COHIBA

CONTROL OF HAZARDOUS SUBSTANCES IN THE BALTIC SEA REGION

COHIBA GUIDANCE DOCUMENT NO. 8

MEASURES FOR EMISSION REDUCTION OF SHORT CHAIN CHLORINATED PARAFFINS (SCCP) AND MEDIUM CHAIN CHLORINATED PARAFFINS (MCCP) IN THE BALTIC SEA AREA

COHIBA Project Consortium

Deliverable title: COHIBA Guidance Document No.8 for short chain chlorinated paraffins (SCCP) and medium chain chlorinated paraffins (MCCP)

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This Guidance Document was compiled jointly by all listed authors under the leadership of the Federal Environment Agency of Germany (UBA) within Work package 5 of COHIBA project.

Date of submission: December 2011

Electronic format available on:
www.cohiba-project.net/publications

Acknowledgement:
The presented information has been obtained within the framework of the project COHIBA (Control of Hazardous Substances in the Baltic Sea Region), a project coordinated by Finnish Environment Institute SYKE.

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Preface

The Baltic Sea ecosystem is particularly at risk from hazardous substances, due to its natural characteristics, such as slow water exchange, and due to a long history of urbanization and industrialization at the shores and in the catchment area. The ecosystem status of nearly all open-sea and coastal areas of the Baltic Sea is considered to be “disturbed by hazardous substances” (HELCOM 2010). Therefore, HELCOM identified 11 hazardous substances of special concern, amongst them short chain chlorinated paraffins (SCCP) and medium chain chlorinated paraffins (MCCP) and laid down environmental targets in the Baltic Sea Action Plan (BSAP) for a Baltic Sea with life undisturbed by hazardous substances and all fish safe to eat. To achieve the targets of BSAP, measures for emission reduction are needed.

This report analyses and compares different measures for reducing emissions of short chain chlorinated paraffins (SCCP) and medium chain chlorinated paraffins (MCCP) in order to contribute to a knowledge base for decision making. It starts with a review of chemical properties (chapter 2), production and use, emission sources and environmental fate (chapter 3), followed by an overview of existing regulations and an analysis of regulatory gaps (chapter 4). The main part of the report deals with the selection and analysis of emission reduction measures (chapters 5 and 6) and concludes with a comparison of measures (chapter 7) and final conclusions (chapter 8).

This report is part of a series of COHIBA guidance documents, dealing with each of the 11 hazardous substances of special concern to the Baltic Sea as identified by HELCOM. Concerning recommendations for cost-effective strategies for reducing emissions of all 11 hazardous substances, please also refer to the Recommendation Report. This report and other outputs of the COHIBA project are available on the project website (www.cohiba-project.net).

COHIBA

PART FINANCED BY THE EUROPEAN UNION
(EUROPEAN REGIONAL DEVELOPMENT FUND)

Baltic Sea Region
Programme 2007–2013

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1 Introduction to SCCP and MCCP

Short-chain chlorinated paraffins (SCCP) and medium-chain chlorinated paraffins (MCCP) are substances of variable composition, belonging to the group of chlorinated paraffins also known as chloroparaffins or chlorinated alkanes. They are a complex mixture of straight-chain hydrocarbons that have been chlorinated to different degrees. The individual components are made by chlorinating paraffin fractions obtained from petroleum distillation and are classified according to their percentage of chlorination and their carbon-chain length (number of carbons) resulting in the following differentiation: short-chain (C10-13), medium-chain (C14-17) and long-chain (C18-30). The abbreviations for these three groups are SCCP, MCCP and LCCP.

Different chain lengths and percentages of chlorination result in different chemical, physical and biological behavior, making it difficult to capture the whole range of these substances in the different compartments of the environment.

Due to their chemical and physical properties, the substances were used in a wide range of applications as lubricants (e.g. in metal working or the leather industry), flame retardants and softeners (PVC, rubber and textile products) and in sealants, paints and coatings.

Emissions into the environment occur mainly from products containing these substances, e.g. lubricants reaching wastewater during metal working. From coatings, sealants and PVC SCCP can enter the environment via volatilization into the atmosphere.

Due to their low water solubility chlorinated paraffins tend to accumulate in the environment (soil, sediment, and organisms). The shorter the chain length, the higher the aquatic toxicity, the higher the capacity for bioaccumulation and the lower the degradability seem to be. Therefore SCCP are considered as persistent, bioaccumulative and toxic (PBT) substances. MCCP have an eco-toxicity profile similar to that of SCCP. They are also hardly degradable, persistent in the environment and showed a high bioaccumulation factor in fish tests as well as high acute toxicity towards aquatic organisms.

2 Description of Chemical Properties

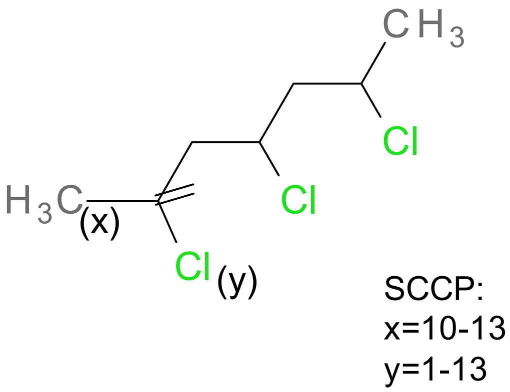


Figure 1: General chemical structure of short-chain chlorinated paraffins (SCCP)

$C_{14}H_{24}Cl_6$ and $C_{17}H_{29}Cl_7$

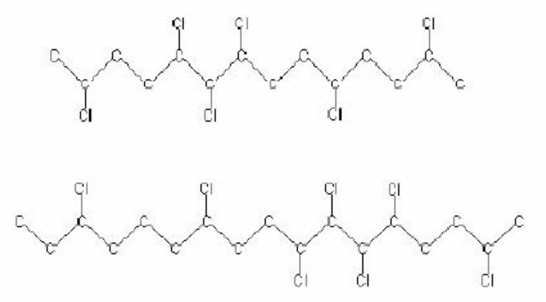


Figure 2: Examples for medium-chain chlorinated paraffins (MCCP)

The physical and chemical properties of the chain chlorinated paraffins are determined by the chlorine content (typically 49-70% for commercial SCCP substances and 40-60% for commercial MCCP substances). Commercial products may contain a wide range of chlorinated paraffins (of different chain lengths, degrees of chlorination and position of the chlorine atoms along the carbon chain). Increasing chlorine leads to an increase in viscosity and a decrease in volatility. The short chain chlorinated paraffins are relatively inert substances, which are resistant to chemical attack and are hydrolytically stable. They are chemically very stable but release detectable quantities of hydrogen chloride when heated to high temperatures (or for prolonged periods). Dehydrochlorination also can occur on prolonged exposure to light.

All chlorinated paraffins have low solubility in water but C10-13 types are significantly more soluble than the other classes which show decreased solubility with increasing chain length. Chlorinated paraffins are capable of mixing with many organic solvents such as aliphatic and aromatic hydrocarbons, chlorinated solvents, ketones and esters.

Studies have confirmed that chlorinated paraffins adsorb strongly onto suspended materials or sediments in an aqueous environment. SCCP has a measured bio-concentration factor in fish of 7.8 l/kg (B and vB) and a 21-day “no observed effect concentration” (NOEC) of 0.005 mg/l with *Daphnia magna* (T) (*EC 2008*).

Table 1: Physical and chemical properties of short and medium chain chlorinated paraffins according to Böhm et al. (2002) quoting Frimmel et al.(2002) and Rippen (2000); PNEC from EC (2008); data for MCCP according to EC (2005)

Property	SCCP (85535-84-8)	MCCP (85535-85-9)
Elemental formula	$C_xH_{2x+2-y}Cl_y$, where x=10-13 and y=1-13	$C_xH_{2x+2-y}Cl_y$, where x=14-17 and y=1-17
Physical state at npt	liquid (solid)	liquid (solid)
Density	1.18-1.59 g/cm^3 (20°C)	1.1-1,35 g/cm^3 (20°C)
Molecular weight (g/mol)	Dependant on chain length and degree of chlorination 320 – 500	Dependant on chain length and degree of chlorination 232-827
Melting point (ºC)	Commercial mixtures have no distinct melting point Melting point ranging from -30.5°C (49% Cl) to 20.5°C (70%)	Commercial mixtures have no distinct melting point Melting point ranging from -45°C to 25°C
Boiling point	Decomposition > 200°C with liberation of hydrogen chloride	Decomposition > 200°C with liberation of hydrogen chloride
Vapor pressure (Pa, at XXºC)	0.3 – 1.4 x10^{-8} Pa at 25°C (51 – 71% Cl, C_{10-13}) 0.021 Pa at 40°C (50% Cl, C_{10-13})	2.27x10^{-3} at 40 °C (for 45% chlorine content) 1.3x10^{-4} at 20 °C (for 52% chlorine content)
Log octanol-water partition coefficient (log K_{ow}, at pH X)	4.39 – 6.93 (49 % Cl, C10-C13) 5.47 – 7.30 (63 % Cl, C10-C13) 5.37 – 8.69 (71 % Cl, C10-C13)	5.52-8.21 (for 45% chlorine content) 5.47-8.01 (for 52% chlorine content)
Water solubility (mg/l at pH X, 20ºC)	6.4 – 2.370 µg/l (51 – 71 % Cl, C10-13) 150-470 µg/l (59% Cl, C10-13)	0.005-0.0027 (for 51% chlorine content)
Henry's Law Constant (Pa m^3/mol, at XXºC)	0.68 - 648 Pa*m3 /mol (C10-C12)	
Biotic and abiotic decomposition	Persistent	
Bioaccumulation	High (bioconcentration factor up to > 100,000)	
Predicted no effect concentration $(PNEC)_{water}$	0.5 µg/l	taken to be 1 µg/l
Predicted no effect concentration $(PNEC)_{microorganisms}$	6 mg/l	NOEC >= 400 mg/kg dry weight

3 Inventory of Inputs to the Baltic Sea

3.1 Production and use

Chlorinated paraffins are manufactured through chlorination of n-paraffin or paraffin wax. No catalysts are necessary in the reaction although visible light is often used to initiate the reaction. The reaction is exothermic and leads to the generation of the by-product hydrochloric acid. Both batch and continuous processes can be used but batch processes are generally preferred since this allows accurate specification of the different grades to be achieved. After removing residual traces of acid, a stabilizer is added to produce finished batches. Short chain length chlorinated paraffins are transported from production sites to the formulators in road tankers and in drums.

The main uses of short chain chlorinated paraffins are as flame retardants in rubbers and textiles, and as plasticizers in paints and coatings. Additionally, short chain chlorinated paraffins may still be in use in sealants and adhesives as these are products with a long service life.

Short chain chlorinated paraffins were also used on a major scale in the formulation of lubricants for metalworking, where they were used in a wide range of machining and engineering operations (Euro Chlor, 2009). However, short chain chlorinated paraffins are no longer used for this application (*EC 2008*).

3.2 Emission sources in the Baltic Sea catchment area

The main sources of emissions of SCCPs in the past were their use in products, which has meanwhile decreased due to regulations, and waste remaining in the environment, which will be a continuing source for the next 10 to 20 years due to the products' lifetime of several years.

