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Paradigm for Substance Flow Analyses

Guide for SFAs carried out for the Danish EPA

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Preface

The aim of the present paradigm for substance flow analyses is to provide a general framework for Substance Flow Analysis (SFAs) carried out for the Danish EPA.

The paradigm is an updated and revised version of a previous paradigm from 1993 (Hansen & Boisen 1993). The first paradigm was developed to ensure uniformity and comparability of SFAs expected to be carried out for hazardous chemical substances under the Danish EPA´s framework programme on hazardous substances in waste.

In Denmark today, SFA is taken to be a standard tool in the process of identifying important sources for release of hazardous substances to the environment and the first paradigm has been used for a range of SFAs. A comprehensive list of SFAs carried out in Denmark is included in appendix 2. Summaries of nine of these SFAs are included in appendix 5.

An SFA will typically be initiated for substances, which have been identified as actual or potential hazardous to humans or the environment. The outcome of the SFA will subsequently form the fundament for considerations by the Danish EPA as regards the need and instruments for risk minimisation for the substance in question.

A potential field for application of SFA, which may prove important in the future, is the function of providing input to risk assessments for chemical substances carried out according to EU regulation.

The experience with the SFAs carried out until now is that there often has been a need for focusing the analyses on specific parts of the substance flow or extending the analyses to include other aspects related to the use of the substance. A main objective of the update of the paradigm has been to include such focusing end extensions into the main framework of the analyses.

The report is intended to be used by the Danish EPA in the proces of calls for proposal and by both new and more experienced Danish SFA practitioners. In addition, the paradigm hopefully may also serve as inspiration for authorities and practitioners out of Denmark.

Steering Committee

A steering committee, whose members are listed below, has been in charge of preparation of this paradigm.

Lea Frimann Hansen, Danish EPA (chair person)
Lotte Wammen Rahbek, Danish EPA
Alf Aagård, Danish EPA
Henrik Søren Larsen, Danish EPA
Frank Jensen, Danish EPA
Henriette Seiler Hansen, Danish EPA
Carsten Lassen, COWI
Erik Hansen, COWI

Acknowledgement

Special thanks are offered to Ester van der Voet, Leiden University, for productive comments on the paradigm.

Authors

The paradigm has been prepared by Carsten Lassen and Erik Hansen, COWI Consulting Engineers and Planners AS, Denmark.

Summary

The present paradigm for substance flow analyses provides a general framework for Substance Flow Analysis (SFAs) carried out for the Danish EPA. The first part includes a general description of principles and procedures as regards the use of substance balances, uncertainty, detail and reliability, cross-checks, literature, statistics, etc. The second part provides a general outline of SFAs, with a detailed description chapter for chapter. The paradigm is intended to be used by the Danish EPA as basis for new SFAs carried out by both new and more experienced project holders.

Background and Objectives

The aim of the present paradigm for substance flow analyses is to provide a general framework for Substance Flow Analysis (SFAs) carried out for the Danish EPA.

The paradigm is an updated and revised version of a previous paradigm from 1993. The first paradigm was developed to ensure uniformity and comparability of SFAs carried out for hazardous chemical substances under the Danish EPA´s framework programme on hazardous substances in waste.

In Denmark today, SFA is taken to be a standard tool in the process of identifying important sources for release of hazardous substances to the environment and the first paradigm has been used for a range of SFAs. The report provides a list of SFAs of more than 30 substances or substance groups carried out in Denmark during twenty years.

A SFA will typically be initiated for substances, which have been identified as actual or potential hazardous to humans or the environment. The outcome of the SFA will in combination with an assessment of environmental and health effects form the fundament for considerations by the Danish EPA as regards the need and instruments for risk minimisation for the substance in question.

The experience with the SFAs carried out until now is that there often has been a need for focusing the analyses on specific parts of the substance flow or extending the analyses to include other aspects related to the use of the substance. A main objective of this update of the paradigm has been to include such focusing end extensions into the main framework of the analyses.

The report is intended to be used by the Danish EPA as basis for new SFAs carried out by both new and more experienced project holders. In addition the paradigm hopefully may also serve as inspiration for authorities and researchers out of Denmark.

This Investigation

This investigation is an update of a paradigm for SFA developed by Erik Hansen and Hanne Boisen for the Danish EPA in 1993. The revision of the paradigm has been carried out in 1999-2000 by Erik Hansen and Carsten

Lassen, COWI Consulting Engineers and Planners AS, for the Danish EPA. The work has been reviewed by a steering committee with representatives from The Danish EPA and COWI. Productive comments have in addition been offered by Esther van der Voet, Leiden University.

Principles and Procedures

The first part of the paradigm provides general guidelines as regards principles and procedures for carrying out SFAs. With inspiration from internationally agreed framework for Life Cycle Assessments, it has been proposed that a SFA consists of three steps:

- Goal and system definitions
- Inventory and modelling
- Interpretation of the results

The overall goal of the analyses covered by this paradigm is to provide a comprehensive view of the flow of the substance in question through the Danish society forming the fundament for considerations as regards the need and instruments for risk minimisation for the substance. To meet the overall goal, the SFAs include determination of the main sources of discharges to the environment in Denmark (including losses to waste deposits, etc.) and explanations about what uses of the chemical substance cause these discharges.

In the paradigm is distinguished between what is designated the 'core SFA' and a number of optional extensions. The 'core SFA' includes an analysis of the total flow of a substance or a group of substances through the Danish society during one year. In the extensions the system boundaries are expanded either in space or time e.g. covering the monitoring data of the substance in different environmental compartments.

The SFA is based on the principle of substance balance:

Input + formation = output + degradation + accumulation

The substance balances can be made more or less complex depending on the desired level of detail. In fact, SFAs consist of the systematic use of such substance balances to describe a larger system. The substance balances can be used to describe a static situation by simple bookkeeping or be build into more complex modelling of chances in the balances, which can be used to describe the dynamic of the system and forecast future situations.

Undertaking a SFA in many ways resemble doing a jigsaw puzzles. The best way to prove that the jigsaw puzzle has been completed correctly is to make certain, that all pieces fit together. Assessment of data reliability and cross-checking of information and estimates are very important elements in the process, as all data will be more or less uncertain. This first part of the paradigm provides detailed recommendations as regards data quality assessment, dealing with uncertainty, balancing and crosschecking of estimates, literature and statistics.

The General Outline

In the aim of ensuring the uniformity and comparability of the SFAs carried out at a national level in Denmark, the paradigm prescribes a common outline of all SFAs. The main outline is shown in box 1.

Box 1

Preface

Summary and Conclusions in Danish and English

1. Introduction
   - 1.1 Purpose of the Analysis
   - 1.2 Methodology and Limitations
   - 1.3 What is <the substance>?
   - 1.4 International Market and Trends in Consumption
2. Application in Denmark
   - 2.2 Raw Materials and Semi-Manufactured Goods
   - 2.2 Fields of Application (eventually two sections)
   - 2.3 Consumption as Trace Element and Contaminant
3. Turnover with Waste Products
   - 3.1 Recycling of the Chemical Substance
   - 3.2 Other Turnover with Solid Waste
   - 3.3 Turnover with Chemical Waste
   - 3.4 Turnover with Wastewater and Sewage Sludge
   - 3.5 Summary
4. Evaluation
   - 4.1 Application and Consumption in Denmark
   - 4.2 Discharges to the Environment in Denmark
   - 4.3 Substance Balance in Denmark

References

Appendices

In the second part of the paradigm, a detailed description of the outline chapter for chapter is provided. To what extent it will be possible to cover all issues and follow the outline depends on the data available, but in principle, all parts of the substance flow through the society should be addressed. If data is not available, it may be necessary to make more uncertain estimates based on models or monitoring data from other countries.

Extensions of the SFA

The paradigm covers what can be designated the 'core SFA' as defined by the boundaries described above and a list of optional extensions, which cover parts of the substance life cycle outside these system boundaries or other aspects in connection with the use of the substance.

The following optional extensions are included:

- International market and trends in consumption, detailed analysis.

- Qualitative description of the exposure of man by use and disposal of finished products

- Scenarios for future emissions and loss of the substance

- Occurrence and fate in the environment

- National and international regulation on the use of the substance

- Assessment of substitutes

- Recycling, downcycling and material deterioration

For each extension, a general outline is described.

Sammenfatning

Dette paradigme for massestrømsanalyser giver en generel systematisk ramme for massestrømsanalyser, som udarbejdes for Miljøstyrelsen. Første del af paradigmet indeholder en beskrivelse af principper og procedurer med hensyn til brugen af stofbalancer, usikkerhed, detaljeringsgrad og pålidelighed, krydscheck, litteratur, statistik etc. Anden del giver en generel struktur for massestrømsanalyser med en detaljeret beskrivelse kapitel for kapitel. Rapporten er udarbejdet med henblik på at blive brugt af Miljøstyrelsen som grundlag for nye massestrømsanalyser udført af såvel nye som mere erfarne projektudøvere.

Baggrund og formål

Formålet med paradigmet er at give en generel systematisk ramme for massestrømsanalyser udarbejdet for Miljøstyrelsen.

Paradigmet er en opdateret og revideret version af et tidligere paradigme fra 1993. Det første paradigme blev udarbejdet for at sikre ensartethed og sammenlignelighed mellem massestrømsanalyser, som blev udført under Miljøstyrelsens rammeprogram for problematiske stoffer i affald.

Massestrømsanalyser fungerer i Danmark i dag som et værdifuldt værktøj til identifikation af vigtige kilder til udledninger af farlige stoffer til miljøet, og det første paradigme har været anvendt til massestrømsanalyser for en lang række stoffer. I rapporten gives en liste på over 30 stoffer eller stofgrupper, for hvilke der i løbet at de seneste tyve år er udarbejdet massestrømsanalyser

En massestrømsanalyse vil typisk blive sat i gang for stoffer, som har en påvist eller potentielt uønsket effekt for mennesker eller miljøet. Resultatet af massestrømsanalysen vil sammen med en vurdering af miljø- og sundhedseffekter udgøre grundlaget for Miljøstyrelsens overvejelser vedrørende behovet for og instrumenterne til at reducere risikoen knyttet til brugen af det pågældende stof.

Erfaringerne med de massestrømsanalyser, der er udarbejdet indtil nu, er at der ofte har været brug for at fokusere analyserne på bestemte dele af stofstrømmen gennem samfundet eller at udvide analyserne til at omfatte andre aspekter i relation til brugen af stoffet. Hovedformålet med denne opdatering har været at indarbejde sådanne fokuseringer og udvidelser i den overordnede systematiske ramme for analyserne.

Rapporten er udarbejdet med henblik på at blive brugt af Miljøstyrelsen som grundlag for nye massestrømsanalyser udført af såvel nye som mere erfarne projektudøvere. Hertil kommer, at rapporten forhåbentligt kan virke som inspiration for myndigheder og udøvere i andre lande.

Undersøgelsen

Denne undersøgelse er en opdatering af et tidligere paradigme for massestrømsanalyser fra 1993 udarbejdet af Erik Hansen og Hanne Boisen for Miljøstyrelsen. Revisionen af paradigmet er udført for Miljøstyrelsen i 1999-2000 af Erik Hansen og Carsten Lassen, COWI Rådgivende Ingeniører A/S. Arbejdet har været fulgt af en styregruppe med repræsentanter for Miljøstyrelsen og COWI. Her ud over har Esther van der Voet, Leiden Universitet, bidraget med værdifulde kommentarer.

Principper og procedurer

I det første del af paradigmet gives generelle retningslinier vedrørende principper og procedurer for udarbejdelse af massestrømsanalyser. Med inspiration fra de internationalt anerkendte retningslinier for livscyklusvurderinger, LCA, er det foreslået at en massestrømsanalyse består af tre trin:

- Målsætning og systemafgrænsning
- Kortlægning og modellering
- Fortolkning og vurdering af resultaterne

Det overordnede mål for analyserne, som er dækket af dette paradigme, er at give et dækkende billede af strømmen af det pågældende stof gennem det danske samfund, som kan danne grundlag for overvejelser vedrørende behovet for og instrumenterne til at mindske risikoen knyttet til brugen af stoffet.

I paradigmet skelnes mellem, hvad der betegnes ”kerne-massestrømsanalysen” og en række mulige tilvalg. Kerne-massestrømsanalysen omfatter en analyse af den totale strøm af stoffet eller stofgruppen gennem det danske samfund i løbet af et år. I tilvalgene udvides systemgrænserne i tid eller rum, således at analysen fx også omfatter en sammenfatning af eksisterende måledata for stoffet i forskellige dele af miljøet.

Massestrømsanalysen er baseret på princippet for stofbalance:

Input + dannelse = output + nedbrydning + akkumulering

Stofbalancerne kan blive udbygget til mere eller mindre komplekse modeller, afhængig af hvilket detaljeringsniveau der ønskes. Massestrømsanalyser består i realiteten af en systematisk brug af sådanne stofbalancer til at beskrive større systemer. Stofbalancerne kan anvendes til at beskrive en statisk situation, og analysen er da at sammenligne med simpelt bogholderi, eller de kan blive indbygget i mere komplekse modeller som, kan anvendes til at beskrive systemets dynamik og lave prognoser for fremtidige situationer.

At udarbejde en massestrømsanalyse kan på mange måde sammenlignes med at samle et puslespil. Den bedste måde, at sikre at puslespillet er samlet rigtigt er at sikre sig, er at påvise, at alle brikker passer sammen og danner et sammenhængende billede. Vurdering af dataenes pålidelighed og krydscheck af informationer og beregninger er meget vigtige elementer i processen, da alle data er behæftet med større eller mindre usikkerhed. Første del af paradigmet indeholder detaljerede anbefalinger med hensyn til vurdering af datakvalitet, håndtering af usikkerhed, afbalancering og krydscheck af beregninger samt brug af litteratur og statistik.

Den generelle struktur

Med henblik på at sikre ensartethed og sammenlignelighed mellem massestrømsanalyser udført for Miljøstyrelsen foreskriver paradigmet en generel struktur, som er vist i boks 1.

