating a positive impact that resonates on a global scale.

5.6 Consumers

Consumers can use many means to make their voices heard and influence industries, manufacturers, traders, and regulators to stop the use of problematic substances such as SCCPs. Consumers can also advocate for stronger regulations and better product labeling to make informed choices easier.

Adhering to these precautions can help mitigate the risks associated with using SCCPs in metalworking, protecting workers' health and minimizing environmental impact.

Annex to the guidance

Non-Exhaustive List of Chlorinated Paraffins trade names potentially containing SCCPs (Source UNEP/CHW.14/7/Add.2/Rev.1)

Synonyms for SCCPs:

Alkanes, chlorinated; alkanes (C10-C13), chloro (60%); alkanes (C10-C13), chloro (50-70%); chlorinated alkanes; chlorinated alkanes, chlorinated paraffins; chloroalkanes; chlorocarbons; paraffin, chlorinated; paraffins, chloro; paraffins, chlorinated; polychlorinated alkanes; polychloroalkanes

Trade names for CPs, potentially SCCPs

The following generic trade names are usually accompanied by a suffix indicating a specific product (IARC, 1990): A 70; A 70 (wax); Adekacizer E; Arubren; Cereclor; Chlorinated paraffins (CPs); Chlorcosane; Chlorez; Chlorofin; Chloroflo; Chloroparaffin; Chlorowax, Chlorowax 500AO; Chlorowax 45AO, Chlorowax 52AO; Cloparin; Cloparol; Clorafin; CP F; CW; Diablo; Derminolfett; Derminolöl; EDC-tar; Electrofine; Enpara; FL X; Hordafam; Hordaflex; Hordalub; Hulz; KhP; Meflex; Monocizer; Paroil; Poliks; Tenekil; Toyoparax; Unichlor.

References

- Chen, C., Chen, A., Li, L., Peng, W., Weber, R., & Liu, J. (2021). Distribution and emission estimation of short- and medium-chain chlorinated paraffins in Chinese products through detection-based mass balancing. *Environmental Science & Technology*, 55(11), 7335-7343. <https://doi.org/10.1021/acs.est.0c07058>
- Chen, C., Chen, A., Zhan, F., Wania, F., Zhang, S., Li, L., & Liu, J. (2022). Global historical production, use, in-use stocks, and emissions of short-, medium-, and long-chain chlorinated paraffins. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.2c00264>
- Chen, C., Wang, Y., Zhang, H., Wang, T., & Jiang, G. (2022). Global historical production, use, in-use stocks, and emissions of short-, medium-, and long-chain chlorinated paraffins. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.2c00264>
- Chen, M. Y., Luo, X. J., Zhang, X. L., He, M. J., Chen, S. J., & Mai, B. X. (2011). Chlorinated paraffins in sediments from the Pearl River Delta, South China: Spatial and temporal distributions and implication for processes. *Environmental Science & Technology*, 45, 5964-5971.
- European Chemicals Agency (2023). *Guidance on Information Requirements and Chemical Safety Assessment: Chapter R.11 PBT/vPvB Assessment*. Version 4.0, December 2023. ISBN 978-92-9468-326-7. Available at: https://echa.europa.eu/documents/10162/17224/information_requirements_r11_en.pdf/a8cce23f-a65a-46d2-ac68-92fee1f9e54f (Accessed 27 Nov. 2024).
- European Commission. (2000). Water Framework Directive (WFD) amendment 2000/60/EC. Official Journal of the European Communities, L 327.
- European Food Safety Authority (EFSA). (2020). EFSA Journal, 18(3), e05991. <https://doi.org/10.2903/j.efsa.2020.5991>
- European Parliament (2019) Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants (recast), <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R1021&qid=1711609189321>, <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1021&qid=1711609189321> European Union. (2000). Risk Assessment Report: Alkanes, C10-13, Chloro (CAS No: 85535-84-8, Einecs No.: 287-476-5). Office for Official Publications of the European Communities.
- Fiedler, H. (2010). Short-chain chlorinated paraffins: Production, use and international regulations. In J. de Boer, T. El-Sayed Ali, H. Fiedler, J. Legler, D. Muir, V. A. Nikiforov, G. T. Tomy, & K. Tsunemi (Eds.), *The Handbook of Environmental Chemistry: Chlorinated Paraffins* (Vol. 10, pp. 1-40). Springer-Verlag. https://doi.org/10.1007/978-3-642-10761-1_1
- Gao, Y., Zhang, H., Zou, L., Wu, P., Yu, Z., Lu, X., & Chen, J. (2016). Quantification of short-chain chlorinated paraffins by deuterodechlorination combined with gas chromatography-mass spectrometry. *Environmental Science & Technology*, 50(8), 3746-3753. <https://doi.org/10.1021/acs.est.5b06232>
- Ghosh, K., Athar, J., Pawar, S., Kandasubramanian, B., & Kaushik, M. P. (2012). Synthesis, characterization, and rheological evaluation of 1,3-diazido-2-ethyl-2-nitropropane as an energetic plasticizer. *Journal of Energetic Materials*, 30(2), 107-123.
- Guida, Y., Matsukami, H., & Kajiwara, N. (2022). Short- and medium-chain chlorinated paraffins in polyvinyl chloride consumer goods available in the Japanese market. *Science of The Total Environment*, 849, 157762.
- Glüge, J., Wang, Z., Bogdal, C., Scheringer, M., & Hungerbühler, K. (2016). Global production, use, and emission volumes of short-chain chlorinated paraffins – A minimum scenario. *Science of The Total Environment*, 573, 1132-1146. <https://doi.org/10.1016/j.scitotenv.2016.08.105>