For SCCP occurrences in wasted products *ESWI* (*2011*) conducted a prognosis from 2010 to 2020: SCCP stemming from waste from the rubber industry is expected to fall by about 60% from 2010 to 2020, due to reduction of SCCP use in the production of rubber products in the past years. In case of sealants and adhesives it is estimated that "in a best case the waste amount will drop by 50%", and by 75% in the case of paints and varnishes, both due "to the drop of used amounts of SCCP in the last years". For textile industry amounts are expected to remain constant, while "on the other hand it is expected that the waste stream from leather industry will vanish within the next 2 years, considering an average life time of 6 to 12 years".

Sources such as emissions from wastewater treatment plants and sewage sludge are considered to remain constant (*ESWI 2011*), if no measures for emission reduction are enforced.

Table 2: Sources of SCCP and distribution of emissions between compartments in the EU

Source	Emission to wastewater	Emission to water	Emission to air	Emission to land/soil
Production	0.13-27%	-	-	0.04-1%
Use of products	**34-51%**	-	2-4%	-
Waste remaining in the environment	-	6-9%	-	**20-31%**
Emissions from WWTPs to land	-	0.28-1%	-	4-9%
Total	51-61%	7-10%	2-4%	30-34%

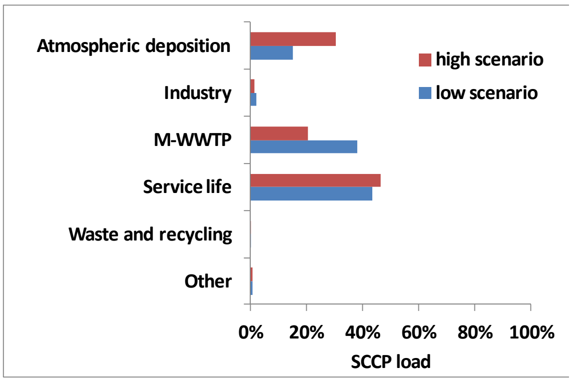
Data based on Andersson (2011) and *EC* (*2008*)

Table 3: Sources of MCCP and distribution of emissions between compartments in the EU

Source	Emission to wastewater	Emission to water	Emission to air	Emission to land/soil
Production of MCCP	4-13%	-	-	-
Use in emulsion based metal cutting fluids	**27-33%**	-	-	-
Use in oil based metal cutting fluids	10-12%	-	-	-
Production of PVC	0.13%	-	5.7-6.9%	-
Release during service life of sealants	1.2-2.9%	-	0.03%	-
Waste remaining in the environment	-	**39%**	-	-
Emissions from WWTP	-	1.16%	-	2.1-2.6%
Total	51-53%	39-40%	5.7-7.0%	2.1-2.6%

Data based on Andersson (2011) and *EC (2005)*

The two main sources of MCCP are the use of MCCP in metal cutting fluids, contributing mainly to MCCP loads in wastewater, and waste (e.g. used products) remaining in the environment, contributing mainly to MCCP loads in water.



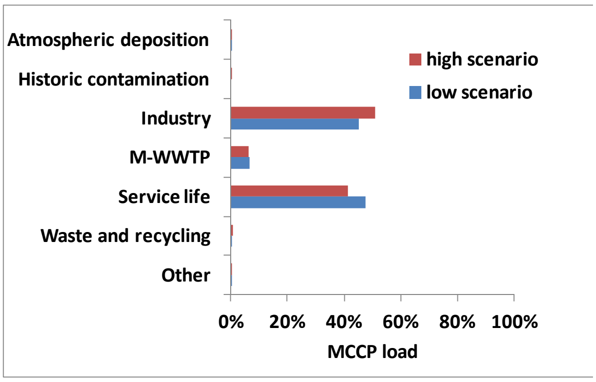


Figure 3: Source specific SCCP loads in the Baltic Sea Area according to COHIBA SFA, according to *Andersson & Pettersson* (*2011*)

Figure 4: Source specific MCCP loads in the Baltic Sea Area according to COHIBA SFA, according to *Andersson & Pettersson* (*2011*)

COHIBA WP4 identified the sources of emissions of SCCP and MCCP to the Baltic Sea, based on substance flow analysis (SFA) and review of literature[1]. An overview of large emission sources to the Baltic Sea and their contribution to the total load of SCCP and MCCP to the Baltic Sea are presented in Figure 3 for SCCP and in Figure 4 for MCCP. The resulting compartment specific loads are presented in Figure 5 and Figure 6 for SCCP and MCCP (Chapter 3.3).

According to the data reviewed by Andersson (2011) the main sources of SCCP in the Baltic Sea area are

- the use of products containing SCCP (emitted during their service life), contributing mainly to SCCP loads into wastewater,
- sewerage, contributing mainly to SCCP loads into surface water bodies (via effluent) and onto land and soil (via sludge and waste remaining in the environment), and
- atmospheric deposition of uncertain origin.

These SCCP-sources are contributing to relevant compartment specific loads into fresh surface water (FSW), forest soil (FS, via atmospheric deposition) and into wastewater (WW).

For MCCP industry and the service life of products are the relevant sources, contributing to relevant loads into wastewater, and onto forest soil.

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1 A full list of possible sources and the reasoning leading to selection of the largest emission sources is presented in Andersson 2011 (ref. SFA report) and in the annex (see Annex on page 36).

3.3 Environmental Fate

Since there is no evidence so far of a natural formation of SCCP, it can be assumed that all existing SCCPs are anthropogenic (*ESWI 2011*). Short chain chlorinated paraffins with low chlorine contents (<50% wt Cl) biodegrade slowly in the environment, particularly in the presence of adapted microorganisms. Certain bacteria have also been shown to dechlorinate short chain chlorinated paraffins with high chlorine contents. Hence, these compounds may also be assumed to biodegrade slowly in the environment (*EU 2000*). No information on the anaerobic biodegradation of short chain chlorinated paraffins has been found.

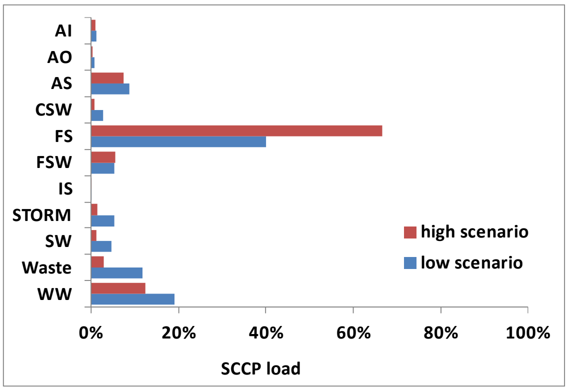

Figure 5: Compartment specific SCCP load in the BSA according to COHIBA SFA

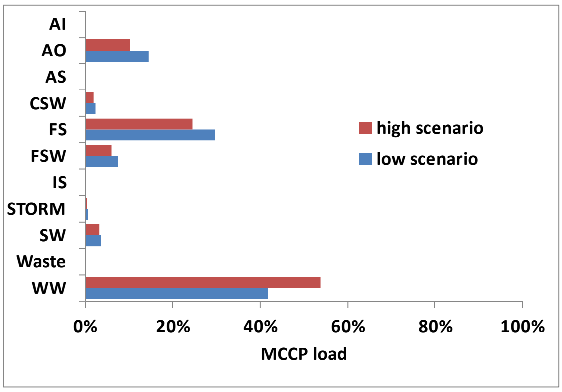

Figure 6: Compartment specific MCCP load in the BSA according to COHIOBA SFA

The potential environmental distribution of short chain chlorinated paraffins has been studied with a generic level III fugacity model. According to the modeling results, once released into the environment, short chain chlorinated paraffins distribute mainly onto the soil and sediment phases. The results also show that if the substance is mainly released to air or water, it is likely that it is then transferred to soil or sediment. This is also indicated by measured levels and the calculated predicted environmental concentrations (PECs). However, it should be noted that since short chain chlorinated paraffins are complex mixtures, individual components of the mixture may have different physico-chemical properties from those used in modeling and that the environmental distribution of those components may be slightly different (*EU 2000*).

Due to their low water solubility as well as the high K_{ow} value, SCCP accumulate in sediments and in sludge. In wastewater treatment plants it is expected that about 90-93% of SCCP ends up in sewage sludge. The remaining 7-10% are expected to pass though a wastewater treatment plant equipped with activated sludge technology (*Bolliger & Randegger-Vollrath 2003*).

There are few measured data on concentrations of short chain chlorinated paraffins in Baltic Sea water. In analyses of water samples from a Lithuanian harbor, short chain chlorinated paraffin concentrations were under the detection limit (< 0.4 µg/l, Dudutyte et al. 2007 reported by *Mehtonen* (*2009*)). On the other hand, according to the modeling results presented above, the sediment (and biota) is a much better environmental compartment to measure than the water phase. Short chain chlorinated paraffin concentrations in fish in the Baltic Sea were lower than the estimated predicted no effect concentrations (PNEC) for the protection of predators such as mammals and predatory birds from secondary poisoning.

Mehtonen (*2009*) refers to a German study which found that medium chain chlorinated paraffin levels were higher than short chain chlorinated paraffin levels in many fish samples from the Baltic Sea (in particular in Kiel Bight). The sum concentrations of short chain chlorinated paraffins and medium chain chlorinated paraffins in fish from the Baltic Sea (90–3170 µg/kg lipid) were comparable to those found for fish in the North Sea (54–3880 µg/kg lipid). The sum concentrations of short chain and medium chain chlorinated paraffins in the livers of cod in the Baltic Sea were considerably higher than in Lofoten and Iceland. Generally, C11 and C12 chlorinated paraffins predominated among the SCCPs detected in fish (*Mehtonen 2009*). Concentrations of short chain and medium chain chlorinated paraffins in Baltic Sea sediment (13–128 and 36–303 µg/kg dw) were higher than in North Sea sediment (18–79 and 54–250 µg/kg dw; in addition, levels in 10 out of 16 samples or sites were below the quantification limit). Generally, C12 and C13 chlorinated paraffins were the main short chain chlorinated paraffin carbon lengths (50–87%) present in the sediment.

In a Swedish screening study, no measurable concentrations, or very low concentrations, of chlorinated paraffins were found in sediment and fish. The measured concentrations in WWTP sludge can be assumed to stem from the use of products containing chlorinated paraffins. Environmental concentrations are so low that chlorinated paraffins cannot be considered to pose any risk to the aquatic environment at present (Swedish Environment Protection Agency, 2006).

4 Existing regulations

Table 4 shows existing regulations for SCCP and MCCP at international, EU, HELCOM and national level.

Short chain chlorinated paraffins have been identified as priority hazardous substances under the EU Environmental Quality Standards (EQS) Directive (2008/105/EC). Additionally, they are a candidate for inclusion in the Stockholm Convention on POPs. Under the REACH Regulation (1907/2006), short chain chlorinated paraffins have been proposed to be added to the list of substances subject to authorization. According to Annex XVII of the same regulation, short chain chlorinate paraffins shall not be placed on the market for use in metalworking or fat liquoring of leather as substances or as constituents of other substances or preparations in concentrations higher than 1%.

Short chain chlorinated paraffins are classified as a dangerous substance within the meaning of Directive 67/548/EEC. The classification is: Category 3 carcinogen: R40, with the symbol Xn; and Dangerous for the Environment, with the symbol N.