Boks 1

Forord

Resumé og konklusioner på dansk og engelsk

1. Introduktion
   - 1.1 Analysens formål
   - 1.2 Metode og begrænsninger
   - 1.3 Hvad er <stoffet>?
   - 1.4 Internationalt marked og udviklingstendenser
2. Anvendelse i Danmark
   - 2.2 Råmaterialer og halvfabrikata
   - 2.2 Anvendelsesområder (eventuelt to afsnit)
   - 2.3 Forbrug som følgestof
3. Omsætning med affaldsprodukter
   - 3.1 Genanvendelse af stoffet
   - 3.2 Anden omsætning med fast affald
   - 3.3 Omsætning med kemisk affald
   - 3.4 Omsætning med spildevand og spildevandsslam
   - 3.5 Sammenfatning
4. Sammenfattende vurdering
   - 4.1 Anvendelse og forbrug i Danmark
   - 4.2 Udledninger til miljøet i Danmark
   - 4.3 Stofbalance for Danmark

Referenceliste

Bilag

Anden del af paradigmet indeholder en detaljeret beskrivelse af strukturen kapitel for kapitel. I hvilken grad det vil være muligt at dække alle emner og følge strukturen, vil være afhængig af, hvilke data der er til rådighed, men i princippet skal alle dele af strømmen af stoffet gennem samfundet behandles. Hvis der ikke er tilgængelige data, kan det være nødvendigt at lave mere usikre skøn baseret på modelberegninger eller måledata fra andre lande.

Udvidelser af massestrømsanalysen

Ud over ”kerne-massestrømsanalysen” omfatter paradigmet en række tilvalg, som dækker andre dele af stoffets livscyklus eller andre aspekter i relation til brugen af stoffet.

Følgende tilvalg er omfattet:

- Internationalt marked og udviklingstendenser
- Kvalitativ beskrivelse af eksponering af mennesker i relation til brug og bortskaffelse af færdigvarer
- Scenarier for fremtidige udledninger og tab af stoffet
- Forekomst og skæbne i miljøet
- National og international regulering af stoffet
- Undersøgelse af alternativer
- Genanvendelse, genvinding og materialeforringelse

For hvert tilvalg foreskriver paradigmet en generel struktur.

1 Introduction

Substance Flow Analysis (SFA) is an analytical tool used for achieving the understanding of the flow of substances through a given system defined in space and time. The substances may be elements, chemical compounds or groups of chemical compounds.

At the moment there is no agreed international guidelines for SFAs, but in recent years methodological elements of the SFA framework has been discussed within a European concerted action of SFA practitioners, ConAccount. A discussion of terminology and general technical framework of SFAs with references to the international literature can be found in the proceedings of the first ConAccount workshop (Bringezu 1997; ConAccount 1999).

In Denmark the term 'Mass Flow Analysis' (massestrømsanalyse) has traditionally been used as synonymous of 'Substance Flow Analysis'. However, in accordance with the most used international terminology the term 'Substance Flow Analysis' will be used in this paradigm as the term Mass flow Analysis in other contexts are used for analysis where the flow of more substances are aggregated on the basis of mass (Udo de Haes *et al.* 1997). If the analysis cover the flow of more complex materials and industrial products the analysis is most often designated 'Material Flow Analysis' (MFA).

General framework

A general technical framework for SFAs has been proposed by Udo de Haes *et al.* 1997. The framework takes inspiration from internationally agreed framework for Life Cycle Assessments (LCA ISO 14040).

According to this framework the SFA consists of three steps:

- Goal and system definitions
- Inventory and modelling
- Interpretation of the results

These steps are discussed further in section 2.3, but introduced here.

Goal definition

The present paradigm applies to SFAs initiated by the Danish EPA. The SFAs will typically be initiated for substances which, in different ways, are anticipated of causing environmental or health problems. The overall goal of the analyses is to prove a comprehensive view of the flow of the substance in question through the Danish society forming the fundament for considerations as regards the need and instruments for risk minimisation for the substance. Subsequent to the analysis, it may be considered further to investigate the effects of specific actions, including a more detailed analysis of the possibility of substitution of the chemical substance, etc.

In addition the analysis is aimed at providing a common understanding as regards the flow of the substance for all stakeholders in the risk minimisation process: the authorities, industry, NGOs, consumers, etc.

In combination the SFAs provide information on e.g. sources of heavy metals to solid waste incineration and may in combination be used for prioritising risk minimisation actions including more substances.

To meet the overall goal, the SFAs include determination of the main sources of discharges to the environment in Denmark (including losses to waste deposits, etc.) and explanations about what uses of the chemical substance cause these discharges.

The more specific goals of the analysis will depend on at which level of the risk minimisation process the SFA is pretended to be used. Is the aim of the analysis to make an initial identification of the main routes of emission to the environment or is the analysis aimed at providing a detailed basis for regulation of the use of the substance for specific applications? The influence of the different goals on the level of detail and reliability of the analysis is discussed further in chapter 3.

The goal and systems definitions are tightly connected. In the following is distinguished between what is designated the 'core SFA' and a number of optional extensions. The system definitions of the core SFA are the same for all SFAs covered by this paradigm, and is defined on the basis of the overall goal of the SFAs.

In the optional extensions the system boundaries in space and time is expanded as a consequence of some specific goals of the analysis. The overall goals of the extensions are defined for each extension in the detailed outline in Appendix 1.

System definition

The 'core SFA' of the present paradigm cover analysis of the total flow of a substance or a group of substances through the Danish society during one year. The system boundaries are discussed further in chapter 2.

SFAs may also provide input to Risk Assessments for chemical substances carried out according to EU regulation. A SFA is actually a basic part of the exposure assessment according to the EU Technical Guidance Document for Risk Assessments (TGD 1996). However, it should be emphasised that the system boundaries in both space and time of the SFAs used for the Risk Assessment are different from the boundaries of the SFAs covered by this paradigm.

The paradigm does not attempt to describe particular problems that may occur when carrying out other analyses e.g. national level MFAs or SFAs covering only parts of the Danish Society. A number of the comments provided would, however, also be applicable for such analyses.

Contents

The paradigm consists of a main report and Appendix 1. Appendix 1 contains the annotated outline for SFAs for substances at the national level and a description of a list of optional extensions of the analysis.

The main report should be seen as a general introduction to appendix 1 and to some extent to substance flow analysis in general. Furthermore, the main report attempts to draw up some general guidelines as to the level of detail and reliability of SFAs as well as for sources of information and their use.

The manhour input required to carry out such analyses is summarised in Appendix 2.

Optional extensions

As mentioned above the paradigm covers what can be designated the 'core SFA' as defined by the boundaries described above and a list of optional extensions, which cover parts of the substance life cycle outside these system boundaries or other aspects in connection with the use of the substance.

The extensions expand the boundaries in space and time, but still the analysis is not expanded to include aspects regarding human toxicity, ecotoxicity and economic feasibility of substitution and legislative regulation. If these aspects are to be covered it is recommended to initiate a separate study.

The following optional extensions are included:

A: International market and trends in consumption, detailed analysis.

B: Qualitative description of the exposure of man by use and disposal of finished products

C: Scenarios for future emissions and loss of the substance

D: Occurrence and fate in the environment

E: National and international regulation on the use of the substance

F: Assessment of substitutes

G: Recycling, downcycling and material deterioration

The extensions A, B and partly F are recommended to be included into the main SFA report as outlined in appendix 1, whereas the other extensions are recommended to be prepared as appendixes to the report with short abstracts in the summary sections of the main report. The reason for this is to keep a common outline of the 'core SFAs' which make it easier to go across several SFAs and e.g. extract information on sources of heavy metals to solid waste incineration.

Focus areas

Beside extending the core SFA, it may be relevant to focus the analysis on particular parts of the substance flow within the boundaries of the analysis. Within the focus area the analysis goes into more detail than determined by the overall level of detail and reliability (see next chapter).

The following focus areas should be considered before a SFA is initiated:

- Specific compounds within the substance group
- Chemical state of emitted compounds
- Consumption with marginal applications
- Parts of the life cycle
  - Consumption with finished goods

- Disposal with solid waste
- Emission from products in use
- Danish production

- *specific compounds* A focus area can be the turnover of a specific chemical compound that only account for a minor part of the total turnover of the substance or substance group in question. In MFA for tin /Lassen & Hansen 1997/ the focus area was for example organotin compounds.

- *chemical state of emitted compounds* For some substances, the chemical state of emitted compounds may be of particular interest. For example, it may be of interest to know whether the chromium in residues from waste treatment is in a more or less oxidised state.

- *marginal applications* For some analysis aimed at providing a basis for regulation of the substance the consumption of the substance with marginal applications may be a focus area. It means that additional input has to be allocated to the marginal applications although these applications only account for a very small part of the total turnover of the substance.

- *parts of the life cycle* For some substances, parts of the life cycle may be of particular interest and more input may be allocated to these parts at the expense of other parts of the life cycle. For heavy metals the flows related to the treatment of solid waste may e.g. be of particular interest, whereas this part of the life cycle may be of less interest as regards volatile organic compounds

2 Principles and Procedures

2.1 The Principle of Substance Balance

Substance flow analysis (SFA) is an analytical tool, that is used for achieving the understanding of the flow of substances within a given system defined in space and time.

Any substance flow analysis is based on the principle of substance balance:

(Eq. 1) Input + formation = output + degradation

As concerns elements, the mass is always constant, and there is no possibility of formation and degradation. For elements the substance balance is thus a simple mass balance: input = output. In the case of chemical compounds that are composed of more than one element, 'formation' and 'degradation' may have a significant impact as chemical, biological or thermal processes may lead to both formation and degradation of such substances.

Expression (1) may be formulated in a number of ways, depending on the system it aims to describe. If the purpose as here is to assess the consumption of a product in Denmark, the expression will be:

(Eq. 2) Imports + Danish production = exports + consumption

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(Eq. 3) Consumption = Danish production + imports - exports

In all substance flow analyses, it is important to determine the boundaries of the analysis in time. The substance flow analyses covering the Danish society as a whole have most often run for a period of one year. However, many products will have a useful lifetime of more than one year, and, at the same time, the market is constantly changing. For this reason, it is often relevant to include changes in the stock building of the substance.

Within the boundaries in time, the substance balance can consequently be expressed:

(Eq. 4) Input + formation = output + degradation + accumulation

In this expression, 'accumulation' refers to the changes in stock building within the period covered. The equation is discussed further in section 2.2.1.

Expression (1)-(3) all describe simple substance balances, which can be made more or less complex depending on the desired level of detail. In fact, SFAs consist of the systematic use of such substance balances to describe a larger system. The substance balances can be used to describe a static situation by simple bookkeeping or be build into more complex modelling of chances in the balances, which can be used to describe the dynamic of the system and forecast future situations.

2.2 The SFA System

As mentioned before the SFA system is defined by the boundaries in space and time.

Boundaries in space

The focus of the 'core SFA' of this paradigm is the Danish society and all the processes taking place from the extraction/import of raw materials to the final disposal of residual products. The Society may as well be designated the 'technosphere' or the 'physical economy'. The society is surrounded by 'The Environment' divided on the compartments: 'soil', 'water' and 'air'. The 'core SFA' does not cover the flows between these compartments.

A **simplified** model of this system is shown in Figure 1.

Most of the arrows shown in the figure may indicate several different types of transport. For instance, 'recycling' covers:

- The chemical substance in isolation or contained in materials from which the substance can be recovered by industrial processing (e.g. lead plates in batteries for cars)

- The chemical substance as a trace element and contaminant in other materials which are recycled (e.g. lead as a trace element in paper, metals, glass and plastic)

- The chemical substance contained in residual products used for the manufacturing of other industrial products (e.g. lead contained in fly ash from coal-fired power plants where the ash is used for manufacturing of cement and concrete)

In the figure, it has been chosen to indicate 'landfilling' as a separate level in the system between 'treatment of waste/residuals ' and the environment (represented by the boxes 'soil', 'water' and 'air'). In reality, for many organic substances 'landfilling' will be a form of waste treatment, as degradation/transformation will take place in a landfill. In the case of persistent chemical substances, landfills should be regarded as a type of storage from where these substances can slowly disperse into the environment by leaching or evaporation.

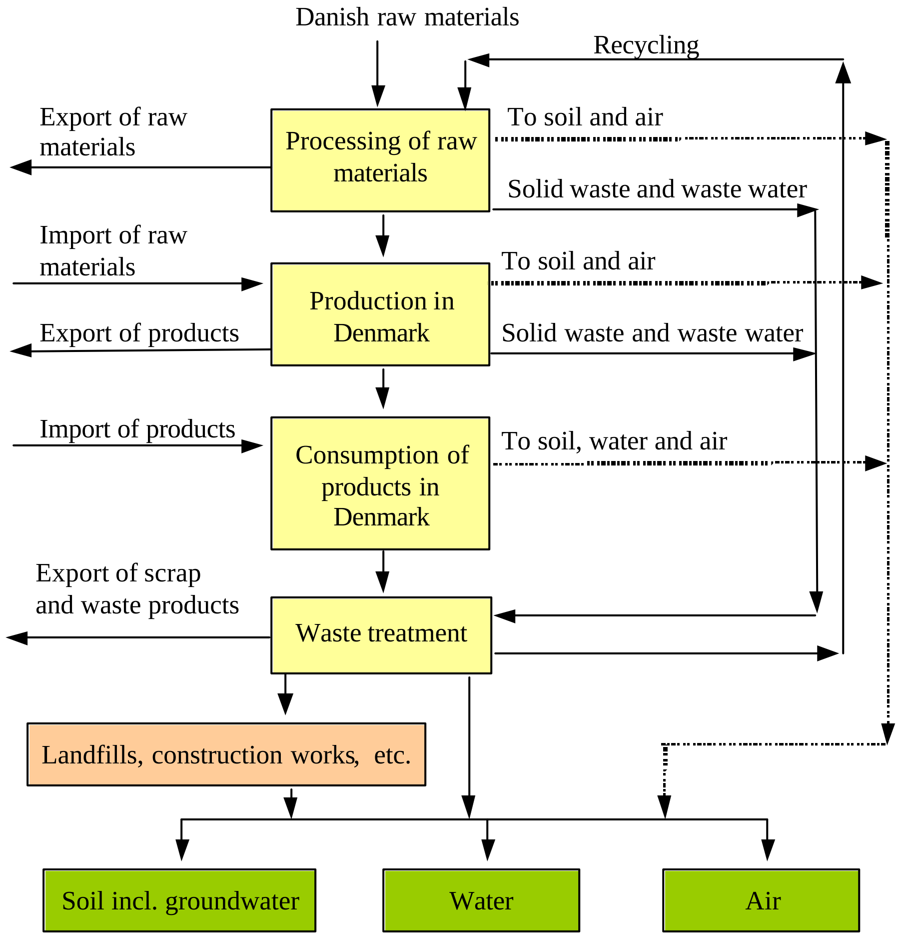

Figure 1
Diagram showing the principles of the transport and turnover of chemical substances in Denmark

Defining the boundary of the analysis at the Danish borders means that emission of the substance by extraction and processing abroad of imported raw materials are not covered by the analysis. Similarly, emissions by processing of exported waste are excluded. It should be noted that other SFA/MFA approaches focus more on these life stages as described in Bringezu 1997.