- Guida Y, Capella R, Weber R (2020) Chlorinated paraffins in the technosphere: A review of available information and data gaps demonstrating the need to support the Stockholm Convention implementation. *Emerg. Contam.* 6, 143-154. <https://doi.org/10.1016/j.emcon.2020.03.003>
- Guida, Y., Capella, R., Kajiwara, N., Babayemi, J. O., Torres, J. P. M., & Weber, R. (2022). Inventory approach for short-chain chlorinated paraffins for the Stockholm Convention implementation in Brazil. *Chemosphere*, 287(Part 3), 132344. <https://doi.org/10.1016/j.chemosphere.2021.132344>
- Guida Y, Matsukami H, Oliveira de Carvalho G, Weber R, Vetter W, Kajiwara N. (2023) Homologue composition of technical chlorinated paraffins used in several countries over the last 50 years— SCCPs are still out there. *Environmental Science & Technology*. 57(35), 13136-13147.
- Gallistl C, Sprengel J, Vetter W. (2018) High levels of medium-chain chlorinated paraffins and polybrominated diphenyl ethers on the inside of several household baking oven doors. *Science of the Total Environment*. 615, 1019-1027.
- Hammer, J., Matsukami, H., Kuramochi, H., & Endo, S. (2021). Direct measurements and modeling of congener group specific vapor pressure for chlorinated paraffins. *Chemosphere*, 281, 130909. <https://doi.org/10.1016/j.chemosphere.2021.130909>
- Huang, X., Zheng, X., Wang, Y., Zhao, Y., Zhu, L., & Zhang, Y. (2011). Bioaccumulation and biomagnification of short-chain chlorinated paraffins in marine organisms from the Pearl River Estuary, China. *Environmental Pollution*, 159(11), 3111-3116.
- IARC. (1990). WHO - IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry: Chlorinated Paraffins. (Vol. 48, pp. 56-73). International Agency for Research on Cancer. <http://monographs.iarc.fr/ENG/Monographs/vol48/mono487.pdf>
- Kellersohn, T. (1998). Chlorinated paraffins. In Ullmann's Encyclopedia of Industrial Chemistry. Electronic release, 6th ed. Weinheim: Wiley-VCH.
- Kobetičová, K., & Černý, R. (2018). Ecotoxicity assessment of short- and medium-chain chlorinated paraffins used in polyvinyl-chloride products for the construction industry. *Science of The Total Environment*, 640, 523-528.
- Li, H., Fu, J., Pan, W., Wang, P., Li, Y., Zhang, Q., Wang, Y., Zhang, A., Liang, Y., & Jiang, G. (2018). Determination of short-chain chlorinated paraffins in multiple matrices of Arctic using gas chromatography-electron capture negative ion-low resolution mass spectrometry. *MethodsX*, 5. <https://doi.org/10.1016/j.mex.2018.07.017>
- Li, Y., Fellin, P., Sverko, E., Mackay, D., & Li, H. (2011). Long-range atmospheric transport of short-chain chlorinated paraffins to the Arctic and cold trapping in the polar marine environment. *Environmental Science & Technology*, 45(22), 10013-10019.
- Lin, L., Abdallah, M. A.-E., Chen, L. J., Luo, X. J., Mai, B. X., & Harrad, S. (2022). Comparative in vitro metabolism of short chain chlorinated paraffins (SCCPs) by human and chicken liver microsomes: First insight into heptachlorodecanes. *Science of the Total Environment*, 851(Pt 2), 158261. <https://doi.org/10.1016/j.scitotenv.2022.158261>
- Manich, A.M., Cuadros, S., Cot, J., Carilla, J. & Marsal, A., 2005. Determination of oxidation parameters of fatliquored leather by DSC. *Thermochimica Acta*, [journal details if available]. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0040603104004940?via%3Dihub>.
- Matsukami H., Takemori H., Takasuga T., Kuramochi H., Kajiwara N. (2020) Liquid chromatography-electrospray ionization-tandem mass spectrometry for the determination of short-chain chlorinated paraffins in mixed plastic wastes. *Chemosphere*, 244, 125531
DOI: [10.1016/j.chemosphere.2019.125531](https://doi.org/10.1016/j.chemosphere.2019.125531).
- Muhammad, F. Z. (2020). Analisis Stress Corrosion Cracking Dengan Media Korosi HNO3 Pada Sambungan Hasil Pengelasan Hotspot Capacitive Discharge Welding Dengan Variasi Energi Pengelasan. Retrieved from