Table 4: Existing regulations for SCCP and MCCP (in brackets: date of implementation)

Existing regulations	SCCP	MCCP
International level	*Listed in Annexes I and II of UNECE CLRTAP POPs Protocol (EB Decision 2009/2* *Proposed as candidate for inclusion into the Stockholm Convention (UNEP/POPS/POPRC.2/INF/6)*	-
EU level	*Waste Framework Directive 2008/98/EC /EWC* *REACH Regulation (EC) No 1907/2006* *Marketing and use restrictions, laid down in Annex XVII of REACH Regulation, Directive 76/769/EEC and Directive 2002/45/EC* *SCCP are included in ECHA's current candidate list for inclusion into Annex XIV*	*Some uses restricted by Directive 1996/61/EC*
National level	*Restricted by PARCOM decision 95/1 by BE; DK; FR; FI; DE; IS; IE; LU; NL; NO; PT; ES; SE; CH; UK*	*National restrictions e.g. in Germany and Norway*
Russia	*Discharges to water bodies are banned; banned for discharge from ships, aircraft, man-made islands, plants and facilities in exclusive economic area*	*Ban on discharges to water bodies*

Short chain chlorinated paraffins are assigned the risk phrases: R40 - Possible risk of irreversible effects, and R50/53 - Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

In accordance with Council Regulation (EEC) 793/931 on the evaluation and control of the risks of "existing" substances, a risk assessment was conducted on MCCP, leading to *EC* (*2005*). According to *EC* (*2005*) and (*Groß et al. 2008*) a number of uses of medium-chain chlorinated paraffins are covered under the Integrated Pollution Prevention and Control Directive (Directive 1996/61/EC), which should include production of medium-chain chlorinated paraffins, metal working, some PVC and plastics compounding/conversion sites and leather processing sites.

Additionally, some countries have national legislation covering the use of MCCP containing products. In Germany, chlorinated paraffin-containing wastes, e.g. metal working fluids with >2 g halogen/kg and halogen-containing plasticizers, are classified as potentially hazardous waste and are incinerated (BUA 1992). In Norway, medium-chain chlorinated paraffins are included in the national 'List of Priority Substances' for which emissions are to be substantially reduced by 2010 at the latest (Entec, 2004). And in the UK, the MCCPs user forum was formed in 2001 by users and suppliers targeting a voluntary agreement on the reduction of risks to the UK environment from MCCPs, especially a reduction in emissions.

Toropovs (*2011*) reported about the legal situation regarding SCCP and MCCP in Russia: There, "discharges (...) are banned to water bodies, however no restrictions exist for import, production or use of these substances". Besides that "SCCPs were banned for discharge from ships, aircrafts, man-made islands, plants and facilities in exclusive economic area of Russia (Baltic Sea)" in 2000. "Their use in different processes or materials as such is not restricted".

5 Measures for Emission Reduction

5.1 Evaluation methodology

In order to identify appropriate measures for reducing emissions of hazardous substances to the Baltic Sea a pragmatic approach is applied. In view of the multitude of possible sources and measures, source-measure combinations promising a large reduction potential are pre-selected. For the identification of large reduction potentials two criteria are considered: firstly the load at the source and secondly the effectiveness of the applied measure (chapter 5.2).

In a second step these pre-selected measures are analyzed in detail and compared (chapters 6 and 7). If appropriate data on effectiveness and costs are available a quantitative assessment of the cost-effectiveness of measures is performed by using the following evaluation criteria:

Effectiveness

The effectiveness of a measure at a given source relates to the reduction it achieves in the emissions of a given hazardous substance. The effectiveness of technical measures is usually expressed as elimination rate in percent. In combination with the load of the respective source, the effectiveness can be expressed as load reduction in kilograms.

Costs

The evaluation of costs is subdivided in direct costs and running costs. Whilst direct costs include initial expenditures (e.g. construction costs, investment costs, costs for developing a substitute, rule making costs), running costs comprise ongoing expenditures (e.g. operation and maintenance costs, (additional) costs for using a substitute, costs for implementation and enforcement). In order to adapt the costs to local circumstances, they are further broken down into costs for labor, energy and material, if data are available.

Cost-Effectiveness Analysis

The cost effectiveness of different measures is expressed by the ratio of cost to the reduced load of hazardous substances. As there are large uncertainties, different scenarios – a worst case scenario (low load reduction effectiveness – high costs) and best case scenario (high load reduction effectiveness – low costs) - are used for the calculation of cost effectiveness.

The quantitative assessment is complemented by a comprehensive qualitative evaluation to include sustainability aspects, which is mainly based on experts' estimates rather than on empirical data. For this additional assessment the following qualitative evaluation parameters are used:

Secondary environmental effects

Besides the direct effects on emissions of the targeted hazardous substance, measures can have a wide array of positive or negative secondary environmental effects (e.g. effects on emission reduction of other hazardous substances or nutrients, effects on waste production which requires deposition on landfills, effects on climate change through energy consumption or effects on land use).

Technical feasibility

The technical feasibility describes the ease of technical implementation of the respective measure under different boundary conditions. This touches on aspects like practical experiences (emerging, pilot or existing technology), necessary process modifications, or impact on ongoing processes. These can present limitations for the application of the respective measure. One indicator of technical feasibility is e.g. the time needed for (technical) implementation of the measure.

Secondary socio-economic effects

Besides the primary costs of a measure, there are also secondary socio-economic effects (including indirect costs) of a measure. Possible secondary socio-economic effects of a measure include indirect costs, effects on employment, on job qualification (e.g. qualification needed for operation and maintenance of advanced technologies) and on product prices including the question whether industries pass on higher costs to consumers. An important aspect is which stakeholders are affected, who pays for the measures and who benefits from them.

Geographical and time scale of effects

Another additional parameter to describe measures is the geographical and time scale of effects. Some measures are effective on a local or watershed level and other measures show effects on a national or international level. The time scale of effects varies from immediate effects to long lag times until the measure becomes effective (e.g. varying time spans of effects due to different technical lifetimes for certain measures).

Political enforceability

The political enforceability of measures depends on how well the measure is aligned with other political targets, on the national financial scopes (e.g. compensation payments), on possible conflicting interests and on their acceptance by existing interest groups. The political enforceability is also influenced by the other parameters, such as effectiveness, costs, technical feasibility and secondary environmental and socio-economic effects.

5.2 Overview of measures

Due to the chemical properties of SCCP and MCCP a range of measures can be effective for reducing SCCP and MCCP emissions into the environment of the Baltic Sea area. Measures range from measures for source control, regulatory, economic and financial measures, to voluntary agreements and end-of-pipe measures. A variety of possible measures is listed in Table 8 in the annex (A). However, some measures, such as the core measure 'mechanical and biological waste water treatment', are only the prerequisite for subsequent measures, such as advanced wastewater treatment and controlled sludge treatment, since SCCP and MCCP adsorbing on sludge generated in these core measures.

Relevant measures are measures that are effective and that target relevant sources. Therefore, based on the figures in chapter 3 (see Table 2 and Figure 3) the most relevant measures for SCCP are:

- Controlled waste management, targeting waste remaining in the environment as the dominant source, contributing to emissions to water and to land/soil
- Advanced waste water treatment, targeting emissions in wastewater from use of products
- Additional ("minor") measures for SCCP control:
  - Sludge treatment, due to some emissions from wastewater treatment plants to land via sludge application
  - Ban on and substitution of SCCP in the remaining areas of application.

Based on the figures in chapter 3.2 (see Table 3 and Figure 4) the most relevant measures for MCCP control are:

- Ban/restriction/regulation of MCCP for usage in emulsion and oil based metal cutting fluids, since this use contributes significantly to total emissions (relevant source for emissions to wastewater)
- Proper waste handling / management and treatment, since waste in the environment seems to be a significant source of emissions into the environment
- Advanced waste water treatment would also be an important measure in addition to the above restrictions which would show results only many years from now.
- Possible additional measures are: Regulating use of MCCP in PVC products (rather minor source), and sludge treatment.

For the three main sources of SCCP and MCCP emissions (products, wastewater, waste) selected measures for emission reduction are displayed in Table 5 and described and evaluated in chapter 6.

Table 5: Overview of analyzed measures and relevant sources for SCCP and MCCP

No.	Measures	Relevant sources
1, 2	Ban or/restriction of SCCP & MCCP; Substitution of SCCP & MCCP	SCCP/MCCP-containing products
3, 4, 5	Advanced waste water treatment: - activated carbon (AC) treatment - membrane filtration - oxidative techniques	Household / municipal waste water & industrial waste water
6	Sludge treatment - controlled incineration	
7	Waste management – controlled landfilling / controlled incineration	Waste

6 Description and Analysis of Measures

6.1 Ban of SCCP in remaining areas of application Ban/restriction of MCCP for usage in emulsion and oil based metal cutting fluids

6.1.1 Description of source

To avoid production, use and waste of products containing SCCP and MCCP, the use of MCCP in emulsion and oil based metal cutting fluids should be regulated, and regulatory measures on SCCP could be extended to processes where the use of SCCP has not been restricted so far.

6.1.2 Description of measure

The European Parliament has called for an extension of the ban on the use of SCCP in metal-working and leather processing applications to cover all applications, including use as a plasticizer in paints and coatings and flame retardants in rubber, plastics and textiles (*Kesteven 2002*), similar to the PARCOM phasing-out decision (1995) which is already being applied by several European countries (see Table 4).

Since MCCP have not been restricted so far, and since emissions from industry contribute to a large extent to the total load to the Baltic Sea area, the usage of MCCP in emulsion and oil based metal cutting fluids should be restricted, since this application is one of the main contributors to total emissions from industry.

6.1.3 Effectiveness

Regulations and even voluntary approaches that affected the main uses of SCCP have already been effective in the past. Sales in the EU decreased significantly over the years, as can be seen in Figure 7.

However, the effectiveness of regulations is limited if applied only to restricted regions (e.g. EU27). Products containing SCCP and/or MCCP can be produced outside these regions and imported (as long as import of SCCP/MCCP containing products itself is not restricted).

The production of SCCP is one good example of the limitations of regional restrictions: While the production of SCCP in EU27 has meanwhile decreased, it is reported that CPs of various chain lengths are produced in the USA, Russia, India, China, Japan and Brazil (*ESWI 2011*). For example, *Jabr* (*2011*) reports that China increased its production of SCCP by a factor of 30 within the last 20 years. And although Europe has restricted use of SCCPs, their manufacture is growing in China and possibly in India, raising concerns that world-wide exposure levels for people and wildlife might be increasing (*Jabr 2011*).