Concentration and accumulation of the substance in the environmental compartments are not covered by the 'core SFA ' but may be included in an extension to the analysis as described in section 3.7.2.

Boundaries in time

In the 'core SFA', the system in time is defined as one year. It means that the analysis aim at estimating the actual flows between the compartments the year of reference.

In fact, it is often necessary to include information from a broader time period as the emissions to the environment and loss to waste the year of reference can only be estimated on the basis of information on historical consumption figures. For 'sun-down' chemicals, the emission to the environment and loss to waste may for instance be much larger than actual consumption.

For the discussion of the environmental implications of the present consumption of the substance, it may be relevant to expand the boundaries in time and try to predict future emissions as result of nowadays consumption. Such predictions are included in the optional extension described in 3.7.1.

2.3 Procedures

Whereas the principles of SFAs are very simple, the practical procedures will seldom be. The reality, which is described by means of an SFA, is often complex and it may be difficult to obtain the necessary data. In addition, the data, which can be obtained, is seldom 100% accurate, but usually subject to varying degrees of uncertainty.

This section is not intended to thoroughly go through all procedures, but to focus on some procedures that by experience often cause difficulties.

The procedures used in the individual case will depend on the pattern of application and flow of the chemical substance to be analysed as well as the purpose of the analysis and the level of detail and reliability considered appropriate. According to experience and internationally proposed framework, the following phases of the SFA study is proposed:

- Phase 1: Goal and system definition
- Phase 2: System analysis
- Phase 3: Inventory, evaluation of data and modelling
- Phase 4: Interpretation of the results

Compared to the steps introduced in the Introduction a step with 'system analysis' is added. The main reason is that the SFAs covered by this paradigm in general are projects where goal definition and interpretation of the results are carries out at two levels. The goal definition and interpretation of the results by the initiator of the analysis (here the Danish EPA) in a way encompass the goal definition and interpretation of the results by the researcher.

Phase 1. Goal and system definition

The initial goal and system definition is often carried out by the Danish EPA or other clients. The present paradigm is pretended to provide a reference point both in the preparation of call for tenders and preparation of tenders. After initiation of the project, the goal and system definition may be changed in cooperation between the researcher and the client on basis of the system analysis.

Phase 2: System analysis

The system analysis is considered a separate phase because this is often the first phase involving the researcher and the outcome of this phase may effect both the goal and system definition and the inventory. In this phase, the whole system is considered thoroughly and all types of transport and processes, which have an impact on the flow of the substance/material through society, are identified. This phase forms the basis of the subsequent inventory, as it is during the system analysis phase that the requirements are determined as to what data and degree of accuracy are needed. Such a system analysis will be based on knowledge about industrial applications (intended applications and application as a trace element and contaminant) of the chemical substances in question. In addition, detailed knowledge about treatment of waste and disposal of residual products in Denmark is required (cf. Section 4).

It is important to keep in mind that the flow system established in this phase would seldom be perfect. Presumably, there will be aspects which have been overlooked and types of transport/processes considered to be essential will turn out to be unimportant. In practice, it is an iterative process through which the system is modified continuously as more profound knowledge is obtained.

Phase 3: Inventory and modelling

This phase starts out with the collection of easily accessible data. In this context, easily accessible data comprises statistical data about the production, import and export of relevant raw materials, semi-manufactured goods and finished products. In addition, there will be monitoring data concerning finished products and waste streams, etc.

On this basis, a strategy is worked out for the continued collection of data. Should data be collected from enterprises and if so, what information from what enterprises etc.? Are individuals at Danish research institutions likely to possess information etc.? If a questionnaire is used or interviews are made, how can the questions be phrased so as to obtain the needed answers? Are certain persons likely to be reluctant to supply information and perhaps give wrong information, and how can this situation be prevented and monitored? The relevant sources of information will be plentiful and depend on the types of information required (cf. Section 4).

The above questions are primarily meant as a checklist for the considerations to be kept in mind in the planning of the data collection. General rules cannot be laid down. The right solution in the individual situation must be based on experience and the personal preference of the researcher. If a wrong solution is chosen at first, the analysis will have to start all over again, until sufficient data have been collected for a realistic estimate to be made.

An example of estimation of the total consumption of a substance for a specific application based on information from producers is shown in box 1.

During the inventory the pieces of the puzzle (the individual data) are put together. Often, the figures will not correspond precisely and there will be a need for a more detailed evaluation of the data to find out why. Can the discrepancies be explained by inaccuracies of estimates and monitoring results or has something been overlooked or based on wrong estimates? Again, this is an iterative process as there may be a need to improve the collection of data until a satisfactory result is achieved (the jigsaw puzzle is complete).

Some of the flows can due to the lack of monitoring data only be determined indirectly using models. This will be further discussed in section 2.3.4.

Phase 4: Interpretation of the results

Interpretation and discussion of the results can be done at more levels. The SFAs carried out according to the old paradigm (Hansen & Boisen 1993) has been criticised not to go into more detail with the interpretation of the results and keep the analysis and interpretation at a level of bookkeeping. This criticism is right as much of the interpretation is left for the authorities and other readers of the reports.

The basic interpretation, which should be part of the reporting, includes a discussion of the obtained flow chart based on the cross-checks which are discussed further in section 2.3.2. The main sources of emission to the environment and losses to waste are pointed out and emissions of potential importance where more data are needed are flagged.

A further discussion of the emissions of the substance in terms of contribution to environmental impact or sustainability indicators may be relevant, but such an impact assessment is not included in the SFAs covered by this paradigm.

The interpretation of the results in terms of regulatory actions is kept out the analysis and reporting, but left for the authorities initiating the analysis. By the interpretation of the results, the researcher may for example point out the main sources of discharges of the substance to the aquatic environment, but does not propose specific regulatory actions to minimise these discharges. The reasons for this is, as mentioned in the Introduction, that one of the goals of the analysis is to provide a common understanding for all stakeholders of the risk minimisation process.

2.3.1 Dealing with Uncertainty

Almost all data used for the SFAs will be subject to a certain degree of uncertainty. The sources of uncertainty will not be discussed in detail here. A systematic way of describing the sources of uncertainty can be found in /Hoffmann et al. 1997/. In this chapter will be focused more on how to represent and manage the uncertainty.

The uncertainty should be specified for all figures. It is recommended to represent uncertain figures as probability distributions and indicate the uncertainty by intervals; e.g. 200-250 tonnes.

For most figures, there will be a 'true value'; e.g. the actual consumption of the substance within the reference year, but the researcher conducting the SFA does not know this value. When a number of monitoring data exist, it may be possible to use standard statistics to estimate a confidence interval assuming the data are normal distributed, but for most figures in the analysis the uncertainty has to be determined by 'expert judgements'.

As the figure is uncertain, it will not be possible to represent the figures by an interval within which the 'true value' at 100% certainty can be found.

In order for the intervals not to be unreasonably wide, it is recommended to use intervals representing a 90% (or 80%) certainty level. In other words: the figures are represented by the interval within which the author estimates the 'true value' with 90% certainty can be found. In addition it can be assumed that the probability is normal distributed with the mean value as the most probable and a symmetric distribution around the mean.

This means that the width of the interval directly indicates the uncertainty on the results. It makes no sense to state: 'The consumption is roughly estimated at 100-110 tonnes'. A rough estimate will inherently be quite uncertain and if the estimate is rough it will be more correct to state: 'The consumption is roughly estimated at 20-200 tonnes'.

By experience, most people have a tendency to underestimate the uncertainty. To get an idea of how wide the intervals should be it is recommended to practice with standard statistics e.g. in spread-sheet applications. If e.g. three independent information sources estimate the consumption to be 200, 300 and 400 tonnes, respectively, and we assume the information sources to be equally trustworthy, the 80% confidence interval calculated with standard methods will be 191-408 tonnes.

If all figures are represented as probability distributions, a consistent way of adding up the figures is to use the rules for e.g. addition of normal distributions. Principles and software for carrying out life cycle assessments using figures represented as probability distributions is described in /Hoffmann et al. 1997/.

Managing the figures by these rules of probability distribution arithmetic, however, makes the analysis less transparent and it is recommended simply to add up figures by adding up the lowest and highest values within the intervals, respectively.

Consumption with product A	100-300
Consumption with product B	300-600
Total	400-900

The consequence of using this simple addition principle is that the intervals representing the total actually represent a higher certainty level than the two input-data.

The interpretation of the intervals used in the analysis should be described in the 'Preface' or 'Introduction' of the report. For example it should be mentioned whether the intervals for input data are considered to represent 80% or 90% certainty levels?

In a few instances when a number of analysis data are available it will be possible to use standard statistical methods e.g. to calculate a confidence interval on the mean value. As an example data on the concentration of the substance in sewage sludge may be available from many sewage treatment plants and a 90% confidence interval can be calculated presuming that the analyses represent random samples.

Most often the available date, however, cannot be presumed to be random samples from a common distribution, and it may be expedient to divide the data into more distributions, treating each distribution independently. By this method the uncertainty on the total result will often be lower.

For instance it is relevant to treat analyses of flue gas from solid waste incinerators as three distributions depending on the present flue gas cleaning technology: dry, semi-dry or wet cleaning technology.

Beside the natural variation among the samples each analysis are subject to an uncertainty dependent on the applied analysis method. As far as the uncertainty is unbiased (symmetric distributed around the mean), this uncertainty will simply make a part of the measured variation between the samples and need no specific treatment. It is, however, essential to be sure that the analysis method not systematically overestimate or underestimate the actual content of the samples. Especially when using older analysis results it is thus necessary to assess whether new analysis methods has revealed that the applied method overestimate or underestimate the actual content.

2.3.2 Cross-checks

The most important tool to handle and evaluate the uncertainty is 'cross-checking'. Whenever there is a possibility to cross-check, it should be done in order to verify the coherence of the SFA. One of several important cross-checks consists in checking whether the consumption by the manufacturers of raw materials corresponds to the consumption of raw materials and semi-manufactured goods registered in the statistics. If these data correspond, the estimated consumption for different purposes is likely to be true. If the data do not correspond, one ore more estimate(s) may be wrong or stock building etc. may be taking place.

In reality, many of the data collected for SFAs are so uncertain that they do not really have any value until they have been cross-checked. SFAs for chemical substances at the national level in many ways resemble jigsaw puzzles. The best way to prove that the jigsaw puzzle has been completed correctly is to make certain, that it is not possible to point out pieces, which do not fit together.

The following types of cross-checks based on the application of mass-balances is considered to be relevant:

- Does the consumption of raw materials/semi-manufactured goods registered in the statistics correspond to the consumption of raw materials of the manufacturers?

- Does the consumption of raw materials of the manufacturers correspond to their production and estimated losses to wastewater, soil, air and waste as well as the volume recycled?

- Does the estimated total loss to solid waste from enterprises and consumers correspond to the volumes measured in solid waste?

- Does the estimated total loss to wastewater from enterprises and consumers correspond to the volumes measured in wastewater?

- Does the estimated total loss to chemical waste correspond to the volumes received by Kommunekemi (the Danish central treatment facility for chemical waste) or other recipients?

- Do the volumes presumed to be recycled correspond to the volumes received by the recycling companies?

Box 1

Evaluation of information received from manufacturers

This box describes an example of the collection and evaluation of data from manufacturers. The example is hypothetical, but must be considered representative of the type of assessments to be carried out as part of SFAs for chemical substances at the national level.

Based on statistical information, the annual consumption of the substance X for manufacturing of products in Denmark is known to be approx. 1,500 tonnes. It is also known, that this consumption is distributed on the fields of application A, B, C, D and E. The task is to determine this distribution as precisely as possible.

For the field of application A, the Danish Technological Institute informs that 3 large-scale manufacturers exist in Denmark each with a market share of 20-30% as well as 5-6 small-scale manufacturers. It is decided to collect information from the three large manufacturers as well as two of the small ones. Due to severe competition, most manufacturers do not wish to indicate their own consumption. However, they are willing to provide an estimate of the total consumption for the field of application A in Denmark. The following information is obtained:

Manufacturer 1: Total consumption estimated at 200-250 tonnes
Manufacturer 2: Total consumption estimated at 200-300 tonnes
Manufacturer 3: Total consumption estimated at approx. 250 tonnes
Manufacturer 4: Own consumption approx.: 2 tonnes. Market share estimated at 5-10%.
Manufacturer 5: Total consumption estimated at 100-200 tonnes

As manufacturer (1)-(3) are the 'large' manufacturers, they are presumed to have a better impression of the market than manufacturer (4)-(5). The preliminary figure for the consumption within the field of application A is therefore estimated at 250 tonnes with an inaccuracy margin of ± 50 tonnes.

The final figure can only be determined when information has been collected for all the fields of application A-E. As it turns out, the total consumption estimated on the basis of the information collected from the manufacturers amounts to 1,500-1,800 tonnes. As the statistical information is considered to be reasonably reliable (at any rate, more reliable than much of the information obtained from the manufacturers), the total consumption for the fields of application A-E is estimated at approx. 1,500 tonnes. Consequently, the information for each field of application has to be re-evaluated in order to find out where there is an estimate, which may be too high. As a result of this re-evaluation, it is decided to change the estimate for field of application A to approx. 200 tonnes with an inaccuracy margin of ±50 tonnes.

2.3.3 Assessment of Consumption

Consumption

By experience, there is often some confusion regarding the interpretation of the terms 'consumption' and 'supply' used in the analyses. For this reason, the consumption assessment will be discussed in more detail here although the consumption assessment is only one part among others of the analysis.

The substance is most often both consumed with raw material and semi-manufactures for production of finished products in Denmark and consumed with finished products sold at the market.

In this paradigm, the term '**Consumption in Denmark**' represents the consumption of the substance with finished products. The consumption of the substance with finished products during the year of reference is equal to the total content of the substance in finished products sold in Denmark during the year. This is independent of whether the products are actually used up by the consumer during the year or they last for many years.

For example, the flow of the brominated flame retardant TBBPA with printed circuit boards is illustrated in figure 3.1.