https://www.researchgate.net/publication/339887056_Analisis_Stress_Corrosion_Cracking_Dengan_MediaKorosi_Hno3_Pada_Sambungan_Hasil_PengelasanHotspot_Capacitive_Discharge_WeldingDengan_Variasi_Energi_Pengelasan

Nasr, A. (2017). Reusing limed fleshing waste as a fatliquor in leather processing. *Egyptian Journal of Chemistry*, 60(5), 919-928. <https://doi.org/10.21608/EJCHEM.2017.1161.1059>

Pellizzato, F., Ricci, M., Held, A., & Emons, H. (n.d.). Determination of short-chain chlorinated paraffins by carbon skeleton gas chromatography. European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM). <https://core.ac.uk/download/pdf/38621620.pdf>

SETAC. (2021). SETAC SciCon session summaries – Chlorinated paraffins: State of science, insights, challenges, and the way forward. SETAC Globe. Retrieved August 10, 2021.

Schweizer, S., Schulz, T., & Vetter, W. (2022). A fast gas chromatography coupled with electron capture negative ion mass spectrometry in selected ion monitoring mode screening method for short-chain and medium-chain chlorinated paraffins. *Rapid Communications in Mass Spectrometry*, 36(22), e9382. <https://doi.org/10.1002/rcm.9382>.

Sonnier, R., Taguet, A., Ferry, L. & Lopez-Cuesta, J.M., 2018. Towards Bio-based Flame Retardant Polymers. *SpringerBriefs in Molecular Science: Biobased Polymers*. Springer. Available at: <https://link.springer.com/book/10.1007/978-3-319-67083-6>.

Lauren South, Amandeep Saini, Tom Harner, Shan Niu, J. Mark Parnis, Jacob Mastin, Medium- and long-chain chlorinated paraffins in air: A review of levels, physicochemical properties, and analytical considerations, *Science of The Total Environment*, Volume 843, 2022, 157094, ISSN 0048-9697, <https://doi.org/10.1016/j.scitotenv.2022.157094>

UNEP (2016). Report of the Persistent Organic Pollutants Review Committee on the work of its twelfth meeting Addendum Risk management evaluation on short-chain chlorinated paraffins. UNEP/POPS/POPRC.12/11/Add.3.

UNEP (2019). Guidance on preparing inventories of short-chain chlorinated paraffins (SCCPs) (Detailed guidance). Secretariat of the Basel, Rotterdam and Stockholm conventions, United Nations Environment Programme, Geneva.

UNEP (2024). Report outlining the options for identifying persistent organic pollutants in stockpiles, products and articles in use and in wastes and issues related to the production, import and export of products and articles containing persistent organic pollutants. UNEP/POPS/POPRC.20/INF/9.

Wang, C., Gao, W., Liang, Y., Jiang, Y., Wang, Y., Zhang, Q., & Jiang, G. (2019). Migration of chlorinated paraffins from plastic food packaging into food simulants: Concentrations and differences in congener profiles. *Chemosphere*, 225, 559-566. <https://doi.org/10.1016/j.chemosphere.2019.03.039>

Xia, D., Vaye, O., Lu, R., & Sun, Y. (2021). Resolving mass fractions and congener group patterns of C8–C17 chlorinated paraffins in commercial products: Associations with source characterization. *Science of The Total Environment*, 763, 144701. <https://doi.org/10.1016/j.scitotenv.2020.144701>

Yuan B, Strid A, Darnerud PO, de Wit CA, Nyström J, Bergman Å. (2017) Chlorinated paraffins leaking from hand blenders can lead to significant human exposures. *Environment international*. 109, 73-80.

Zhang, W., Gao, Y., Qin, Y., Wang, M., Wu, J., Li, G., & An, T. (2019). Photochemical degradation kinetics and mechanism of short-chain chlorinated paraffins in aqueous solution: A case of 1-chlorodecane. *Environmental Pollution*, 251, 681-689. <https://doi.org/10.1016/j.envpol.2019.01.065>

Zhang, X., Fan, R., Xu, Y., Gao, Y.-Z., Bizimana, A., Naidoo, A. R., Han, B.-C., & Meng, X.-Z. (2022). Occurrence, distribution and health risk of short-chain chlorinated paraffins (SCCPs) in China: A critical review. *Separations*, 9(208). <https://doi.org/10.3390/separations9080208>