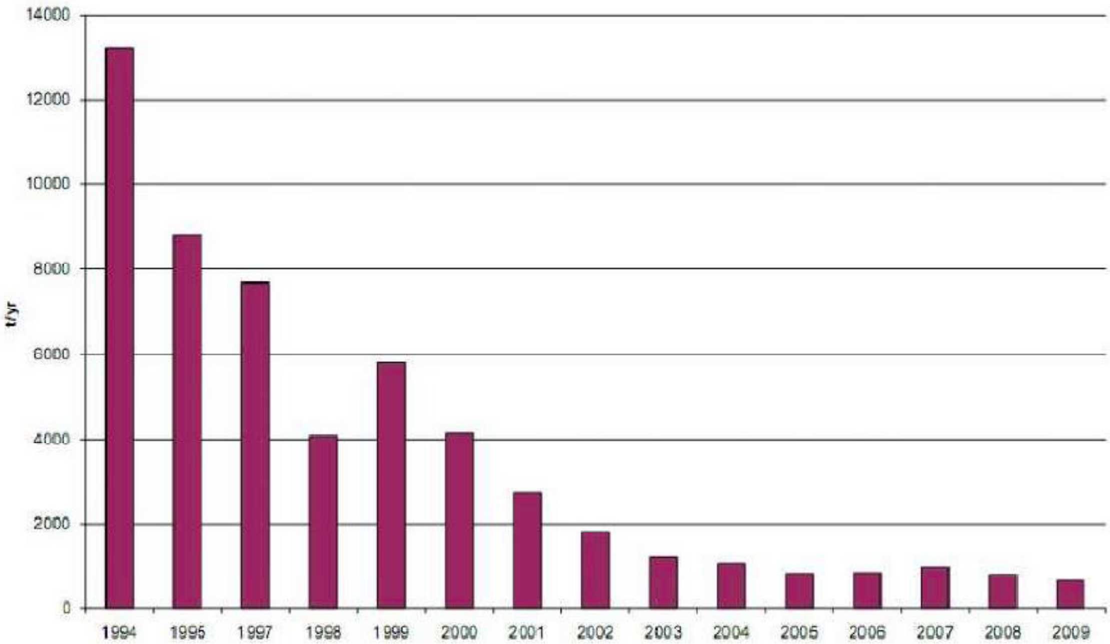

Figure 7: Total annual sales of SCCP in the EU 1994-2009, EU15 in 1994/2003, EU25 in 2004/2006, EU27 in 2007/2009; data provided by Eurochlor (*ESWI 2011*)

6.1.4 Costs

Costs generated will mainly be costs for substitutions for SCCP and MCCP and/or costs for product redesign to avoid use of SCCP and MCCP.

6.1.5 Secondary environmental effects

None, since this measure is substance specific.

6.1.6 Geographical and time scale of effects

As can be seen in Figure 7, regulatory and voluntary measures can lead to substantial reductions in occurrence of SCCP and MCCP over ten years. However, some of the SCCP and MCCP containing products might be in storage for several years. Additionally products such as conveyor belts have lifetimes of 12-22 years (*ESWI 2011*). Rubber products other than conveyor belts have an average lifetime of about 7.5 years. Therefore reductions of SCCP emissions into the environment can probably be measured with a delay of about 20-30 years.

6.1.7 Political enforceability

National or regional regulations can be effective for individual installations.

6.1.8 Cost-effectiveness analysis

Since the costs incurred will mainly be costs for substitutions for SCCP and MCCP and/or costs for product redesign to avoid the use of SCCP and MCCP the cost effectiveness of a ban on SCCP and MCCP depends on the costs for substitution. However, these cannot be stated in general (see chapter 0).

Substitution of SCCP in rubber products and substitution of MCCP in emulsion and oil based metal cutting fluids

6.1.9 Description of source

SCCP and MCCP are used in the rubber industry, in sealants and adhesives, paints and varnishes and in the textile industry due to their softening and flame retardant abilities. In metalworking MCCP are used as a replacement for SCCP due to their lubricating ability and as replacement for SCCP as fat liquors in leather processing.

6.1.10 Description of measure

To render products non-flammable in functions where this is required, flame retardants can be added to the material (as is the case with SCCP and MCCP in rubbers and textiles) or the product can be constructed in a way physically hindering flammability. Similar substitutions have to be found for the other areas of usage: plasticizer in paints and coatings, and in sealants and adhesives, and for lubrication in metal working and fat liquoring in leather processing.

<u>Metal working</u>

Since MCCP have similar characteristics to SCCP, they are used as replacements for SCCP e.g. as extreme pressure additives in metalworking fluids, as plasticizers in paints, and as additives in sealants (OSPAR 2001). However, MCCP are considered as hazardous substance of special concern to the Baltic Sea as well and can therefore not be recommended as substitute for SCCP. In Sweden, long chain chlorinated paraffins (LCCPs) have been used in some demanding applications in metalworking fluids instead of SCCPs. LCCPs have also been suggested as a replacement for SCCPs in the leather industry as well as in paints and coatings, in sealants and rubber (OSPAR 2001). Nevertheless also LCCP cannot be recommended as substitutes for SCCP or MCCP, because the environmental behavior (non or little biodegradable, liability to bioaccumulation, persistent) of LCCP is partially similar to MCCP and SCCP.

Additionally other substitutes are available. For example, alkyl phosphate esters and sulfonated fatty acid esters may function as replacements for SCCPs as extreme pressure additives in metalworking fluids (*Böhm 2003*; *OSPAR 2001*).

Leather industry, paint and coatings, sealants

For the leather industry natural animal and vegetable oils can be used as alternatives to SCCP and MCCP containing fat liquors. In paints and coatings, phthalate esters, polyacrylic esters, diisobutyrate as well as phosphate and boron-containing compounds are suggested as replacements. Phthalates esters can be used as alternatives for use in sealants (OSPAR 2001).

Flame retardants

Alternatives as flame retardant in rubber, textiles and PVC are antimony trioxide, aluminum hydroxide, acrylic polymers and phosphate containing compounds. Sweden considers these substances as being less harmful than chlorinated paraffins. (OSPAR 2001)

Summary of alternatives

A summary of information on possible alternatives to SCCP is given in *BRE et al.* (*2008*) and listed in the Appendix in Table 9. However, the substances MCCP and HBCDD suggested in this publication are considered to be hazardous substances of special concern to the Baltic Sea within the COHIBA project. Therefore, they cannot be recommended as substitutes. Fate and behavior of LCCP are so far not sufficiently evaluated but can be assumed to be similar to SCCP and MCCP. Therefore, LCCP can also not be recommended as substitutes at this point of time. Additionally there might still be uses for which these alternatives do not fulfill all technical and safety demands.

6.1.11 Effectiveness

Experience with avoiding SCCP and , partly, MCCP is available from several European countries that followed PARCOM decision 95/1 (see *Böhm* (*2003*) and *Bolliger & Randegger-Vollrath* (*2003*).

Substitutes such as e.g. sulfur based additives are available and often equally efficient as CP-based products (lubricants etc.). However, according to *Böhm* (*2003*) their suitability to serve as replacement is highly dependent on process conditions (temperature, friction, viscosity, process velocity).

6.1.12 Costs

The costs of some additives substituting SCCP and MCCP are in a comparable range (e.g. sulfur containing additives). However, additional costs can be incurred. Therefore final costs depend on the individual case and may vary. General information on costs cannot be given, neither now nor in the past (*e.g. by Böhm 2003*).

6.1.13 Secondary environmental effects

Due to the multitude of substitutes for the different uses in which SCCP and MCCP are to be replaced, a general statement regarding secondary environmental effects cannot be made.

Some of the substitutes are toxic as well or are ecologically problematic. Biodegradability is dependent upon the substitute's structure. According to an evaluation of different material safety data sheets (MSDSs) by *Böhm* (*2003*) biodegradation is possible for some products, however, for most products biodegradation is rather poor. General statements regarding toxic effects on aquatic organisms or bioaccumulation factors of substitutes cannot be made, based on MSDSs.

Additional information on the substitutes' behavior in the environment and on their degradability, generated in OECD standard tests, needs to be collected from the suppliers.

6.1.14 Technical feasibility

CPs can be substituted in nearly all of their applications. In quite a few European countries (including Germany and Switzerland) CPs have been replaced in most applications.

While CPs are generally applicable in a wide range of applications, for substitutes the specific boundary conditions and technical requirements have to be evaluated more thoroughly. From the large variety of potential substitutes the right components have to be chosen for each individual process. As *Böhm* (*2003*) stated: detailed experience is already available from some sectors of industry and can be transferred to other industrial areas (e.g. from automotive industry to other metal working industries).

A number of possible advantages (ecological and in terms of human health) which substitutes may have over CPs could not be evaluated by *Böhm* (*2003*) on the basis of available MSDSs.

6.1.15 Secondary socio-economic effects

Unknown

6.1.16 Geographical and time scale of effects

After development time, the measure becomes effective in reducing emissions of SCCP and MCCP (after replacement with substitute, emissions of substitute are possible). According to industry, innovation cycles may take up to 15 years. However, for most applications experiences are already available.

6.1.17 Political enforceability

Substitution of SCCP and MCCP is possible in most applications and has already been completed in some European countries due to political enforcement.

6.1.18 Cost-effectiveness analysis

Due to the wide range of applications where SCCP and MCCP have to be substituted, and due to the even wider variety of substitutes, a general statement cannot be made.

6.2 Advanced waste water treatment – AC treatment

6.2.1 Description of source

The kinds and loads of pollutants in waste water vary greatly between different cities/districts/MWWTPs, and can also vary markedly in time. Therefore, predicting what kinds and loads of pollutants are treated at MWWTPs has a very high uncertainty.

6.2.2 Description of measure

A prerequisite for advanced wastewater treatment and also for sludge treatment (see chapter 6.5) is mechanical and biological wastewater treatment because in this treatment SCCP and MCCP accumulates in sludge which then has to be further treated. It is expected that about 90-93% of SCCP and even more of MCCP ends up in sewage sludge. The remaining 7-10% are expected to pass through the wastewater treatment plant and have to be treated by advanced wastewater treatment steps, such as activated carbon (see chapter 6.2), membrane filtration (see chapter 6.3), and oxidative techniques (see chapter 6.4), in cases where relevant loads are emitted. Membrane technology, but also filtration methods using activated carbon are able to improve the elimination rates of municipal wastewater treatment plants with regard to various priority substances (Hillenbrand et al. 2007).

Activated Carbon (AC) filters (AC) are a proven technology for removal of pollutants from wastewater. AC has a large surface area and is an effective sorbant for many substances. Different technical systems are commercially available (e.g. powder (PAC) and granular activated carbon (GAC)).

6.2.3 Effectiveness

Advanced wastewater treatment steps will most likely have a positive effect on the reduction of SCCP and MCCP emissions. However, data are scarce.

The effectiveness of AC filters at MWWTPs for elimination of pollutants depends on the concentration range of the pollutant, technical parameters and the matrix. Spent activated carbon with adsorbed SCCP and MCCP has to be incinerated (LANUV 2008).

The measure has major cross substance effects, e.g. removal of TBT, PFOS, nonylphenol, Cd, Hg and other pollutants.

6.2.4 Costs

Economic analysis in the “Strategie MicroPoll” project (Switzerland) found costs of EUR 10-60 per person and year, including discounted investment costs and running costs (*Sterkele & Gujer 2009*). Specific costs are strongly dependent on the size of the MWWTP (large WWTPs show low specific costs, economies of scale).