The consumption of TBBPA in Denmark is represented by the consumption of the substance with the finished electronic products. Beside this it is relevant to assess the consumption of TBBPA for production of compounds, the consumption of laminates for production of printed circuit boards, and the consumption of printed circuit boards for production of electronic products. The main emphasis of the assessment of production of semi-manufactures is the losses by the processes, and consequently the focus should be on processes where losses occur.

Consumption for production processes is in the SFA specifically termed '**Consumption for production processes in Denmark**'.

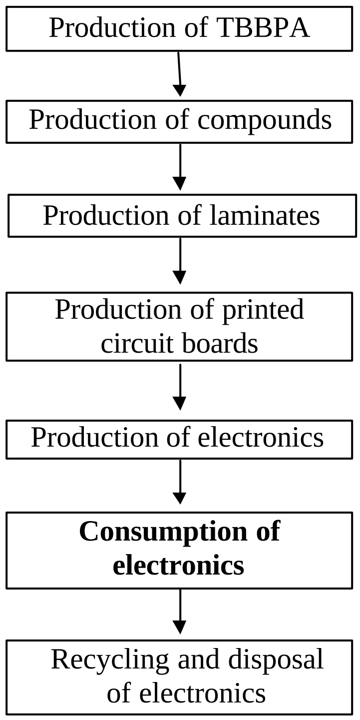

Figure 3.1
Flow of TBBPA with printed circuit boards (modified from Lassen et al. 1999 B)

By assessing the consumption of the substance with raw materials and semi-manufactures for production in Denmark e.g. from the import/export statistics it is important to avoid "double account" where the same quantity is accounted two times. This is further discussed in section 3.4.1 of appendix 1.

Supply

The terms 'supply' and 'consumption' describe in fact the same reality from two different points of view. In this paradigm, however, the term 'supply' is used in a pure trade statistical context where:

Supply = Danish production + imports - exports

The equation is similar to Equation 3, but consumption is replaced by supply. The term is used when data from the statistics is presented and the supply is calculated as a single value from the available statistical data. The supplied commodities may both be consumed for production processes and as finished products, and in addition, the statistical data may be vitiated by errors. It is an essential part of the SFA to determine to what extent this registered supply actually is equal to the consumption.

Accumulation

The consumption as defined above does actually not represent the total input to the Danish society; as also emissions and waste from production processes must be considered inputs (and at the same time outputs).

For the calculation of the present accumulation of the substance in the Danish society equation 4 can be modified in the following way:

(Eq. 5) Accumulation = consumption(finished products) + loss(production processes) - total emissions - total loss to waste

'Loss (production processes)' represents emissions to the environment and loss to waste from production processes. The loss can be ideally be calculated as:

Loss(production processes) = import (raw materials) + extraction(raw materials) - export(raw materials) - production(finished products)

The picture is, however, in reality often very complicated due to intensive import and export of semimanufactures. The losses from the production processes are therefore most often calculated from the figures on production and typical emission factors. If the number of Danish producers is small the loss from production processes may be estimated from information obtained from all producers.

These losses are also included in 'total emissions' and 'total loss to waste'. The reason for this emphasis on the loss from production processes is that by experience these losses are often omitted from the assessment of inputs and only included as emissions.

It should be noted that the accumulation in the society does not say anything specific about the accumulation of the products sold the year of reference. For substances where the consumption is declining, the accumulation may be negative meaning that the amount of the substance accumulated in the society is declining.

2.3.4 Modelling

In principle all potential flows identified during the system analysis should be estimated. Although the 'core SFA' is aimed at being a simple 'bookkeeping' of the substance flows it is often necessary to use simple or more complex models to determine some of the flows. In addition, some of the extensions include more complex modelling.

It is essential to keep in mind that the SFA is not only a systematic way of representing the available information on the flows of the substance. The SFA is a systematic way of representing all flows; whether or not data are available. It is not uncommon that less trained researchers confuse the available information on flows with the "true" flows.

Less investigated substances

When carrying out SFAs for less investigated substances, there may not be any Danish monitoring data of the substance in wastewater, residual products, flue gasses, etc. For most substances data on emissions from production processes are also absent.

In this situation it has to be decided whether the SFA should exclude this part of the analysis or the most probable values should be estimated on the basis of analyses from foreign countries or theoretical models.

If models and foreign results are used in the SFA, it should be clearly indicated all through the report. For instance such estimates has been used in SFA for brominated flame retardants /Lassen *et al.* 1999 B/.

Foreign analysis results

When using foreign analysis results, the use pattern of the substance in the foreign country should be comparable to the use pattern in Denmark. For substances with same use pattern in Denmark and Sweden, by way of example, analysis from Swedish wastewater treatment plants may be used in the absence of Danish result, when all assumptions are clearly indicated and it is indicated that the estimates are based on Swedish results. Such results can be used to indicate whether Danish analysis programmes should be initiated.

Models based on physical/chemical properties

In the absence of directs measurements of emissions from production processes or products in use the emissions may be estimated from models e.g. based on physical/chemical properties of the substances and the materiel they make part of. Such estimates will usually be very uncertain and only the order of magnitude can be estimated.

Process specific emission factors have been developed in EU for use in Risk Assessments and emission factors for different industrial sectors can be found in the "Use Category Documents". Similar documents are under development under the auspices of the OECD. An example of using the "Use Category Documents" can be found in SFA for brominated flame retardants /Lassen *et al.* 1999 B/.

Models based on historical consumption figures

Often the loss of the substance to e.g. solid waste can only be determined from information on historical consumption figures as the products discarded today may have been introduced into the society many years ago.

Today loss of the substance with a specific product will depend on two parameters:

- An assessment of the life-time distribution of the product
- An assessment of the annual consumption of the substance with the product within a historical period covering the whole range of the life-time distribution

A detailed example can be found in SFA for cadmium, where the amount of NiCd disposed of in 1998 is estimated based on the basis of such a model (Drivsholm et al. 2000).

These models in many ways resemble the scenarios for the future loss/disposal of the substance discussed in Appendix 1 section 3.7.1.

2.3.5 Sun-down chemicals

For sun-down chemicals, chemicals on the way to be phased out, there is some specific procedures that will be mentioned here.

For substances, which are commonly used for the application in question in Denmark, the total consumption in Denmark may be extrapolated from information from the main producers and suppliers. This procedure will, however, not apply for 'sun-down chemicals', because the manufactures will usually not know whether other manufactures still use the chemical or use a substitute. In addition, it will often be so that the largest producers have substituted the substance, but it is still used by small producers. In this instance, the total consumption cannot be extrapolated from information from large suppliers representing e.g. 80% of the market of the product, as the remaining 20% may represent the total consumption in Denmark. It is thus necessary that the assessment cover practically all suppliers. An example of such an analysis can be found in SFA for chlorinated hydrocarbons (Maag 1999).

This means that it is necessary to have a nearly 100% coverage which can only be obtained by questionnaire surveys or telephone interviews. By experience, the reply percentage of questionnaire surveys is quite low unless the inquiries are followed up by direct telephone calls.

3 Level of Detail and Reliability

The SFAs may be conducted at different levels of detail and reliability. As regards the analyses carried out and published in Denmark so far, it is relevant to distinguish between:

1. Detailed analyses aimed at providing a basis for action plans and regulation of the substance in question

2. Overview analyses aimed at identifying the main fields of application and sources of environmental exposure related to the substance in question.

In addition, the analysis can be extended with one or more of the extensions. A number of possible extensions are specified in Appendix 1.

The definition of level is a part of the initial 'Goal definition' and it is recommended to define the level of detail and reliability to be achieved/aimed at, before a substance flow analysis is initiated. Accordingly, all reports on SFAs should specify the degree of uncertainty that applies to the results. This way, it will be possible for the client to assess, for instance by spot checks, whether the analysis has been completed satisfactorily.

In principle, the uncertainty of consumption data in relation to detailed analyses and overview analyses, respectively, cannot be documented, as that would require the existence of knowledge about the 'true' values. As regards detailed analyses, the method of analysis in itself including the use of cross-checks (cf. Box 1) is assumed to support the correctness of the stated degree of uncertainty.

Detailed analyses

Examples of detailed analysis are the SFAs for mercury /Hansen 1985; Maag et al. 1996/, lead /Hansen & Busch 1989;Lassen and Hansen 1996/, copper /Lassen et al. 1996/ and tin /Lassen & Hansen 1997/. These analyses have typically required an effort of 3-5 man months per substance and are estimated by the authors to have fulfilled what is designated the 80/20 rule, i.e. a minimum of 80% of the consumption has been identified according to fields of application and determined within an interval of $\pm$ 20% around the mean value. The remaining part of the consumption has been determined with a considerably higher degree of uncertainty. In the previous analyses it has often not been stated explicitly how the intervals should be interpreted, but it is recommended that the interval itself according to section 2.3.1 in subsequent detailed analyses represent a 90% certainty level.

As regards the assessment of losses to the environment, it also applies that a precise level of uncertainty cannot be stated.

In the case of substances that are predominantly imported into Denmark as additives contained in finished products, the uncertainty of the outcome of a detailed analysis may be significantly higher. One important factor in this context is that cross-checks for consumption data cannot be carried out. Obviously, this leaves little possibility to check the distribution of the consumption on different fields of application. In such cases, it will be difficult, even with an extensive effort, to achieve a result with a lower degree of uncertainty than that of an overview analysis.

In reality, the result may be verified only by comparison to investigations from other countries or by obtaining information about the size of the production in Europe or world-wide, and on this basis, make an estimate of the likely consumption per inhabitant in Denmark. For substances predominantly imported into Denmark with finished products it is recommended to extend the SFA with a detailed analysis of the application of the substance in an international perspective.

Overview analyses

Among the examples of overview analysis are those for arsenic, chromium, cobalt and nickel /8/. The typical time requirement of these analyses has been about 1 man month per substance (only possible because of the greater efficiency achieved by carrying out more analyses in parallel) and, in terms of accuracy (as assessed by the authors), it is estimated that 80 per cent of the consumption has been determined with an accuracy of $\pm$50% and the remaining 20% with significantly greater uncertainty. The estimates of losses to the environment will also be subject to greater uncertainty than what is the case in detailed analyses.

Another characteristic difference worth mentioning is the fact that, in connection with detailed analyses, a considerably greater effort is put into verification of data on consumption by means of cross-checks, whereas such cross-checking has been practically impossible in the case of overview analyses. This is due to the fact that, in some of the overview analyses carried out until now, a significant part of the consumption was estimated on the basis of information about the consumption in the USA. For comparison, at least one enterprise (often 2-4 usually but not all industries) within all significant fields of application were contacted as part of the detailed analyses.

Other levels of detail

In principle, SFAs can be made both more or less detailed and reliable than what is described above.

If the analyses are to be more accurate than level (1), it will, in practice, be necessary to collect information from virtually all relevant enterprises, including importers of manufactured products, and to verify discharge data etc. In addition, detailed information will need to be obtained about all links in the chain of treatment and final disposal of waste and residual products. In principle, it should thereby be possible to reduce the uncertainty of consumption data to a marginal level. At the same time, it should be possible to minimise the uncertainty of data on discharge to the environment to a level corresponding to that implied in sampling and chemical analysis. Up until now, no analyses at this level of detail have been carried out in Denmark and the time consumption involved would probably also be unreasonably high (1 year or more per analysis?).

In order to minimise the time consumption, it may be necessary to use foreign analyses/data as a basis and presume that these data (proportionally according to population) also apply to Danish conditions. Provided that foreign data are available, it is thus possible to make estimates of the consumption distributed on fields of application, which may provide an initial overview of the situation but usually not in any significant degree of detail. As the Danish systems for treatment and disposal of waste and residual products differ significantly from the practice in other countries (for instance, incineration of solid waste is more widely used in Denmark than in the rest of Europe), it will normally not be possible to use foreign data to estimate the environmental exposure in this part of the process. Furthermore, the differences in the industrial structure and discharges from manufacturing processes may also be significant.

As it appears, there is a close connection between the level of detail and reliability of SFAs and the effort invested. The information given above about inputs required builds on experience with heavy metals and organic compounds with rather complex but still known patterns of application and flow in the society. In the case of substances with a simple pattern of application and dispersion, the analysis will be less time-consuming than what is stated above. Other substances may, on the contrary, require more input.

4 Sources of Information

Many sources of information are available for the preparation of SFAs. Providing a full overview of these is a comprehensive task, which falls outside the scope of this paradigm. This section points out a number of the most important sources of information.

4.1 Technical Reference Books

Two technical encyclopaedia of particular importance are 'Ullmann' /Ullmanns'/ and 'Kirk-Othmer' /Kirk-Othmer/. These encyclopaedia may be used to achieve an initial overview of the fields of industrial application of chemical substances. The encyclopaedia also provide a great deal of information about processes and thereby a solid background on which to foresee what losses to the environment are likely to be caused by industrial processes in Denmark. In addition, Kirk-Othmer for many of the substances provides information about global consumption by application area.

When the main fields of application have been identified, additional information can be found in specialised technical literature on the individual materials in which the chemical substances is used. Such literature is not listed here, but reference is made to the Technical Library of Denmark and other technical libraries.

4.2 Statistical Information

Statistics Denmark

Information about Danish production, imports and exports of goods is available from Statistics Denmark, who prepare annual and quarterly statistics of the production of goods in Denmark as well as foreign trade.

The methods used by Statistics Denmark, reliability of data, etc. is in detail described in the publications and in a 'Declaration of Contents' for each publication. The Declarations of Contents can be found at the Internet /DS 1999/ and is only briefly summarised here.

Production of goods in Denmark

Statistics on the production of goods in Denmark are published quarterly in the publication 'Manufacturers Sales of Commodities. Series A-D'. This statistical report follows the European Unions statistical system and covers, in principle, about 10,000 tariff items. The report is published about 3.5 months after the expiry of the quarter concerned. The statistics covering the fourth quarter of the year also contain figures for the entire year. The information given includes the production of goods in terms of Danish currency and in terms of tonnes/litres/item or any other relevant unit of measure. The statistics are based on information received from enterprises in Denmark with more than 9 employees. In principle, the information is provisional. Final data for the year is available 6-7 months after the expiry of the year and may be obtained upon request from Statistics Denmark. For more detail see /DS 1999/.