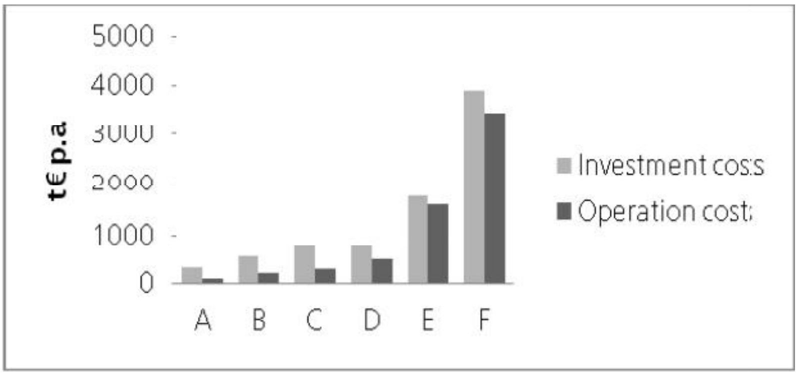

Figure 1: Yearly investment costs and running costs, economic data from Rosenstiel & Ort (2008)

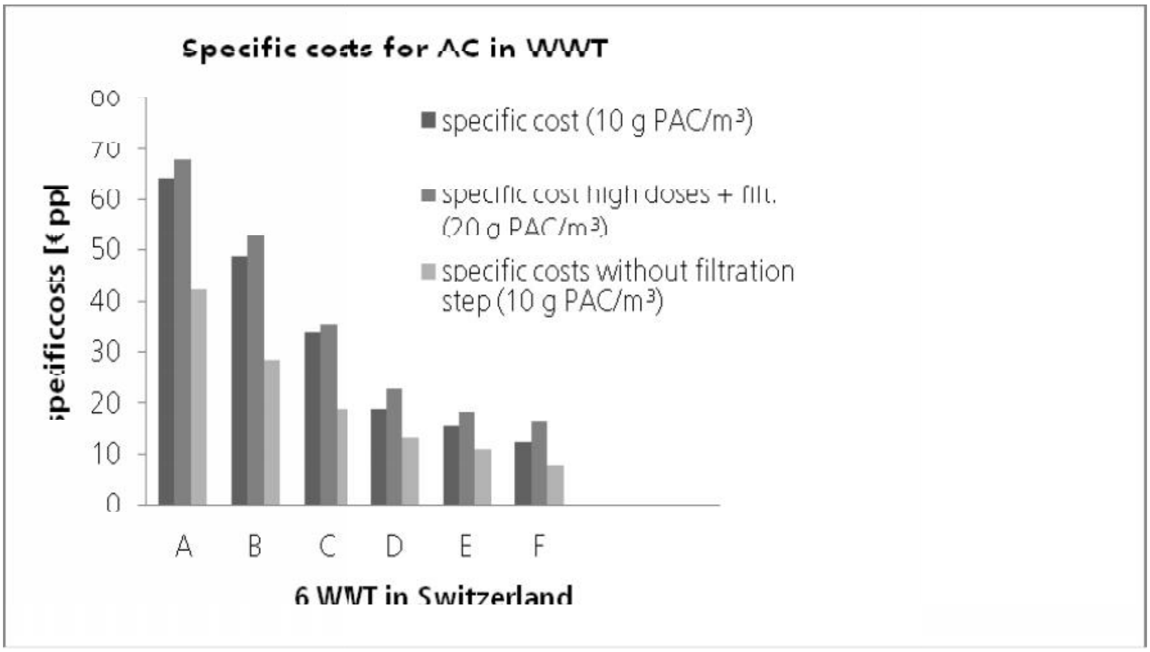

Figure 2: Specific costs per person in 6 MWWTPs in Switzerland, economic data from *Rosenstiel & Ort (2008)*

6.2.5 Secondary environmental effects

AC filtration at MWWTPs, which is sometimes called the 4th stage of waste water treatment, affects emissions of all HS of special concern to the Baltic Sea, which are typically present in municipal waste water in low concentrations. It also has potentially large positive water related secondary environmental effects: on phosphate emissions and on other pollutants, such as heavy metals, organic micropollutants (which are not on the HELCOM list), pharmaceuticals and their metabolites, or endocrine disrupters. Negative secondary environmental effects are related to e.g. energy use and GHG emissions during construction and operation, and for manufacture of activated carbon (*Wenzel et al. 2008*).

6.2.6 Technical feasibility

- Proven technology
- Effectiveness depends on matrix (e.g. COD, other micropollutants), concentration of sorbent, bed exchange rate
- Filter material contains HS and must be handled accordingly (e.g. incinerated, not included in example calculation)

Limitations: The technical prerequisite is a well-functioning MWWT with low concentrations of suspended solids and dissolved organics (BOD and COD), skilled personnel required for O&M (but not different from O&M of large MWWTPs), handling of wastes.

6.2.7 Secondary socio-economic effects (including indirect costs)

If large MWWTPs are equipped with a "4th stage", the question is who pays for it. One option is that the respective MWWTPs charge the costs to their clients. Large MWWTPs often have lower per capita costs than smaller MWWTPs.

The other option is to have the costs paid for by all citizens (via taxes), as the whole community benefits from a toxfree environment. The latter option was put into practice in Switzerland (total costs of waste water treatment rose by 6%). A very good option, but hard to put into practice, is to tax production *and* use of products containing hazardous substances. This would follow the polluter pays principle.

6.2.8 Geographical and time scale of effects

This measure becomes effective immediately and has a technical life span of 80 years for built infrastructure. It seems sensible to target large plants because of economies of scale effects, which are usually located near large settlements. In the context of the projects, MWWTPs near the shore can be interesting targets.

6.2.9 Political enforceability

In Switzerland AC treatment has been mandatory for large MWWTPs since 2010.

6.2.10 Cost-effectiveness analysis

From detected concentrations of SCCP and MCCP in the effluent and sludge of wastewater treatment plants two scenarios are derived for each:

- low SCCP load in regular effluent: 16 mg/cap*a
- high SCCP load in regular effluent: 113 mg/cap*a
- low SCCP load in regular sludge: 13 mg/cap*a
- high SCCP load in regular sludge: 42 mg/cap*a
- low MCCP load in regular effluent: 79 mg/cap*a
- high MCCP load in regular effluent: 612 mg/cap*a
- low MCCP load in regular sludge: no data available
- high MCCP load in regular sludge: no data available

The effectiveness of AC filters in removing SCCP and MCCP from municipal waste water is assumed to be high with 90-99%. Results of *Nielsen et al.* (*2011*) support this assumption.

Costs are assumed to be between 15 to 20 €/cap*a for a MWWTP with 500 000 p.e., based on a cost study from Switzerland[2].

The costs for removing SCCP by activated carbon filtration as a fourth step in a MWWTP would vary within a range of 0.13-1.67 Mio. €/kg removed product, and between 0.02-0.34 Mio. €/kg removed product for MCCP.

6.3 Advanced waste water treatment - membrane filtration

6.3.1 Description of source

See chapter 6.2.1.

6.3.2 Description of measure

Membrane technology is a physical separation process which filters out particles of varying size depending on the size of the pores of the membrane. Corresponding to the separation dimensions, a distinction is made between micro-, ultra- and nanofiltration and reverse osmosis. In industry, membrane technology is already used on a large scale to separate substances as well as to treat wastewater. It has only been used in municipal sewage treatment for a few years; the first large-scale plant was put into operation in Germany in 1999 (WWTP Rödingen) (*Hillenbrand et al. 2007*). Table 10 in the appendix shows several plants operated in Europe.

Membrane technology can be applied at two points: integrated into the activated stage to substitute conventional final clarification for separating the activated sludge (membrane activated sludge process), or downstream from conventional final clarification for advanced treatment of the effluent.

Micro- or ultra-filtration membranes are often used in membrane separation activated sludge processes. According to information from the *DWA-Fachausschuss KA-7* (*2005*), the maximum separation limit is 0.4 µm, but modules are sometimes used with a pore size as small as 0.04 µm (*Vossenkaul 2005*).

The most important reason for using membranes downstream from a conventional sewage plant is usually the obvious improvement in effluent quality (*Lange et al. 2006*). Pollutants,

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2 detailed cost study from Swiss project Strategy MicroPoll (discounted at 30 years); a factor of 0.69 was applied for conversion of SFr to EUR?

micro organisms and even viruses can be retained to the extent that they are attached to larger particles.

6.3.3 Effectiveness

Reliable data regarding effectiveness of membrane filtration for removal of SCCP and MCCP are not available but it is assumed that retention rates are in a range of 75-99%.

6.3.4 Costs

The membranes themselves account for a large share of the total investment. However, there has been a clear drop in costs in the last few years due to learning and economies of scale effects (*Hillenbrand & Hiessl 2006*), and costs can be expected to drop further in the future. Technical simplifications are also expected regarding the mechanical equipment and its incorporation into the total system (*DWA-Fachausschuss KA-7* (*2005*) cited in *Hillenbrand et al.* (*2007*)).

The costs of the membrane play a significant role since the service life of the membrane is generally much shorter than the depreciable life of the machine technology. Attempts are being made to reduce the costs of replacing membranes by both lowering the specific membrane costs and lengthening the service period (target: 7 to 10 years). Energy costs (specific total energy consumption approx. 0.8 to 1.6 kWh/m³, sometimes even up to 2.0 kWh/m³, compared to 0.3 to 0.5 kWh/m³ in conventional systems without water disinfection; (*DWA-Fachausschuss KA-7* (*2005*) and *Krampe & Laufer* (*2005*), both cited in *Hillenbrand et al.* (*2007*); (*Lange et al. 2006*; *Wedi 2005*)), and the costs for needed chemicals also make up a significant part of the operating costs. Table 6 gives an overview of the various cost shares of membrane activated sludge systems which illustrates that the cost for replacing the membrane is of overriding significance. A comparison of operating costs based on quotes showed operating costs of 0.24 to 0.25 €/m³ for the largest currently operated municipal membrane activated sludge plant (KA Nordkanal) which is approx. 15 % higher than the conventional solution (0.20 to 0.22 €/m³, *Engelhardt* (*2002*)).

Table 6: Overview of the various cost shares of activated membrane plants (*DWA-Fachausschuss KA-7* (*2005*) cited in *Hillenbrand et al.* (*2007*))

		Costs [Ct/m³]	**Category*1)**
Crossflow aeration	0.20 – 0.75 kWh/m³	2.0 – 7.5	O
Permeate/recirculation	0,08 – 0.10 kWh/m³	0.8 – 1.0	O
Additional aeration demand	0.08 – 0.10 kWh/m³	0.8 – 1.0	O
Chemicals	0.20 – 1.10 €/m² a	0.3 – 1.8	O
Membrane replacement	10 – 5 a	13.3 – 26.6	C

*1): O = operating costs; C = capacity cost

Electricity: 10 Ct/kWh; resultant sewage 90 m³/(resident ● a), spec. membrane area: 1.5 m²/resident, usual market costs for H_2O_2, acids and bases, membrane costs 80 €/m²

The costs of introducing a downstream membrane stage are between 0.25 €/m³ and 0.42 €/m³ filtrate, according to results of pilot studies (*Dittrich et al. 1998*). First estimates put the costs of activated carbon treatment including grit filtration at about 10 cents per m³ or at 6 cents if a grit filter is already fitted (*Neifer & Krampe 2006*).

6.3.5 Secondary environmental effects

See chapter 6.2.5. Additionally, membrane separation activated sludge treatment has operational advantages compared with conventional sewage plants since higher concentrations of dry solids can be suspended in the aeration tanks and thus higher concentrations of micro organisms. As a result, not only does the conventional final sedimentation stage become superfluous, but the activated stage can also be scaled down.

6.3.6 Technical feasibility

In Germany, experience has only been gained with a few large-scale systems. According to (*Lange et al. 2006*), 3 plants are currently in operation – partly in research and development projects (Geiselbullach, Merklingen, and Bondorf-Hailfingen).

6.3.7 Secondary socio-economic effects

For general effects see chapter 6.2.7.

The particular advantages of the membrane method of wastewater treatment are

- complete retention of solids and, as a result, an improved effluent quality with respect to the parameters COD and BSB_5; hygienic effluent (i. e. filtration and decontamination system in one stage); effluent quality not affected by floating sludge, bulking sludge or foam formation (improvement of operational reliability),
- the demands made on advanced wastewater treatment concerning the protection of water and groundwater can be fulfilled because of the high purification capacity (e. g. lower pollutant concentrations, avoidance of floating sludge),
- the plants are easy to expand because of their modular , and they can be used in both large, municipal wastewater treatment plants and small, decentralized ones.

Drawbacks include

- the higher operating costs caused by higher energy costs and higher costs for maintenance of the membrane modules,
- the more complex preliminary mechanical treatment necessary to protect the membrane,
- the additional demands made on process control as well as
- the greater sensitivity of the membrane to shock loads.

(*DWA-Fachausschuss KA-7 2005*; *MUNLV 2003*)

Particulates are largely removed in accordance with the functional principle of membrane technology. This also removes any pollutants adhering to these particles. For example, heavy metals or PAHs show a high adsorption tendency. *Böhm et al.* (*2002*) estimated that membrane filtration can remove an additional 30 to 70% of heavy metals present in waste water. However, so far, there are little detailed studies available on the additional elimination capacity of membrane technology in municipal sewage plants. But in principle, activated sludge plants with membrane filtration can also improve the elimination of organic, non-readily degradable pollutants. This is achieved because the biocenosis which is formed in a plant with a high sludge age is better adapted to pollutants present in low concentrations. This aspect is being examined especially in connection with the emissions of endocrine substances from municipal sewage plants (*Hegemann et al. 2002*; *Schiewer et al. 2001*; *Schröder 2003*).

Besides the retention of priority pollutants, other additional water-relevant effects should be noted which may be of relevance within the scope of a comprehensive river basin management:

- wastewater disinfection (especially relevant if the water continues to be used, e. g. for recreational purposes),
- almost complete removal of particulate substances and the phosphorus bound to them (the reduction of particulates in wastewater also decreases the formation of sludge and sediment in the water, i e. improvement of natural habitats),
- improved degradability of organic trace elements when using membrane biology, corresponding at least to the share adsorbed by particulates, and
- possible further use of the purified wastewater as service or process water.

Additionally, membrane separation technology has the advantage over water disinfection using ultraviolet treatment, ozonization or chlorination that no unwanted by-products are formed.

6.3.8 Geographical and time scale of effects

See chapter 6.2.8.

6.3.9 Political enforceability

To enforce the use of membrane technology in wastewater treatment specific water protection requirements can be taken into account when issuing plant permits (*Hillenbrand et al. 2007*). Subsequent utilization requirements (bathing water, other recreational activities) also should be considered.

6.3.10 Cost-effectiveness analysis

Compared with conventional municipal sewage plants, activated sludge treatment with membranes greatly improves effluent outlet qualities (see Appendix Table 11). The additional investments required for this consist of the actual membrane itself, more powerful aeration, chemical and dosing systems as well as more complex mechanical preliminary treatment. These costs are set against the savings that arise when the membrane treatment eliminates the need for the final clarification stage and part of the aeration tank volume – because higher solid concentrations are possible in the activated stage. In addition, membrane separation activated sludge treatment may be advantageous in terms of the simplified possibilities for sludge stabilization as well as the reduced space required. As a consequence additional investments for implementation of this step might be balanced, depending on the given local conditions (*Lange et al. 2006*; *Wedi 2005*).

Based on the estimated loads in chapter 6.2.10, an assumed effectiveness of membrane filtration of 75-95%, and estimated costs between 25 to 42 €/cap*a, the costs for removing SCCP by membrane filtration as a fourth step in a MWWTP would vary in a range of 0.23-3.50 Mio. €/kg removed product, and between 0.04-0.71 Mio. €/kg removed product for MCCP.

6.4 Advanced waste water treatment - oxidative techniques

6.4.1 Description of source

See chapter 6.2.1.

6.4.2 Description of measure

Different oxidative techniques are available, e.g. ozonation, radiation by UV light. Long chain molecules are attacked and oxidized either directly by very reactive ozone molecules or indirectly by radicals generated by the process.

6.4.3 Effectiveness

Reliable data regarding the effectiveness of oxidative techniques for removal of SCCP and MCCP are scarce.

6.4.4 Costs

Reliable data regarding the costs of oxidative techniques for removal of SCCP and MCCP are not available.

6.4.5 Secondary environmental effects

See chapter 6.2.5.

Due to the presence of chlorine in SCCP and MCCP AOX could form. However, reliable data are not available.

6.4.6 Technical feasibility

Reliable data regarding the technical feasibility of oxidative techniques for removal of SCCP and MCCP are not available.

6.4.7 Secondary socio-economic effects

See chapter 6.2.7.

6.4.8 Geographical and time scale of effects

See chapter 6.2.8.

6.4.9 Political enforceability

To enforce the use of oxidative techniques in wastewater treatment specific water protection requirements can be taken into account when issuing plant permits (*Hillenbrand et al. 2007*). Subsequent utilization requirements (bathing water, other recreational activities) also have to be considered.

6.4.10 Cost-effectiveness analysis

Since reliable data are not available, neither on costs nor on effectiveness, a cost-effectiveness analysis cannot be conducted at present.

6.5 Sludge treatment - Controlled incineration

6.5.1 Description of source

It is expected that about 90% to 93% of SCCP and MCCP is adsorbed on sewage sludge and the rest stays in the water phase (*Bolliger & Randegger-Vollrath 2003*).

6.5.2 Description of measure

About 50% of sewage sludge from waste water treatment plants in EU27 is recycled, which means application to land in most of the cases. About 16%each is landfilled, incinerated, or treated otherwise (e.g. exported). Of these measures only controlled incineration of sludge is effective for the control of hazardous substances contained in sludge. Incineration of sewage sludge can be conducted as co-incineration in power plants or in the cement industry, or in sludge incineration plants, so called “mono-incineration”. The technical process is similar to the incineration of waste with temperatures above 850°C and flue gas treatment.

6.5.3 Effectiveness

Due to decomposition of SCCP and MCCP at high temperatures (above 200°C for SCCP), incineration of SCCP and MCCP containing sludge will most likely be effective. Although reliable data are not available, it is assumed that removal rates of 90-100% can be reached.

6.5.4 Costs

Costs for sewage sludge mono-incineration vary depending on size, location and other conditions. For a mono-incineration plant with a capacity of 30,000 Mg dm/a *Schaum et al. (2010)* reported investment costs of EUR 64-69 million (EUR 43-46 per Mg dry matter over a lifetime of 50 years without interests etc.), and operating costs of EUR 235 per Mg dry matter. For co-incineration investment costs would be in a range of EUR 34-43 million (not including costs for incineration plant).

6.5.5 Secondary environmental effects

Since the process has similarities to the incineration of waste, see chapter 6.6.

Additionally, due to the possibility of phosphorus recovery from ashes, mono-incineration plants should be favored.

6.5.6 Technical feasibility

Process is already well proven on a large scale.

6.5.7 Secondary socio-economic effects

Since this process is a main measure for all HS present in sludge, see general COHIBA recommendation report for details.

6.5.8 Geographical and time scale of effects

Since this process is a main measure for all HS present in sludge, see general COHIBA recommendation report for details.

6.5.9 Political enforceability

Since this process is a main measure for all HS present in sludge, see general COHIBA recommendation report for details.

6.5.10 Cost-effectiveness analysis

Based on average loads of SCCP in sludge between 13-42 mg per person and year, an assumed effectiveness of sludge incineration of 100%, and estimated costs between EUR 8 to 9.8/cap*a, the costs for removing SCCP by sludge incineration would vary in a range of 0.19-0.75 Mio. €/kg removed product. For MCCP reliable data about loads in sludge are not available.

6.6 Waste management – Controlled landfilling / controlled incineration

6.6.1 Description of source

Disposal of SCCP and MCCP containing products to controlled landfill sites is possible. Preferred waste management option for waste conveyor belts, gaskets and hoses, sealants and adhesives, and textiles.

ESWI (*2011*) gives a detailed overview of SCCP mass flows from relevant sources to current disposal/recovery operations in the EU27. According to this reference, the main source of SCCP in products are currently conveyor belts for underground mining, since SCCP are not restricted in this use due to their special characteristics (softener and flame retardant) that are needed in these products. Generally, emissions from rubber products account for about 60%, waste from sealants and adhesives for about 21% and paints and varnishes for about 15% of all SCCP containing waste in EU27.

6.6.2 Description of measure

Controlled landfill means that the site needs to be fitted with a leachate barrier system and leachate collection system.

In controlled incineration waste is burned at temperatures of 850-950˚C. Flue gases that are generated during the process are treated to reduce the amounts of hazardous substances before being emitted (ECB European Chemicals Bureau, 2008). Since SCCP decomposes at temperatures above 200 °C (*Bolliger & Randegger-Vollrath 2003*), the majority of SCCP in the waste is therefore decomposed during incineration. Emissions of SCCP from incineration plants are believed to be negligible.

6.6.3 Effectiveness

It is assumed that SCCP are largely destroyed during incineration at conditions in accordance with Directive 2000/76/EC. However, no exact figures on removal potential have been found in the literature. It is therefore assumed that 90-100% of the SCCP is decomposed during incineration.

6.6.4 Costs

Landfill has always been the cheapest waste disposal option, but costs of landfill as waste disposal option are rising rapidly. The situation as well as the cost incurred by handling of hazardous waste varies from landfill to landfill and according to boundary conditions.

Landfill costs vary from EUR 150-200/m^3 (Svedberg Bo et al., 2010), EUR 260-350/t (EC, 2002) to EUR 309/t (RPA, 2008).

6.6.5 Secondary environmental effects

Chlorinated paraffins can act as a source of chlorine radicals during incineration processes which can lead to the formation of polychlorinated dioxins and furans. Since this formation is a well known problem with incineration, controls are already in place in most cases (*EC 2008*). Additionally SCCP could be a possible source of PCB (polychlorinated biphenyls) and PCN (polychlorinated naphthalenes) formation in waste incineration (*OSPAR 2009*).

6.6.6 Technical feasibility

Controlled landfilling and controlled incineration of waste are well proven and often applied technologies. Thus, technical feasibility is not the limitation but the collection of waste products can be a large challenge.

6.6.7 Secondary socio-economic effects (including indirect costs)

Lack of landfill space increases the costs. After closure all leak detection systems and groundwater monitoring systems are required to be maintained. Post-closure care usually lasts for 30 years after closure.

6.6.8 Geographical and time scale of effects

Landfilling is not preferred in all countries because of a lack of land.

6.6.9 Political enforceability

Since this process is a main measure for all HS present in sludge, see general COHIBA recommendation report for details.

6.6.10 Cost-effectiveness analysis

SCCP and MCCP loads in waste cannot be clearly determined. The amount of SCCP and MCCP in waste depends largely on which waste fractions are collected and landfilled. If waste conveyor belts, gaskets and hoses, sealants and adhesives, and textiles are collected separately, the load of SCCP and MCCP is higher than would be the case if a mixture of household waste and the named rubber wastes is collected.