Foreign trade

Statistics on foreign trade are registered similarly to statistics on production of goods in Denmark and published quarterly in the journal entitled 'External

Trade by Commodities and Countries'. The statistical report covering the fourth quarter of the year also contains figures for the entire year. The figures are given for the import/export of goods in terms of Danish currency and tonnes and may also be stated in number of items, m² or any other relevant unit of measurement.

The statistics are published approx. 5 months after the expiry of the quarter concerned. In principle, the information given is provisional. Final data for the year is available 6-7 months after the expiry of the year and may be obtained upon request from Statistics Denmark.

For external trade different methods are used for EU- trade and trade with non-EU countries.

- EU-trade

The EU-trade is the trade between Denmark and the other EU Member States. The statistics are based on information declared monthly to Statistics Denmark from importers and exporters. This so-called INTRASTAT system was introduced in 1993 when the internal market of the EEC entered into force. Up until 1993, the statistics for all external trade were based on data submitted by the custom authorities.

Only companies with an annual EU-import of more than 1.5 million DKK or an annual EU-export of more than 2.5 million DKK have to declare to Statistics Denmark. In terms of value, however, still 98% of the EU-trade is covered by the statistics /DS 1999/. The threshold values change frequently and the indicated values cover 1999.

- trade with non-EU countries

Trade with non-EU countries is based on the declarations submitted by the custom authorities. The statistics in principle cover all import and export, but for transactions below a threshold value of 6,500 DKK and a weight of less than 1,000 kg a simplified declaration may be used. Transactions below the threshold values, covering 2-4 % of the total non-EU trade, are registered under 'miscellaneous' tariff items number.

Sources of error

Sources of error is described in detail in the 'Declaration of Contents' from Statistics Denmark.

Statistics Denmark estimate that the total import/export figures for EU trade in general are slightly underestimated in spite of the absent declarations from companies with external trade below the limit values. It must, however, be expected that products manufactured in craftsman-like processes may be underestimated due to the statistical threshold values.

Beside the statistical errors as incorrect or missing registration, and the uncertainty introduced by the threshold values, there are some possible errors that can be introduced by the use of the statistical data.

Products are in general registered according to their main constituent. For instance, the heavy metal fraction from shredders is registered under the tariff item number "Zinc scrap", but a significant part of the fraction is alloys of copper, lead and other heavy metals.

The registered volumes may include aqueous solutions which, in fact, mainly consist of water (see the vitamin B-12 example in box 2).

The same constituents are imported and re-exported under different tariff item numbers (see the mercury example in box 2).

The only profound method to reveal errors, distortion, etc. in statistical data and the use of statistical data is to build up profound knowledge of the products and groups of products concerned by establishing a network of contacts to experts, importers, manufacturers, etc.

The Input/Output Statistics

These statistics contain information about the consumption of approx. 1,600 groups of products in Denmark distributed on approx. 117 lines of business including industries as well as service trades and public activities. The information about the consumption of products within each line of business is specified in Danish currency and on the basis of raw materials counts carried out every five years. As regards raw materials for the energy sector, including oil, coal etc., the actual volumes are also registered. Moreover, the 1,600 groups of products covers the whole range from raw materials, such as crude oil, gravel, etc. through semi-manufactured goods such as crude plastic iron sections, etc. to manufactured products such as tractors, cosmetics, etc. The statistics are prepared as economic instruments and have, so far, been used primarily to predict the effects of economic intervention**.** Until now there is no examples of using the Input/Output statistics for SFAs in Denmark. The statistics are not published in total, but data can be obtained from Statistics Denmark. The statistics constitute a valuable tool in order to analyse the patterns of consumption as regards different groups of product in Denmark.

Box 2
Examples of sources of errors in statistics

Example 1: Import of vitamin B-12 to Denmark
In connection with the SFA carried out for cobalt /Andersen *et al*. 1984/, it was necessary to know the volume of vitamin B-12 imported into Denmark. According to the statistics on foreign trade, this import amounted to approx. 70 tonnes (1982 data). A Danish pharmaceutical company was contacted in order to verify the correctness of this figure. The medical manufacturer informed that the product imported was in fact a solution of vitamin B-12 in water. The actual content of B-12 was in the order of 1%. The stated import of 70 tonnes thus equalled an import of vitamin B-12 of approx. 700 kg, whereas the rest was water.

Example 2: Import of CFC and similar compounds to Denmark
For the purpose of monitoring the consumption of ozone depleting compounds in Denmark, specific customs tariff item numbers were established in 1989 for the main CFC, HCFC and similar compounds. In 1992, an SFA was conducted concerning the consumption of these compounds in 1990 /Hansen & Petersen 1992/. For this analysis, information was obtained from importers and Danish consumers (manufacturing companies) as well as Statistics Denmark. On certain points, the information from Statistics Denmark deviates significantly from that of the other sources. These deviations have been explained by presuming that incorrect tariff item numbers had been used for part of the imports (incorrect registration). This is considered to be a likely explanation in view of the fact that the tariff item numbers at this time were new combined with the general lack of specialised knowledge about chemicals among forwarding agents and customs officers.

Example 3: Import of organic mercury compounds to Denmark
In connection with the SFA carried out for mercury /Hansen 1985/, an import into Denmark equalling approx. 300 kg of mercury contained in organic mercury compounds was registered (foreign trade statistics). This observation created some confusion, as there was no known use for these substances in Denmark. The paint, varnish and lacquer industry no longer used mercury compounds as a preservative in emulsion paint and preservatives for seed corn were imported as finished products from other countries. After further investigation, it was discovered that the imports were intended for the production of emulsion paint in tropical countries. A Danish paint manufacturer with subsidiaries in tropical countries imported these organic mercury compounds to Denmark. The compounds where then packed together with other additives and re-exported to the subsidiaries. These exports were registered as paint additives.

Foreign statistics

Among foreign tabular surveys 'Mineral Commodity Summaries' and 'Minerals Yearbook' published by the US Geological Survey are of particular interest /USGS 1998 A and B/. Both publications are available for free at the Internet. 'Mineral Commodity Summaries' contains information on the US Consumption and World mine production, reserves and resources of most mineral raw materials including metals. 'Minerals Yearbook' holds information on the production and use of the minerals and metals. The emphasis is on the US situation, but the publication also includes trends in international production and trade.

Information on the use of a number of mineral resources in a historic perspective can be found in the report "World Resources (years)" from World Resources Institute /WRI 1999/. The report is updated every second year and is available at the Internet.

The 'Metallstatistik' from the German Wirtschafts Vereinigung Metalle e.V is another survey, which contains information relating to Europe / WVM 1999/. The statistics is available at the Internet.

As regards organic substances, similar statistical surveys do not exist. Information about production data can sometimes be found in international databases (e.g. ECDIN, EUCLID), in the literature, via the Internet and upon request from the manufacturers DuPont, Ciba-Geigy, Bayer, etc.).

Market reports

For some substances market surveys have been carried out by consulting companies specialised in business communication. Information on whether such market surveys are available can be obtained from the relevant industrial associations or from the Internet. However, statistical information cannot be expected to be available for all organic chemicals.

Examples of companies carrying out market reports are Frost & Sullivan (USA), IAL Consultants (UK) and Business Communications Company Inc. (USA). The market reports are often quite expensive (10,000-50,000 DKK) and the use of market reports has to be specified in the budget of the project. There may be some restrictions on the use of the information from market reports.

An example of using market report can be found in SFA for brominated flame retardants /Lassen *et al.* 1999 B/.

Eurostat

A CD-ROM is available from the Eurostat (the statistical office of the EEC) which contains complete official foreign trade statistics covering the 15 Member States and all partner counties in the period 1976-1992. The statistics is named COMEXT. The statistics are updated monthly on CD-ROM /European Union 1999/.

4.3 Manufacturers, Importers etc.

The most important sources of information to explain the pattern of consumption of substances in Denmark, are the manufacturers, importers etc. involved in trade with the substance or products in which the substance occurs.

A good tool for identifying the relevant enterprises is the 'Kompass Inventory of Trade'. Beside a printed version, Kompass is accessible as a database via the Internet. Some parts of the database can be accessed for free, other require subscription.

The 'Purchase guide for Engineers' and similar procurement reference books are recommended, along with contacts to trade associations etc.

Information from private enterprises can, in principle, be obtained through interviews or questionnaire surveys. In reality, it is a matter of experience to determine which survey method is most appropriate in each case. Generally, interviews are well suited when:

- There is a need for detailed information about manufacturing processes, patterns of application, etc.
- It is difficult to phrase simple and precise questions
- The information requested can be obtained through contact to a limited number of key persons or enterprises

On the other hand, questionnaire surveys are appropriate when:

- It is necessary to contact a great number of enterprises (more than 10) to obtain the same kind of information.

- It is possible to phrase simple and precise questions.

It should be emphasised that information obtained from private business is often confidential and are to be treated accordingly (cf. Section 5.1).

Internet

Basic company-specific technical information can often be obtained from the Web-sites of the companies. Especially regarding technical information from foreign companies, the Internet is a strong tool in obtaining information of the newest developments.

Covering letter

Private business cannot be expected to afford to take the time to respond to random inquiries**.** Irrespective of whether the SFA is carried out on behalf of a private client, the Danish EPA or another public institution, any inquiry in writing should be accompanied by a covering letter explaining the purpose of the analysis and the manner in which the results will be published and used. Such a covering letter also serves the purpose of documenting the credibility of the investigator and must be signed by the client.

The relevant associations of trade and industry should also be informed, before the initiation of the analysis.

4.4 **Other Sources of Information**

Research institutions and literature constitute other sources of information. Generally, great amounts of information can be obtained from these sources which are relevant in connection with SFAs, including information about special fields of application of chemical substances, typical production technologies, losses through industrial processes, treatment methods for residual products etc. The possible sources of information are numerous and, in order to fully exploit these, a good grasp of the situation is required which, in practice, can only be obtained through experience. In the following, some of the most important sources of information are listed.

Research institutions

In Denmark, a number of institutions exist within different fields of expertise, among others:

- The Technical University of Denmark and other universities

- The Danish Technological Institute

- The Danish Academy of Technical Sciences including the FORCE institutes etc.

- Ministerial agencies and research institutions including the Danish Environmental Protection Agency, the National Environmental Research Institute, the RISØ National Laboratory, etc.

- Rendan

- DEFU, dk-TEKNIK, consulting engineering companies etc.

In addition, a number of trade associations exist including associations covering the paint, varnish and lacquer industry, the plastics industry, the mechanical engineering industry, etc. Furthermore, the electricity companies can be approached for information regarding the use of coal for power generation and the resulting residual products.

ConAccount

A list of institutions and consulting companies in Europe working within the field out SFA has been drawn up in 1998 as a part of a EU Concerted Action Programme, ConAccount /ConAccount 1999/. The list includes references to relevant projects carried out by the institutions.

The Product Register

The Danish Product Register contains information about the composition of a large number of chemical products marketed in Denmark. The register only contains information on chemical products that contain one or more substances classified dangerous. The information in the register is confidential, but public authorities including the Danish EPA can make data retrievals on the consumption in Denmark of selected chemical substances by application fields. The data from the register should be interpreted with caution, especially for substances with a marked decreasing trend in consumption, as the data often represent the situation some years ago. If data from the register are to be used as a substantial part of the analysis, a quality check of the data to ensure that all declarations are up to date should be discussed with the responsible authorities.

Literature

The relevant literature for SFAs at national level in Denmark include statements and reports published by the Danish EPA and other institutions within the Danish Ministry of Environment and Energy. Of particular interest are the working reports and the environment project series of the Danish EPA.

As regards information about consumption, waste, wastewater, emissions from energy conversion etc., it is recommended in addition to make a search on SFAs and other reports published by environmental authorities and research institutions among others:

- Nordic Council of Ministers
- OECD (e.g. Risk Reduction Monograph series)
- WHO (e.g. Environmental Health Criteria series)
- European Commission (e.g. Use Category Documents, other Technical Documents or Risk Assessments)
- 'KemikalieInspektionen', 'Naturvårdsverket' and 'Institut för Vatten- och Luftvårdsforskning' (IVL), Sweden
- 'Statens Forurensningstilsyn' and SINTEF, Norway
- 'Umweltbundesamt', Germany and Austria
- Ministry of Housing, Spatial Planning, and the Environment, The Netherlands

- US Environmental Protection Agency

- UNEP (United Nations Environment Programme)

In addition, valuable information can be found in the general technical literature including technical magazines - Danish as well as foreign.

The Internet

The Internet has an increasing significance as a tool for information retrieval. Many reports and statistical data are published at the Internet and the Internet can be used for literature searches (see e.g. the literature list of this report). More detailed description of the use of 'web portals' and 'search engines' for searches at the Internet can be found elsewhere.

Waste treatment facilities

Data on the presence of the substance in waste and residues from waste treatment has often to be obtained directly from the waste treatment facilities, among others municipal wastewater treatment plants, solid waste incinerator enterprises and Kommunekemi (the Danish central treatment facility for chemical waste).

Optional extensions

Some of the optional extensions require specific literature retrieval from other sources. The information sources are mentioned for each extension in appendix 1. Literature sources for the extension regarding exposure is, however, mentioned below.

- *exposure*

If exposure of man by use and disposal of the products is included as an optional extension, it will be necessary also to search the scientific literature. The search should cover evidence of emission of the substance to the indoor and outdoor environment as well as evidence of exposure of man by using and disposal of the products.

A data source is the International Agency for Research on Cancer (IARC) which is part of the World Health Organization /IARC 1999/. The agency publishes monographs on the evaluation of carcinogenic risks to humans and the monographs include exposure assessments. In addition, relevant databases for the search will be HSDB and RTECS.

5 Reporting Techniques

References

As a general rule, clear references must be given for all information included in an SFA in accordance with normal scientific research standards. This rule applies both to information obtained from the literature and to information obtained through personal contacts to individuals and enterprises.

Transparency

Accordingly, clear statements must be made for all calculations of the assumptions on which they are based to make the estimates transparent. If the lack of precise information makes it necessary to use estimates as a basis for calculations, it must be clearly indicated, in each case, when an estimate has been used and who is responsible for this estimate.

Reliability and reproducibility

These rules are meant to ensure the reliability and reproducibility of the SFA and, at the same time, they make it possible to improve inaccurate estimates, if required.

In the following, a number of guidelines concerning reporting techniques are given, which aim primarily at SFAs carried out for public authorities.

Confidentiality

When collecting information from private enterprises, the rule of clear reference can only be fulfilled for purely technical information, whereas sources of information on turnover and conditions of production often has to be kept confidential.

It should be emphasised that private enterprises in Denmark are normally reasonably willing to supply information for analyses initiated by public authorities provided that their need for confidentiality is respected. This need will normally be satisfied if the enterprises are guarantied that the information supplied by them will only be reported after statistical processing, i.e. in a form which will not allow recognition of data for individual enterprises.

One way of doing this is to indicate in the report what enterprises have been contacted (may be listed in an appendix), but without specifying the exact information received from each enterprise. Then going through the individual fields of application, the information will be summed up by means of formulations such as: 'Based on information from Danish manufacturers/importers the total consumption for this purpose in 1990 is estimated at XX tonnes'. If information has not been collected from all manufacturers, it would be fair to indicate how many manufacturers have supplied information or the size of the market share covered by the information available.

A particularly difficult situation arises if there are only 1 or 2 manufacturers or importers within a specific field of application. In that case, it may be necessary to blur the figures in such a way that the competitors will not learn anything they did not already know while maintaining the information value. One way of doing this is to apply an inaccuracy margin to otherwise precise data. As regards fields of application of less significance in terms of volume and environmental impact, it may also be considered to conceal the information in the section about 'other fields of application' and only give sum totals for more fields.

It should be emphasised that these reporting guidelines do not mean that the author is free to distort information. The author must be prepared to discuss each individual figure contained in the report with the client.

Rules of the game

It is essential to have completely clear rules of the game between the client, the researcher and the enterprises/institutions supplying information for the analysis. If the client cannot accept the reporting techniques described above, this should be made clear at the initiation of the analysis so that no companies or institution supplies information under false pretences. It is thus unacceptable, if a researcher yields to pressure by the client to publish information submitted to him/her on the assumption that it would be treated in confidence.

Cross-checks

SFAs aiming to fulfil the requirements of detailed analyses (level 1, cf. Section 4) must be based on the concept of cross-checking, which should, in many ways, be decisive for the structure of the report. In the preparation of the report, the author should be clear about the types of cross-checks which could and should be carried out and plan the report so as to make these cross-checks an integrated part of the report.

Relevant cross-checks has been described in section 2.3.2

In practice, the integration in the report of such cross-checks means that:

- The report should include a section specifying statistical information on the consumption of raw materials and semi-manufactured goods and explaining possible discrepancies with the consumption of raw materials of the enterprises.

- The report should investigate and evaluate the routes of the chemical substance used in different industrial applications. This applies not only to releases from enterprises, but also to the volumes that end up in different products. In principle, the following routes should be evaluated:

  - Loss to air
  - Loss to wastewater or sea/fresh water
  - Loss to soil
  - Loss to solid waste (possibly with a distinction between combustible/non-combustible)
  - Collection as chemical waste
  - Collection for recycling
  - Accumulation in society (relevant for products with a long in-service lifetime)

- As regards substances/materials which occur in products with a long in-service lifetime (beyond 1 or 2 years), it may be necessary to look into the historical trend in consumption, as the volumes ending up as waste etc. are partly decided by the historical consumption.

- The report should contain specific sections about recycling, wastewater, waste, chemical waste etc., in which it is evaluated whether the volumes registered correspond to the expected input based on the estimates made for each field of application (cf. above). Possible discrepancies must be discussed.

It is emphasised that it might be necessary for the description of the individual applications to include estimates of the loss to solid waste, wastewater etc., which may be very inaccurate because of the lack of precise information. Preferably cross-checks has to be carried out, fully or partly, to verify the correctness of the magnitude of the estimates, otherwise it should be noted through the analyses that the indicated losses is based on very uncertain estimates.

References

Internet addresses by autumn 1999 are indicated for some of the references. The exact addresses of the documents are frequently changed and for this reason the main web-site addresses (URLs) are indicated by underline.

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Appendix 1
Standard Reporting Outline of Substance Flow Analyses Carried out for the Danish EPA

Table of Contents

1 Introduction

Purpose

This appendix contains the standard outline of a substance flow analysis (SFA) carried out for the Danish Environmental Protection Agency. The aim of the outline is to ensure the uniformity and comparability of the conducted studies.

The outline covers the substance flow from import and extraction of raw materials to the final disposal of residual products from waste treatment plants etc.

The outline should be regarded as a framework, which can and should be adjusted to match the intended level of detail of the analysis and the patterns of application and flow of the chemical substance in question.

This appendix starts off by presenting the overall structure (cf. Chapter 2) followed by a detailed description of the individual sections with indication of the information and evaluations to be included in each section of the report.

2 Main Structure of the Outline

The main structure of the outline appears from Box A1.

Box A3
Main structure of the outline

Preface

Summary and Conclusions in Danish and English

1. Introduction
   - 1.1 Purpose of the Analysis
   - 1.2 Methodology and Limitations
   - 1.3 What is <the substance>?
   - 1.4 International Market and Trends in Consumption
2. Application in Denmark
   - 2.2 Raw Materials and Semi-Manufactured Goods
   - 2.2 Fields of Application (eventually two sections)
   - 2.3 Consumption as Trace Element and Contaminant
3. Turnover with Waste Products
   - 3.1 Recycling of the Chemical Substance
   - 3.2 Other Turnover with Solid Waste
   - 3.3 Turnover with Chemical Waste
   - 3.4 Turnover with Wastewater and Sewage Sludge
   - 3.5 Summary
4. Evaluation
   - 4.1 Application and Consumption in Denmark
   - 4.2 Discharges to the Environment in Denmark
   - 4.3 Substance Balance in Denmark

References

Appendices

The 'core SFA' is contained in Chapters 1 to 4 and organised, as explained below.

Preface

The preface contains information about the project; client, steering group, working group, etc.

Summaries

Summaries in both English and Danish should be prepared according to the standard outlines of the Danish Environmental Protection Agency. Preface and summaries has no chapter numbers.

Chapter 1

Chapter 1 contains a general introduction to the analysis and the substance in question. The chapter include an introduction to the methodology, describe the substance or substance group and gives information on the international market and trends in consumption. The International market for the substance may be covered by an analysis at overview or detailed level.

Chapter 2

Chapter 2 contains a specification of raw materials and semi-manufactured goods as well as actual fields of application. The fields of application are divided into 'intended fields of application' and 'application as trace element and contaminant'. The intended fields of application include all fields of application where intentional utilisation of the properties of the chemical substance takes place. Application as trace element and contaminant includes unintentional applications where the substance occurs as trace element or contaminant in other substances and products, or where small quantities of the substance are formed as a result of industrial processes.

Based on the division into fields of application, the consumption is specified for each field and an assessment of likely losses is made. The assessment of turnover and losses should be pursued as far as practically possible, i.e. as far as it is reasonable to consider each field of application separately.

As regards certain products - particularly in the application as trace element in coal, oil etc. - it will be possible to consider each product individually through the entire life cycle. In that case, it should be done as part of the description of the different fields of application contained in chapter 3.

As regards industrial products, it is usually only possible to consider the individual products in isolation as far as production and use are concerned. The distinction between fields of applications cannot be maintained when it comes to waste treatment, as the existing data on discharges and losses concerning this part of the life cycle normally represent a mixture of products.

For instance, the emission of lead to air from waste incineration plants originates in a number of different lead-containing products. No knowledge exists about the exact significance of the individual product, and it would therefore be wrong to specify the loss to air caused by incineration for each individual product. On the other hand, it does make sense to calculate the amount of lead directed to combustible waste in different groups of products, and thereby, estimate the probable significance of each group of products for the emission caused by incineration of waste.

Chapter 3

Accordingly, the turnover and losses by waste treatment are discussed jointly in Chapter 3. This discussion also serves to cross-check the estimates of losses to waste, wastewater etc. made for the individual fields of application in Chapter 2.

Chapter 4

Chapter 4 puts the pieces of the jigsaw puzzle together, estimating the total consumption and loss to the environment and setting up the total substance balance for Denmark. In this chapter, comparisons can also be made with previous surveys and foreign analyses, if considered relevant.

Appendices

The appendices contain additional statistical data and optional extensions of the analysis.

3 Detailed Explanation of the Outline

The detailed explanation of the outline contained in this chapter follows the main structure shown in Box A1, in that the sections of this Chapter correspond to the main structure.

3.1 Preface

The preface of the report should be kept short (about 1 page) and include the following subjects:

- Background
- Client, financing
- Acknowledgements
- Composition of steering committee/reference group
- Authors of the report

Background

The reason for carrying out the analysis should be specified shortly. Is it an update of a previous analysis or is the substance considered problematic in a specific context?

A more detailed description of the purpose of the analysis and international commitments and obligations as regards the use and emissions of the substance should be included in chapter '1 Introduction'.

Client, financing

Specification of the party (or parties) responsible for initiating and financing the analysis.

Acknowledgements

Persons and institutions which has contributed substantially may be acknowledged here.

Steering Committee/Reference Group

The composition of the Steering Committee or Reference Group should be specified. In principle, all members should be mentioned by name and institution. As regards large-scale investigations comprising many representatives of a large number of institutions, however, it is acceptable to just mention the names of the institutions.

Authors

The authors of the report should be listed by name and institution. This is important to accommodate readers wishing to seek further information.

3.2 'Summary and Conclusions (Summary in English)'

Summaries in both English and Danish should in principle be prepared according to the standard outline of the Danish Environmental Protection Agency. These outlines can be find in /Danish EPA 1999/. It is, however, recommended to make an extended summary in English if the report is in Danish and *vice versa*.

In the following the content of the short summary is described according to the standard outlines of the Danish EPA by the fall 1999, but these outlines are revised now and then.

Purpose

The purpose of the summary is to provide an adequate briefing about the report and its content to the reader willing to invest about half an hour reading it.

Outline

The chapter should according to the standard outline be divided into:

- Menu
- Background and aim of the project
- The survey
- Main conclusions
- Main results

The content of the first four sections is well described in the standard outlines and only the content of the section 'Main results' will be discussed here.

If the analysis cover both consumption and discharges to the environment, it is recommended that ' Main results' is based on:

- A figure providing an overview of imports/exports, consumption, discharges to the environment etc. regarding the substance in question. This figure could be built up along the lines of Figure A2 shown below, which is a simplified version of Figure A2 in section 3.6.

- A table showing the total consumption by main fields of application in absolute (tonnes/year) as well as relative (%) figures.

- A table specifying the release to the environment by sources as well as recipients (air, water, soil, landfills).

In addition the probable trends in consumption and release should be discussed.

If the analysis include optional extensions, a short summary of these should also be included in the 'Main results' section.

Extended summary

The extended summary is recommended to be identical to the short summary except for the section 'Main results'.

Instead of the overview figure shown in Figure A1 it is recommended to include a more detailed figure similar to in Figure A2 in chapter 3.6. When using the detailed figure the table specifying the release to the environment by sources can be excluded.

In addition it is recommended to include tables showing the sources of the substance to solid waste and wastewater.

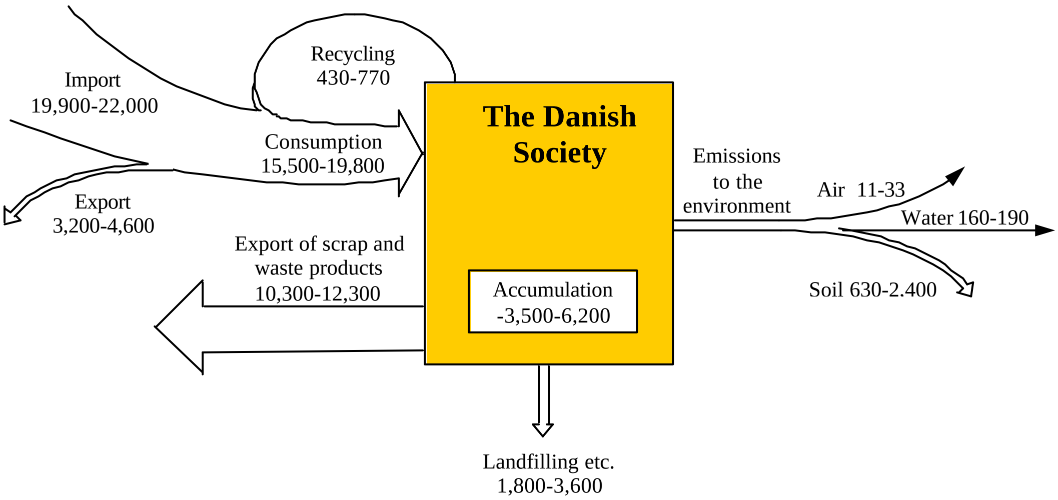

Figure A1
Example of figure providing an overview of the situation (lead balance for Denmark 1994 - tonnes lead/year /1/)

3.3 '1. Introduction'

The 'Introduction' includes all information considered relevant as background for the understanding and interpretation of the succeeding SFA.

The extent of the introduction will depend on whether the SFA covers a single relatively well-known element or it covers a complex group of chemical substances.

3.3.1 '1.1 Purpose of the Analysis'

Background

The reason for carrying out the analysis (goal definition) should be specified here in more detail. If the substance is considered problematic in a specific context, it should be mentioned. The section should be kept short.

International commitments and obligations as regards use and emissions of the substance should be included in the description of the background.

3.3.2 '1.2 Methodology and Limitations'

A description of the methodology of the analysis can more or less be covered by a reference to this paradigm. If a specific research methodology has been used it should be mentioned.

Interpretation

Interpretation of the intervals used for representation of all figures should be specified. What is actually meant by the sentence: ' The total consumption of the substance with application xx is estimated at 200-400 tonnes'. Furthermore, the reference year (or other space of time covered) should be specified.

If a specific level of detail has been defined in advance, this should also be stated.

Focus areas

If the analysis focus on specific parts of the life cycle (se main report about focus areas) the focus area should be specified along with the specification of areas that may be covered with less detail.

3.3.3 '1.3 What is <the substance>?'

The sections gives a short introduction to the substance or substance group. The introduction includes relevant physical/chemical properties of the substance or substances.

If the substance is an element the section may also include information on relevant chemical compounds.

If the substance is a complex group of organic substances the section may be supplemented with an appendix with physical/chemical properties of all substances.

3.3.4 '1.4 International Market and Trends in Consumption'

The international market assessment may be carried out at two levels:

- Overview assessment
- Detailed assessment (optional)

The overview assessment is considered part of the core-SFA.

Purpose

The purpose of this chapter is to provide information on the market of the substance in an international perspective. The exact content of the chapter will depend on the level of detail defined for the chapter, which may be different from the level of detail for the 'core SFA'.