The load of SCCP in waste and the absolute amount of SCCP that is decomposed as a result of incineration of one tonne of waste cannot be clearly determined. The amount of SCCP in incinerated waste depends largely on which waste fractions are burned. If only waste conveyor belts, gaskets and hoses, sealants and adhesives, and textiles are burned, the load of SCCP would be higher than if a mixture of household and the named rubber wastes is burned.

Due to these unknown facts, cost effectiveness cannot be evaluated at present.

7 Comparison of measures

Since the use of SCCPs has been restricted in their main former uses, substitutes have been introduced in recent years in several European countries for many applications. Although costs for the substitutes are often in a similar range to the costs for SCCP, for each individual process and field of application the proper substitute has to be evaluated. Therefore no information can be given on the costs for substitution of SCCP or MCCP.

Based on the above assumptions, costs for advanced wastewater treatment processes vary between EUR 0.23 to 3.50 million per kg removed SCCP and between EUR 0.02 and 0.71 million per kg removed MCCP. The wide range is mainly due to varying loads in wastewater. The lower specific costs for the removal of MCCP are due to higher loads in wastewater.

For sludge incineration the costs would vary between EUR 0.19 to 0.75 million per kg removed SCCP. For MCCP reliable data on loads in sludge were not available.

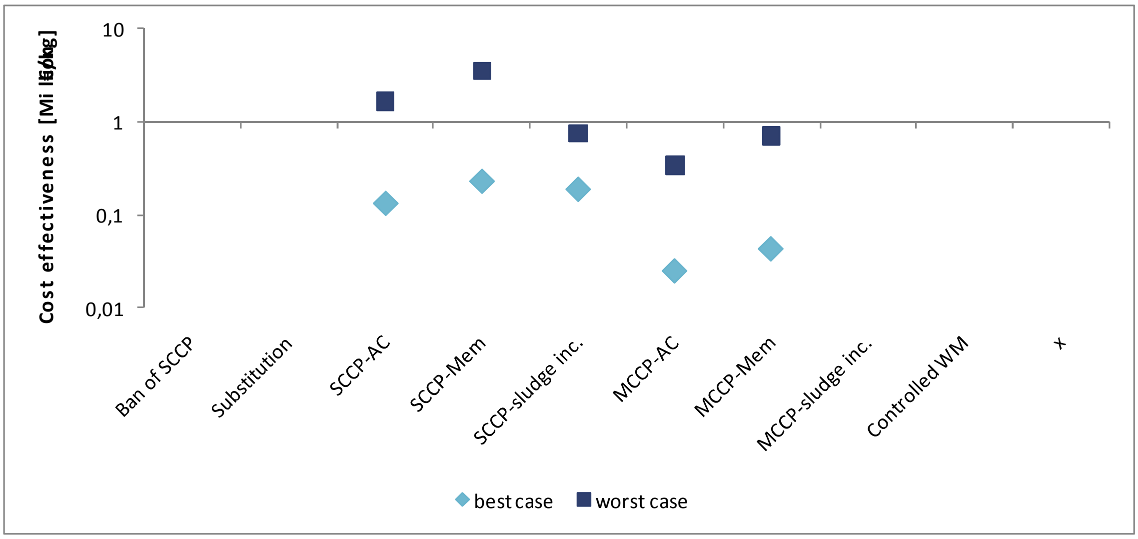

Figure 8: Cost effectiveness of measures

Table 7: Comparison of SCCP/MCCP reduction measures

Measures	Effectiveness	Cost	Secondary environmental effects	Technical feasibility	Secondary socio-economic effects	Geographical/time scale of effects	Political enforceability	Cost effectiveness
Measure 1: Ban on SCCP in remaining areas of application Banning/restricting the use of MCCP in emulsion and oil based metal cutting fluids	++	++	-	++		+	++	
Measure 2: Substitution of SCCP in rubber products and substitution of MCCP in emulsion and oil based metal cutting fluids	+++	++		++		+	++	++
Measure 3, 4, 5: Advanced waste water treatment (activated carbon (AC) treatment, membrane filtration, oxidative techniques)	++	++	+++	++		++	++	++
Measure 6: Sludge treatment – controlled incineration	++	++	+++	+++		++	++	++
Measure 7: Waste management – controlled landfilling / controlled incineration	++	++	+++	+++		++	++	++

Key

+	Only limited effectiveness	Very high costs	Negative secondary environmental effects	Technology not yet available or very new management option	Negative or no socio-economic effect	Only long-term realization, > >10 years	Strong political opposition expected	Costs per kg (or per Teq) emission reduction high
++	Partially effective	Moderate costs	Several positive secondary environmental effects	Pilot process or transferable non-technical	Some positive socio-economic effects	Medium-term realization, approx. 3 -10 years	Political opposition expected	Costs per kg (or per Teq) emission reduction medium to

				measures available				high
+++	Substantial effects	Low costs	Numerous positive secondary environmental effects	Proven and available technology	Many positive socio-economic effects	Rapid realization possible, 1-3 years	Political support expected	Costs per kg(or per Teq) emission reduction medium to low

All selected measures show good to high effectiveness in reducing emissions at moderate substance specific costs. Secondary environmental effects can mainly be seen for 'non substance specific measures', such as advanced wastewater treatment and waste management, since these measures also target other hazardous substances.

All measures described above have been tested or are proven and available technologies. Due to the lifetime of the products, measures targeting the production of SCCP and MCCP and the production of products containing SCCP and MCCP will need at least several years until effects in terms of reduced emissions to the environment will be seen. Political enforceability is possible and relevant measures have already been enforced in some European countries. Nevertheless some political opposition and opposition from industry groups can be expected.

All measures show a moderate cost-effectiveness. Due to generally higher loads of MCCP in the different compartments, cost-effectiveness at similar removal rates is higher for MCCP than for SCCP.

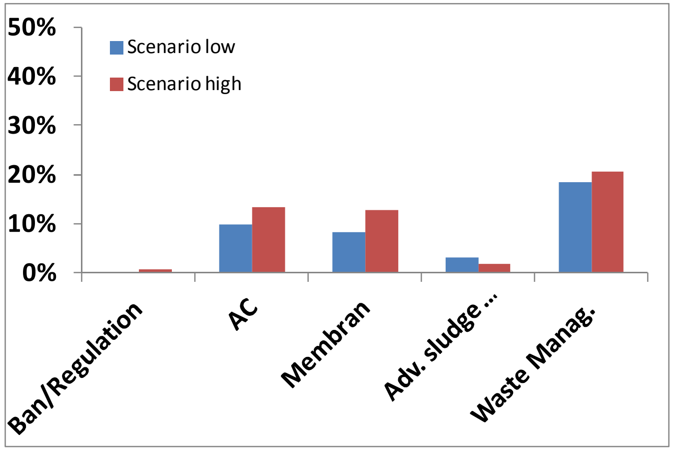

Figure 9: Fraction of SCCP load affected by selected measures

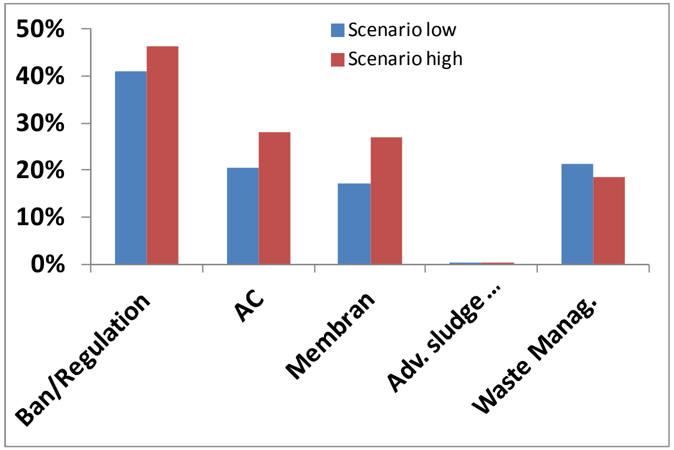

Figure 10: Fraction of MCCP load affected by selected measures

Assumption for technological measures: implementation potential: 50%

As can be seen in Figure 9 (data based on assumptions stated above) measures targeting products at the end of their lifetime (e.g. waste management measures) should have the highest impact on the reduction of SCCP emissions to the environment.

Since for MCCP only few regulations have been issued, this type of measure should have the highest impact on the reduction of MCCP emissions to the environment. However, political enforceability will be more difficult here due to less clarity about risks. At the same time, measures with a significant cross substance effect (advanced wastewater treatment, waste management) will also have a major effect on the reduction of MCCP emissions to the environment (see Figure 10).

8 Conclusion

Use of SCCP in the two most relevant former uses has been restricted at EU level (metal working and fat liquoring in the leather industry). However, SCCP containing products (e.g. SCCP containing leather) are still in use and will continue to end up as waste over the coming years. Due to additional voluntary approaches (PARCOM 95/1) use of SCCP has also further decreased in all other industries in the EU and substitutes have been found for many areas of application. Nevertheless, SCCP are still used in the rubber industry (about 80% for conveyor belts[3][4]), sealants, paints & varnishes and textiles (all products have lifetimes of several years).

While SCCP containing products end up as waste after their service life, diffuse emissions from products containing SCCP during their service life mainly enter waste waters or other compartments e.g. via atmospheric deposition.

The main measures for the waste water compartment are end-of-pipe measures at waste water treatment plants. While conventional wastewater treatment does not seem to be effective enough to achieve significant reductions of SCCP emissions to the environment, it can be assumed that advanced waste water treatment such as activated carbon filtration, membrane filtration or advanced oxidation processes will have a significant effect.

SCCP are assumed to mostly adsorb onto sludge during waste water treatment resulting in relevant concentrations in sewage sludge (however, probably 95% of sludge is only contaminated little and 5% is higher contaminated). Therefore controlled sludge treatment instead of application of sludge to agricultural land can be considered as an additional measure.

For the remaining products containing SCCP, appropriate waste management (e.g. controlled collection and incineration) should be applied as measure for reduction of SCCP emissions. For these reduction measures the relevant main characteristics of SCCPs are their high adsorption capacity (adsorption onto sludge -> sludge treatment), and a decomposition at temperatures above 200°C. Consequently, controlled incineration of sludge and waste is an effective measure. However, due to valuable nutrients contained in sludge (phosphorus) sludge and waste should be incinerated separately (mono incineration).

As additional measures restrictions on the use of SCCP could be extended to include the remaining areas of application (rubber, paints & varnishes). More important, since substitution of SCCP has proven to be possible in most areas of application, the knowledge regard-

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[3] About 95% of SCCP used in conveyor belt production is contained in the product. Little release over lifetime, most of it (~93%) will remain in the waste product.

[4] Additional use of SCCP in rubber industry for shoe soles, gaskets and hoses

ing substitution should be transferred to regions outside EU where SCCP are still produced and used in large amounts (reduction of immissions via long range transport).

The key messages regarding measures to reduce MCCP emissions are similar to those for SCCP. Possible restrictions and substitution of MCCP need to be further evaluated, since industry and the use of products containing MCCP seem to be the dominant sources of MCCP emissions to the environment. The use of MCCP as substitute for SCCP should be avoided.

Again appropriate waste management (collection, controlled landfilling or incineration) should be applied to prevent distribution of MCCP via the pathways ‘products’ and ‘waste to the environment’.