The information on the consumption of the substance at global or European level may along with other sources be used for the estimation of the consumption of the substance with imported products. In addition the chapter makes the basis for a comparison of the Danish consumption of the substance to the consumption in other countries, especially EU Member States.

Structure

There is no general international trade statistics and it is consequently not possible exactly to define which information should be included in this chapter, but it can be defined which information sources should be searched.

Overview analysis

To the extent information is available the chapter should contain the following information.

- Global production and consumption by application areas (in tabular form)
- Global trends in consumption
- European and EU consumption by application areas (in tabular form)

Global trends in consumption

For the understanding of the global trends in consumption, it may be necessary to discuss specific issues regarding the extraction/production of the substance and global market mechanisms. For heavy metals, it may e.g. be relevant to discuss whether the metal is extracted as a by-product by the extraction of other metals.

Detailed analysis (optional)

The detailed analysis should beside the information included in the overview analysis also include the following topics to the extent information is available:

- Short review of substance flow analysis or consumption assessments from Sweden, Norway and The Netherlands including comparison with the Danish results.

- Detailed information about the global and European market for the substance based on international market analyses.

An example of an analysis containing detailed information about the global and European market for the substance based on international market analyses can be found in substance flow analysis for brominated flame retardants (Lassen et al. 1999 B).

Information sources
- overview analyses

If the substance is an element or a mineral, information on global production, consumption by application area and market trends should be summarised from at least Mineral Commodity Summaries and Mineral Yearbook (see. chapter 4.2 of main report).

In addition information should be searched from the encyclopaedias Kirk Othmer and Ullmann's and from reports specifically covering the substance in question from OECD, WHO, EU, UNEP and relevant international trade organisations (see chapter 4 of main report).

- *detailed analyses*

For the detailed analyses additional information should be received from international market reports if available and from assessments carried out in neighbouring countries (see section 4.2 of main report).

The results of the assessments in neighbouring countries should if included here be discussed together with the Danish results in Chapter '4. Evaluation'.

3.4 '2. Application in Denmark'

3.4.1 '2.1 Raw Materials and Semi-Manufactured Goods'

Purpose

The purpose of this section is to provide information on the supply of raw materials and semi-manufactured goods as registered by Statistics Denmark and discuss how these figures corresponds to the estimated consumption of raw materials for each field of application in Section 3.2 'Fields of Application'.

This section should be included in the report if there is Danish production or import to Denmark of the substance as a raw material or a semi-manufactured product. If the substance is only imported to Denmark with finished product this section is not needed and should not be included in the report.

The terms 'raw materials and semi-manufactured goods' refer here to the substance in its pure form as well as chemical compounds or alloys of which the substance constitutes a significant part. Materials and alloys of which the substance constitutes only a very small proportion do not need to be included in this section.

Production, import and export of scrap and waste products should not be included in this chapter, but included in chapter "3. Turnover with Waste Products':

Content

The information and evaluations to be included and carried out in this section include:

- The information available from Statistics Denmark about the year(s) covered by the analysis concerning production in Denmark as well as the import and export of raw materials and semi-manufactured goods shown in tabular form. In principle, the following information should be included for each raw material/semi-manufactured product:

  – Commodity item number and description of the goods
  – Registered production, imports and exports of the goods
  – Estimated average content of the substance in the goods
  – Estimated supply of the substance with the relevant goods

  As background for the discussion of the data, statistical information regarding production, import and export for at least a 5-year period is included in an appendix (see section 3.7).

- If a great number of different raw materials and semi-manufactured goods are registered by Statistics Denmark, it may often be advisable to present the detailed statistical information in an appendix, and provide a summary of this information in the table included in this section. It may also be appropriate to separate information about different types of raw materials/semi-manufactured goods. As regards heavy metals, for instance, it may be relevant to distinguish between pure metal/alloys and chemical compounds.

- For each type of raw material/semi-manufactured goods, the relevant fields of application should then be specified. In the case of raw materials that are used for many different purposes, it may be appropriate to draw up a specific table to summarise the information about fields of application. If there are raw-materials/semi-manufactured goods for which the fields of application are not known, this should also be indicated.

- Subsequently, indication should be made of the losses to waste and wastewater and release to the environment, which occur as a result of the production of raw materials and semi-manufactured goods in Denmark. In this context, only raw materials and semi-manufactured goods used for several different purposes should be commented on. To the extent that the production of raw materials and semi-manufactured goods is used for one type of finished product only, the assessment of losses and release should be placed under the relevant finished product in the 'Fields of application' section (a reference to the relevant subsection should be included to assist the reader in forming a general view of the situation).

- Finally, an assessment should be made as to whether there is reasonable coherence between the consumption of the substance with raw materials/semi-manufactured goods and the estimated consumption for different fields of application. It should also be discussed whether inconsistencies if any can be explained by changes in stocks or something else.

It should be noted that some of these assessments are based on data, which are introduced in subsequent chapters. In view of the fact that the assessments focus on the supply of raw materials it has, however, been considered appropriate to gather these assessments in this section.

Double accounting

As mentioned in the previous section the same materials may be processed several times and registered more times under the same item number in the statistics from Statistics Denmark. By way of example, imported aluminium profiles are cut into shorter profiles in Denmark. The same profiles are thus registered as both imported and produced. For an estimation of the supply of aluminium profiles for further production processes in Denmark it has been necessary to take this into account /see Lassen *et al.* 1999 A/.

3.4.2 '2.2 Fields of Application'

This section goes through the intended fields of application one by one describing the turnover of the substance in the production and consumption phases. Depending on the pattern of application, it may be relevant to have more sections on intended fields of application. Concerning metals, it would, for instance, be reasonable to include a section 2.2 covering the substance as pure metal and in alloys and a section 2.3 covering chemical compounds.

Each of these sections may be divided into a number of subsections each covering a field of application.

It is recommended to start out with the field of application with the largest consumption of the substance, followed by the application with the second largest consumption, etc. The last subsections most often covers 'other fields of applications'; applications not specifically discussed in the preceding subsections. By detailed analyses, 'other fields of applications' should be kept to a minimum and account for less than 20% of the total consumption of the substance for intended purposes.

For each field of application, the following aspects should be covered:

- Description of the field of application and relevant finished products
- Production in Denmark
- Imports/exports of finished products
- Consumption of finished products in Denmark
- Trends in consumption and stock building in society
- Alternatives (optional)
- Losses to waste, wastewater and the environment during production

- Losses to waste, wastewater and the environment during the use of the product

- Final disposal of used products including recycling

- Exposure during use and disposal (optional)

If appropriate a level four of headings could be applied to include each of the listed aspects.

Description

The description should be kept short (max. 1 page per field of application) and precise. It should indicate the included finished products and fields of application as well as the function of the substance in the products. Furthermore, the various technical conditions relevant for the understanding should be explained. If the substance is used in alloys or compounds, the composition of these should be specified. Concerning products in which the substance is evenly distributed in the product/material (e.g. pigments in plastics), it may also be relevant to specify the concentration of the substance in the actual finished product.

Production in Denmark

The industrial processes taking place in Denmark should be described, including specification of the finished products manufactured in Denmark, and if possible, the number of enterprises involved. Furthermore, it should be specified what raw materials/semi-manufactured goods are utilised as well as the consumption of the substance in raw materials/semi-manufactured goods and the quantity of the substance contained in the finished products. This information will typically have to be obtained from the manufacturers. If the information is not readily available, but has to be calculated on the basis of a number of assumptions, both the assumptions and the calculations must be described in detail.

Imports/exports

Estimates must be made of the import and export of the substance in finished products. Typically, this estimate will be based on statistical information about the import/export of relevant finished products combined with the calculated average content of the substance in these products. The basis of calculations as well as the actual calculations must be explained in detail.

Consumption in Denmark

The consumption in Denmark with finished product can then be calculated as Danish production + imports - exports; summarised for all finished products.

There may be some confusion about the definition of consumption in Denmark. Note that 'consumption in Denmark' in general covers the consumption of the substance in Denmark with **finished products**. (see the discussion in section 2.3.3).

Trends in consumption and stock building

It should be indicated whether the consumption is increasing, decreasing or stagnant. If the field of application covers several types of finished products, it may be relevant to assess each type of finished product separately. If available, historical consumption data about the consumption may also be included. In the case of finished products with a long in-service lifetime, it would be advisable to estimate the extent of stock building in society of the substance as part of these products. This estimate will constitute an important basis for the calculation of losses related to the use of these products (cf. below: 'losses by utilisation'). More detailed analysis of the historical consumption used for scenarios of future disposal and emission may be included as an optional extension (se section 3.7.1)

Substitutes (optional)

If the SFA includes the optional extension 'Assessment of substitutes' (see section 3.7.4) a short review may be included here.

Losses by manufacture

By manufacturing processes in Denmark, there may be losses of the chemical substance to chemical waste, solid waste, wastewater, the atmosphere and presumably also soil. The losses are calculated as the actual discharges from the enterprises after treatment, if any. The size of these losses after treatment should be estimated and it should be indicated how final disposal of the waste and treatment residues takes place. Furthermore, estimates should be made of the volumes of the chemical substance collected for recycling, if any.

The main sources of information will be the enterprises, themselves. It is also possible to use information about typical loss and emission factors, which may be obtained from literature or from specialists at research institutions. In some cases, information may be available from supervisory authorities, Kommunekemi (the Danish Treatment Facility for Chemical Waste) and treatment plants who possess knowledge about the discharges or receive residual products.

It will, normally, be very difficult to estimate the losses to soil as these are diffuse losses of dust etc. which normally cannot be or are not measured. It is therefore acceptable not to estimate the size of these losses but only indicate whether there is reason to expect significant losses to soil as a result of manufacture. For enterprises with poor facilities for air purification, a significant proportion of the emission to air may consist of particles, which will cause increased deposition of the chemical substance in the area surrounding the enterprise. If considered relevant and possible, this neighbourhood deposition may be calculated and included in the estimate as losses to soil instead of losses to air. Normally, there will not be sufficient resources to carry out estimates going into such detail within the framework of SFAs.

Losses by use

The size of losses by use of the products depends on the nature of the finished products and fields of application. Some products (e.g. washing powder) are lost 100% while being used (residues may be deposited with the packaging). Other products are subject to a certain degree of wear and tear or corrosion, but will be practically intact at the time of disposal.

The estimate of the losses during use requires both information about relevant emission factors and information about the volume of products accumulated in the society. The loss by use is calculated as the total loss of the substance from products in use during the reference year independent on the age of the products. In practise, losses by use can only be estimated with a high degree of uncertainty (cf. disposal).

Disposal

The quantities of the substance discharged to waste, wastewater etc. or recycled by discarded products should be estimated. If the consumption is stagnant and has been so for a period of time exceeding the in-service life of the products in question, the estimate may be based on the present consumption (subtracted the losses by utilisation), and supplemented by an assessment of the probable disposal method.

It is relevant to distinguish between the following waste fractions (cf. Chapter '3. Turnover with Waste Products'):

- Combustible solid waste
- Organic solid waste
- Waste collected for recycling
- Chemical waste
- Other solid waste
- Wastewater

If there is a clear increase or decrease in the consumption, it will be necessary to base the estimate on historical consumption data from a range of years corresponding to the in-service lifetime of the finished products. Such calculations are rough estimates, which will be subject to a high degree of uncertainty. However, these calculation are necessary to carry out cross-checks of the volumes of waste collected etc. For this reason alone, the estimates are valuable in spite of the uncertainties.

Exposure (optional)

A qualitative description of the exposure of man by use and disposal of finished products is an optional extension of the SFA. The description should focus on the use and disposal phases. Both consumer and occupational health issues in connection with the use and disposal of the products should be covered, whereas occupational health in connection with the production of raw materials and manufactured products is excluded.

The description should include:

- Evidence of emission of the substance to the indoor or outdoor environment by use or disposal of the product.

- Evidence of exposure of man to the substance by the use or disposal of products. Exposure includes both exposure by inhalation (gasses and particulates), by skin contact and by food contact.

- Possible substantial exposures not confirmed by analysis

When describing possible exposures it is relevant to distinguish between exposure by 'good practice' and by 'reasonable worst case'. Good practice is application of the products in accordance with the guidelines given by authorities or producers; whereas ' reasonable worst case' includes common deviations from these guidelines. Exposures by 'reasonable foreseeable misuse' where the products are used unwarrantably should not be included.

Summary of the entire section

At the end of the entire section, there should be a subsection including a short summary based on a table indicating for each field of application the present consumption, trends, annual recycling as well as annual loss of the substance to air, soil, water/wastewater, solid waste, chemical waste and others. This summary helps the reader maintain an overall view of the situation. At the same time, the summary is valuable to the author, as it serves as a checklist (have all relevant issues been dealt with?).

3.4.3 '2.3 Consumption as Trace Element and Contaminant'

For most substances, there is a turnover of the substance as natural trace element or anthropogenic contaminant in other products. Although the substance is not intendedly consumed, this turnover will be designated 'consumption as trace element and contaminant'.

This section cover relevant fields of consumption explaining the turnover of the chemical substance in the production and consumption phases as well as, if relevant, throughout the remaining part of its life cycle. The section is divided into a number of subsections, each including a field of application.

Heavy metals will typically be consumed as a trace element in coal, oil, wood, fertiliser, feedstuff, agricultural chalk and other fields of application. For heavy metals as for other elements, it applies that, due to the fact that they are natural parts of the environment, they will occur in varying concentrations in most of the products used in society. For other substances, the application as contaminant has to be estimated in each individual case.

Content

The subjects covered in the explanation of each field of application as trace element and contaminant correspond largely to the subjects specified for 'fields of application'.

Coal

Considering the consumption as trace element in coal, it would thus be relevant to consider the following issues:

- Natural content of the substance in coal (there will be variation according to the origin of the coal).
- Emission of the substance to air as a result of burning.
- Production and application of coal/fly ash (a distinction may be made between application for production of cement, concrete and asphalt, road construction, filling purposes and land reclamation, etc. In the summary included at the end of this section as well as that of Chapter '4. Evaluation', the application for construction works is included as landfilling (will typically be reported to the authorities), whereas utilisation for cement, concrete and asphalt, is considered as utilisation for new products, i.e. stock building in society is taking place.
- Discharge of the substance as a result of the utilisation of coal/fly ash (there will be emission to air as a result of the production of cement, discharge to water and soil in connection with road construction and filling purposes etc.).
- Trends in consumption.