The main measures for reducing MCCP emissions via waste water are end-of-pipe measures at waste water treatment plants. While conventional waste water treatment might not be effective enough to achieve significant reductions of MCCP emission to the environment, it can be assumed that advanced waste water treatment practices such as activated carbon filtration, membrane filtration or advanced oxidative techniques will have a more significant effect.

Controlled incineration of sludge could be applied as additional measure instead of agricultural use of sewage sludge to avoid distribution of MCCP via MCCP containing sludge. However, data on MCCP concentrations in sludge are scarce; therefore additional measuring campaigns need to be conducted.

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A Additional background information

Additional information to Chapter 5: Important measures (Long version)

Table 8: General list of potential measures for SCCP and MCCP

Source control	**Product** Awareness raising for users of products (private and commercial) Substance substitution, Changing of product material Redesigning the products
End of pipe	**Urban waste water treatment** *Mechanical waste water treatment* *Biological waste water treatment* Membrane bioreactor (MBR) Sand filtration Urban runoff management **Advanced wwt** ***Sorption*** Activated carbon adsorption Low-cost sorbents Sorption to zeolites ***Membranes*** Membrane filtration (NF / RO) ***Other treatment methods*** Oxidative techniques (e.g. ozone) **Solid phase treatment** *Sewage sludge* Advanced sludge treatment: Controlled incineration Advanced sludge treatment: Gasification Avoid land application of sewage sludge Certification system for sewage sludge *Controlled incineration* *Controlled landfilling*
Regulatory measures	**Ban of individual substances (use and/or production)** Ban industrial / commercial wastewater in MWWT National emission register National chemical product register
Economic and financial measures	Waste water levy
Voluntary agreements	Voluntary agreement

B Detailed information on measures

Additional information to measure

Substitution of SCCP in rubber products and substitution of MCCP, chapter 0

Table 9: Summary of information on possible alternatives to SCCPs (*BRE et al. 2008*)

Use	Alterna-tive	Cost	Availability	Use pattern	Performance
Rubber	MCCPs *	Similar cost of sub-stance, possible higher use rate; additional one-off costs	Commercial-ly available	Similar to SCCPs	Technically viable alterna-tive
	LCCPs **	Higher cost of sub-stance; additional one-off costs	Commercial-ly available	Similar to SCCPs	Technically viable alterna-tive
	Cresyl diphenyl phosphate	Significantly higher substance costs; addi-tional one-off costs	Commercial-ly available	Probable use in PVC rather than rubber	Currently used in PVC belting
	Tertbutyl-phenyl diphenyl phosphate	Significantly higher substance costs; addi-tional one-off costs	Commercial-ly available	Probable use in PVC rather than rubber	Currently used in PVC belting
	Isopropyl-phenyl diphenyl phosphate	Significantly higher substance costs; addi-tional one-off costs	Commercial-ly available	Probable use in PVC rather than rubber	Currently used in PVC belting
Textiles	MCCPs *	Similar cost of sub-stance, possible higher use rate; additional one-off cost	Commercial-ly available	Similar to SCCPs, possi-ble higher use rate	Technically viable alterna-tive
	LCCPs **	Higher cost of sub-stance; additional one-off costs.	Commercial-ly available	Similar to SCCPs	Technically viable alterna-tive
	Decabro-modiphe-nylether	Significantly higher substance cost than SCCPs; additional one-off costs. Requires diantimony trioxide	Commercial-ly available	25% by weight (in conjunction with ATO)	Technically viable alterna-tive
	Hexabro-mocyclo-dodecane *	Significantly higher substance cost than SCCPs; additional one-off costs. Requires diantimony trioxide	Commercial-ly available	25% by weight (in conjunction with ATO)	Technically viable alterna-tive
	Ethane, 1-2 bis(pentabromo-phenyl)	Significantly higher substance cost than SCCPs; additional one-off costs. Requires diantimony trioxide	Commercial-ly available	Typical loading 10- 30 g/m2	Technically viable alterna-tive
Sealants, adhesives, paints, coatings	MCCPs *	Similar cost of sub-stance, possible higher use rate; additional one-off costs	Commercial-ly available	Similar to SCCPs	Technically viable alterna-tive

	LCCPs **	Higher cost of substance; additional one-off costs.	Commercially available	Similar to SCCPs	Technically viable alternative
	Phthalates		Commercially available		Do not provide flame retardancy

* MCCP and HBCDD are considered to be hazardous substances of special concern within the COHIBA-project and can therefore not be recommended as substitutes

** Similarities in environmental fate and behavior of LCCP to MCCP and SCCP can be assumed. Therefore, LCCP cannot be recommended as substitutes until environmental fate and behavior is sufficiently evaluated.

Additional information to Measure 6.3 "Membrane filtration"

Table 10: Sewage plants with membrane filtration in Europe as of 2004 (based on Engelhardt, (2004) cited in *Hillenbrand et al.* (*2007*)

Land	Sewage plant	Pop.	Status	System	Operator
Germany	Rödingen	3,000	1999	Zenon	Erftverband
	Markranstädt	12,000	2000	Zenon	Kom. Wasserw. Leibzig
	Büchel/Bickenbach	1,000	2000	Kubota	Aggerverband
	Knautnaundorf	900	2001	Huber	Kom. Wasserw. Leibzig
	Altenberge	1,000	2001	Huber	Gemeinde Altenberge
	Simmerath	750	2003	Puron	WVER
	Monheim	9,700	2004	Zenon	Gemeinde Monheim
	Nordkanal	80,000	2004	Zenon	Erftverband
	Waldmössing	18,000	2004	Zenon	Gemeinde Schermbeck
	Seelscheidt	11,000	2004	Kubota	Aggerverband
	Konzen	9,200	u.c.	Kubota	WVER
	Rurberg/Woffelsbach	6,500	u.c.	Kubota	WVER
	Markkleeberg	30,000	u.c.	Zenon	Kom. Wasserw. Leibzig
	Merkendorf	250	u.c.	Kubota	Zweckverb. Zeulenroda
	Glessen	9,000	2008	open	Erftverband
Netherlands	Maasbommel	500	2002	Zenon	Rivierenland
	Varsseveld	23,000	u.c.	Zenon	Rijn & Ijssel
	Hilversum	200,000	planned	open	DWR
Switzerland	Säntis	<8,000	2000	Zenon	Säntis Schwebebahn
	Schwägalp	780	2002	Huber	Säntis Schwebebahn
	Uerikon	9,000	u.c.	Zenon	Gemeinde Uerikon
Austria	St. Peter ob Jdgb.	1,500	2002	Mitsubishi	Rotreat GmbH
Italy	Brescia	46,000	2002	Zenon	unknown
England	Porlock	3,000	1998	Huber	Wessex-Water

	Swanage	23,000	2000	Kubota	Wessex-Water
	Campletown	24,000	2001	Kubota	Scottish Water
	Lowestoft	46,000	2002	Zenon	Anglian Water

u.c. = under construction

Figure 11: Development of prices for membrane modules (microfiltration/ ultrafiltration) based on the examples of several selected manufacturers *(Hillenbrand & Hiessl 2006)*; relative, based on cost at market introduction and corrected for inflation

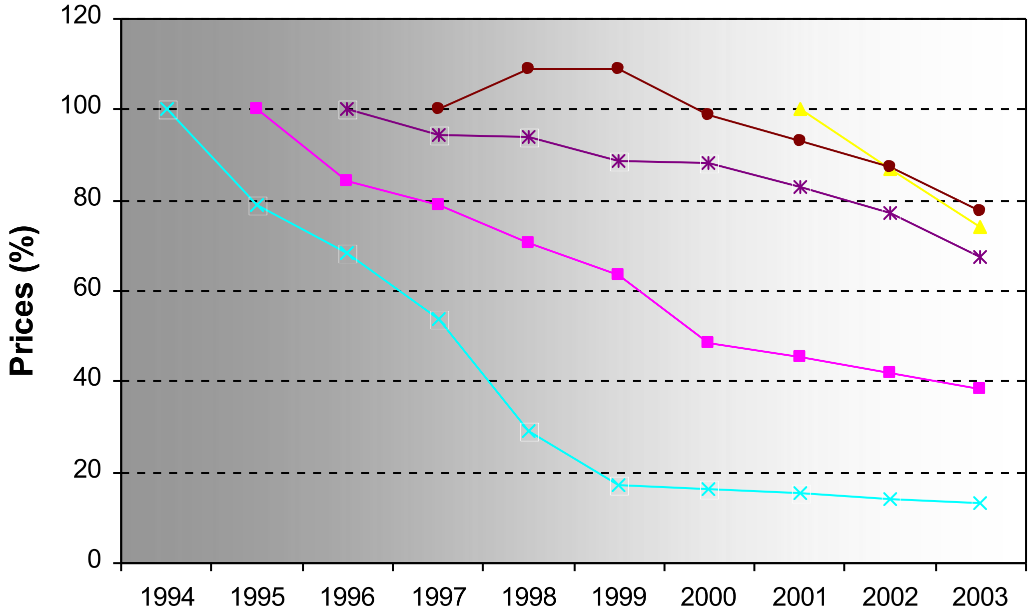

Table 11: Performance data of activated sludge membrane separation systems in comparison with conventional activated sludge systems (*Dohmann et al.* (*2002*) cited in *Hillenbrand et al.* (*2007*))

Parameter		Conventional activated sludge system	Membrane separation activated sludge system
Solids (suspended solids)	mg/l	10 – 15	0
CSB	mg/l	40 – 50	< 30
N_{tot}	mg/l	< 13	< 13
P_{tot} (with simult. precipitation)	mg/l	0.8 – 1.0	< 0.3
Microbiological quality		hygienically questionable	bathing water quality
Mixed liquor suspended solids	g/l	< 5	< 20
Spec. electricity consumption	kWh/m³	0.2 – 0.4	0.7 – 1.5

Additional measures

Change of product material

The replacement of flammable plastic and rubber products with materials that are more inherently flame resistant will reduce the need for flame retardants. Materials that don't require the addition of chemicals for flame resistance include metal, leather, glass, preceramic polymers, aramide blends (Kevlar), and natural fibers such as jute, hemp, and wool. Three plastics – polysulfone, polyaryletherketone, and polyethersulfone – are self-extinguishing and can be used without the addition of flame retardants.

Wherever possible, products containing SCCP and MCCP should be evaluated with regard to whether they could be replaced by materials that do not require the addition of flame retardants.

However, specific information on experience with switching to alternative product materials to avoid using SCCP and MCCP is not available so far.

Redesign of the products

Risks of fire can be reduced by construction changes, such as e.g. increasing the distances between product and potential ignition sources (*Ahrens et al. 2003*).

Furniture, plastic, and electronics products can be manufactured to meet fire standards without the use of chemical flame retardants.

However, specific information on experiences with redesign of products for the avoidance of SCCP and MCCP is not available so far.

Organizational-logistic differentiated fire prevention strategy

Organizational-logistic differentiated prevention strategies to avoid the use of SCCP and MCCP (e.g. type and amount of flame retardants) need to be matched to the actual necessity for fire prevention)

Type and amount of flame retardants need to be matched to the actual necessity for fire prevention.

However, specific information on experience with organizational-logistic differentiated fire prevention strategies for the avoidance of SCCP and MCCP is not available so far.