Oil and other fuels

As regards the consumption as trace element in oil and other fuels, it will be relevant to consider the following issues:

- Natural content of the substance
- Discharges and residual products as a result of refining
- Discharges and residual products as a result of burning

- Discharges by final disposal of residual products
- Trends in consumption

Fertilisers,feedstuff, etc.

Concerning the application as trace element in fertiliser, feedstuff and agricultural chalk, it will, accordingly, be relevant to consider the following issues:

- Natural content of the substance in raw materials
- Discharges as a result of manufacturing
- Losses to the environment as a result of the use of finished products and of 'residual products' such as dung
- Trends in consumption

The above lists are meant as examples. In practice, it will be necessary to consider the life cycle of the substance for each individual field of application as trace element and contaminant.

Summary

The section includes a short summary based on a table indicating, for each field of application, the present consumption and trends as well as the annual loss of the substance to air, soil, water/wastewater, solid waste, chemical waste and other end points.

3.5 '3. Turnover with Waste Products'

3.5.1 '3.1 Recycling of the Substance'

This section summarises the information about recycling of the substance as a pure substance, as an alloy and as a chemical compound. This information is compared to the available statistical data on production, import and export of waste products for recycling. Furthermore, estimates are made of emissions as a result of recycling activities.

Statistics

The section is opened with a table showing statistical data on production, import and export of relevant scrap and waste products based on the statistics from Statistics Denmark. The statistical information on production of scrap is actually somewhat curious and very difficult to interpret and it is usually necessary to obtain additional information from the main scrap dealers to estimate the actual turn over with waste products for recycling.

The scrap and waste often consist of composite products and it is necessary to estimate the specific concentration of the substance. The substance may also be exported in mixed waste fractions for recovery abroad. By way of example, copper is partly exported in a mixed metal fraction from shredders registered as 'zinc scrap' as zinc is the main constituent.

Cross-checks

These statistical data are compared to the result of the summary of the information on recycling activities from all 'fields of application' in chapter 2. In case unexplainable inconsistency is registered when the balances are first set up, it may become necessary to check the estimates made for recycling of the substance from all 'intended fields of application'.

Losses by collection, sorting and stock building

Inconsistency can sometime be explained by losses and discharges by collection, sorting and stock building of recyclable materials. It is, however, not possible to set up general rules, and it will be necessary to look into this question for each chemical substance. Experience shows that it is very difficult to estimate losses and discharges, at this stage - particularly losses to soil. Rough estimates based on mass balances are therefore acceptable provided that a description of the actual processes proves it probable that the estimated losses do, in fact, occur.

This section does not include any assessment of the losses and discharges by actual industrial processing of the chemical substance etc. If such processes take place, the assessment hereof should be included in Section 2.1'Raw Materials and Semi-manufactured Goods' or Section 2.2 'Fields of Application'.

3.5.2 '3.2 Other Turnover with Solid Waste'

This section includes an assessment of the turnover of the chemical substance as a result of the treatment and final disposal of solid waste including incineration, composting, landfilling and recycling of waste products. Recycling of the chemical substance itself is not discussed in this section (included in Section '3.1 Recycling of the Substance').

This assessment also serves to cross-check the quantities of the substance estimated to end up in solid waste.

A prerequisite for the assessment is that monitoring data exists of the chemical substance in solid waste and in the residual products and emissions resulting from the treatment of solid waste. Data will typically be available for the most common heavy metals whereas data for chemical compounds including organic substances are scarce. If the available data are insufficient, the assessments will either have to be discontinued or based on theoretical models or a monitoring programme will have to be initiated.

Note that quantities of residual products will normally represent wet weight whereas the concentration of the substances in the residual products most often is measured per dry weight. For the calculation of the total turnover of the substance with residual products, it is thus necessary to know the water content of the products.

Assuming that adequate data are available to carry out the assessment, it may, in principle, cover the following issues:

- Total annual volumes of solid waste in Denmark divided according to methods of treatment and final disposal
- Turnover by recycling of materials
- Turnover by biological waste treatment
- Turnover by thermal waste treatment
- Turnover by landfilling activities

It would be appropriate to cover each of these issues in a separate subsection. If the turnover by recycling of materials is very complex, it may be relevant to have separate subsections for each material, e.g. a subsection for paper, one for plastic, one for metals, etc.

Quantities and methods

In the subsection about quantities of waste, the total annual volume of solid waste in Denmark by types of waste, methods of treatment and final disposal should be indicated. This information serves as a basis for further evaluation. The level of detail will depend on the requirements as to the accuracy of distinction between different types of waste and methods of treatment and final disposal. Considering methods of treatment and final disposal, there should typically be a distinction between recycling, biological treatment (composting/biofermentation), thermal treatment (incineration) and landfilling.

It might be appropriate to include, in this subsection, a general assessment of the sources of the chemical substance to solid waste. This means that a list should be set up of the expected sources of the substance to solid waste with discarded products etc. An estimate of the size of these sources will have been made in connection with the discussion of the different intended fields of application and the turn over as trace element and contaminant. When setting up this list, a distinction should be made between the different methods of treatment and final disposal, as specified above. Thus, a general overview of the situation is achieved which will be useful in the evaluation of sources to be carried out in the subsequent subsection.

Recycling

The subsection(s) concerning recycling include(s) an assessment of the substance flows and discharges of the chemical substance by recycling and processing of waste materials such as plastic, paper, iron and steel, electronic waste, etc.

General guidelines cannot be given for this assessment, as it will depend on the substance in question and its fate by these recycling and processing methods. It is important for the assessment to end up with an estimate of the quantities of the chemical substance which:

- are discharged to air, soil or water
- are destroyed
- end up in solid waste
- end up in new products produced from these materials

Biological treatment

Here, biological treatment includes composting and biofermentation. This subsection includes an assessment of the substance flow through facilities for these treatments. The assessment should at least include the following components:

- Existing measurement data on the content of the chemical substance in different fractions of waste supplied to such facilities (cf. Box A2).
- Existing monitoring data concerning the content of the chemical substance in different residual products from such facilities.

- Emissions (air, wastewater) of the chemical substance from such facilities.

- Degradation of the substance during the process

- If possible, a mass balance drawn up on this basis for the chemical substance at such facilities (see comments below).

- Final disposal of residual products from such facilities and the volumes of the chemical substance thus directed to soil, deposited at controlled landfills or otherwise (for instance, sifting residues with a significant content of plastic will presumably be taken to a waste incineration plant).

Monitoring data on the content of the chemical substance in different fractions of waste should be subject to critical evaluation (cf. Box A2). If the waste is inhomogeneous, the results of monitoring will normally mainly reflect the general background content in the waste rather than the total content. In spite of this, it would be sound practice to present existing knowledge, i.e. existing monitoring data. Danish data are preferable, but foreign data may be included, where Danish data are not available, if such data are considered to be representative of Danish waste. Monitoring data concerning residual products (e.g. finished compost) will typically be reliable (subject to the general uncertainty related to sampling and chemical analysis) due to mixing and homogenisation of the waste which takes place as part of waste treatment operation. A critical evaluation of these data should be made, as well, in order to identify possible systematic biases (have plastic bits been removed from the compost before analysis etc.?). Series of measurements should be referred to by mean values and standard variation.

If no monitoring data exist about sifting residue, the only practicable way to calculate the content of the chemical substance in sifting residue will be to make an estimate on the basis of a source assessment (see above). In this evaluation, it should be kept in mind to include waste products such as sewerage sludge. The resulting assessment will inherently be uncertain and, most likely, cross-checks cannot be performed.

As regards a number of chemical substances, particularly substances used as additives in plastic etc., it should be expected that a significant part of the content of the chemical substance in compost and residual products from biological treatment plants stems from plastic etc., which has been taken to pieces as a result of the mechanical processes (sifting, turning of winndows, etc.) which are part of the treatment process. A source assessment (see above) may therefore be essential in order to understand and explain the concentrations of chemical substances, which can be measured in the residual products.

The extent to which a full mass balance should be established and a source assessment carried out has to depend on the significance of the substance flow through the biological treatment plant as compared to other types of waste treatment.

Waste incineration

This subsection should include an assessment of the substance flows by solid waste incineration. The assessment should at least include the following components:

- Existing monitoring data concerning the content of the chemical substance in different fractions of waste supplied to solid waste incinerators (cf. comments regarding biological treatment plants and Box A2).

- Existing monitoring data concerning the content of the chemical substance in different residual products from solid waste incinerators.

- Various emissions (air, wastewater) of the chemical substance from incinerators

- If possible, a mass balance worked out on this basis for the chemical substance at incinerators (see comments below)

- Final disposal of residual products from incinerators and the volumes of the chemical substance thus landfilled, utilised for construction works etc.

As regards solid waste incineration plants, it will normally be possible to work out mass balances for heavy metals and other elements. Data can be obtained on the content of the substance in slag, fly ash, flue-gas cleaning residues and flue gas (remember possible steam emission and amounts supplied by ancillary materials for flue gas cleaning). Note when working out the balances that the volumes of residues are usually given in wet weight, whereas the concentration is given per dry weight. On this basis, an estimate can be made of the content of the substance in the waste incinerated. On the contrary, it is likely not possible to establish mass balances for chemical compounds which may be degraded/transformed as a result of thermal treatment, e.g. dioxins.

Source assessment should also be carried out in connection with waste incineration. In this assessment, it is important to remember waste products from other types of waste treatment such as fragmentation residue from scrap yards, sifting residue from biological treatment plants, sewage sludge etc. Considering heavy metals and other elements, the source assessment will constitute a cross-check, as the expected total amount of supplies should be in accordance with the result of the mass balance of waste incineration plants. As regards organic compounds and other chemical compounds, the source assessment will, in most cases, be the only way of achieving an estimate of the supplies to waste incineration plants. As in the case of biological treatment plants, it has to be evaluated whether the source assessment carried out for such facilities can be made sufficiently reliable to be trustworthy.

As regards final disposal of residual products, it may be relevant to assess the leaching from residual products used for construction works. It should be noted that, in the case of chemical substances not easily soluble in water, the discharges will normally be marginal and should only be included in detailed SFAs. As regards chemical substances, which are highly soluble in water, these discharges should be included, also in overview analyses.

It should be noted that, in the summaries included in the reports, landfilling includes the utilisation of residual products for construction works. The reason for this is the fact that utilisation for construction works typically requires notification of and registration by the authorities. However, the utilisation of small amounts of slag/ash does not require notification and should therefore, in principle, be regarded as a loss to soil. The total amount of residual products and thereby the amount of the substance thus supplied/lost to soil should, of course, be estimated, if possible and if the amounts are considered to be significant.

Box A2
Reliability of monitoring for waste fractions.

Monitoring data on the content of chemical substances in solid waste often underestimate the actual content of the substance. An important reason is the difficulty of taking out representative samples of mixed solid waste, combined with the fact that chemical substances often is non-homogeneous distributed in the waste. This is illustrated by the following examples:

Example 1:

This is a calculated example concerning Ni/Cd batteries.

According to /4/ Ni/Cd batteries (loose, closed batteries) have an average weight of approx. 34 g each and contain approx. 6.1 g of Cd (approx. 18%). Packets of batteries for tools, computers etc. have an average weight of approx. 400 g each and contain approx. 72 g of cadmium. The average useful life of such batteries is estimated at approx. 4 years and the consumption in 1988 amounted to approx. 700,000 loose batteries and approx. 145,000 packets of batteries /4/.

Considerable collection of used batteries takes place, but some will still end up in solid waste. The precise amount collected is not known. If it is estimated, that 75% is collected (corresponding to the agreement made between the Danish EPA and the retail trade, which entered into force on 1 February 1992), approx. 175,000 loose batteries and approx. 36,000 packets of batteries corresponding to a total of approx. 3.7 tonnes of cadmium will end up in solid waste. These batteries are likely to end up mainly in household waste or similar types of waste, which is mainly taken to waste treatment facilities.

According to /4/, a total of approx. 1,780,000 tonnes of waste was incinerated in Denmark in 1990, with an estimated average content of cadmium amounting to approx. 6.9 mg/kg waste. Assuming that the 175,000 batteries and 36,000 packets of batteries are evenly distributed in the waste, this corresponds to one battery or packet of batteries for each 8 tonnes of waste. These batteries and packets of batteries will add an amount of cadmium to the waste corresponding to approx. 30% of the total content of cadmium in the waste.

Now, the interesting question is how much waste has to be analysed in order for the investigation to be representative as regards the occurrence of batteries and packets of batteries. No statistical evaluation of this question is known to have been carried out. On the face of it, it is the opinion (of the authors) that there is reason to be critical of investigations covering less than 25 tonnes of waste.

Example 2:

Another example is the well-known Laxå project in Sweden (cf. /2/). As part of this project, household waste was sorted and analysed for 9 heavy metals as well as PCB. As regards cadmium, the result showed that the most important sources of cadmium in household waste were: PVC plastic, rubber/leather and metal (other than tins and tubes - probably zinc alloys).

It is interesting why the Laxå project did not point to pigments in plastic as an important source of cadmium in waste. As a pigment in plastic, cadmium was used for red, yellow, orange, chestnut and similar colours. In the Laxå project, the quantity of cadmium in plastic other than PVC was calculated as 0%. From the description of the methodology (cf. /2/) it appears that plastic is only sorted into two fractions, viz. 'PVC plastic' and 'other plastic'. A number of samples have then been taken from each fraction for analysis. The plastic was thus not sorted according to colour.

In a Danish analysis of household waste (cf. /3/), the waste was also sorted according to colour. It turned out that only approx. 11% of the plastic was coloured by use of cadmium pigments. The part of the plastic coloured by cadmium pigments had a significantly higher content of cadmium. It must therefore be regarded as probable that, in the Laxå project, plastic coloured by cadmium pigments was incidentally not included in the samples. Most likely, the material analysed was therefore not representative.

Conclusion:

From these examples it is concluded that direct monitoring of the contents of waste is only reliable if the extent and the sorting techniques used are likely to produce results which are representative as regard the chemical substances and the fields of application covered by the analysis. Unfortunately, waste analyses seldom live up to these requirements. Typically, such analyses will show values concerning the content of heavy metals etc. in solid waste which are significantly below those, which can be calculated by mass balances for waste incineration plants.

Landfilling

This subsection includes an evaluation of substance flows by landfilling. The evaluation should at least include:

- Existing monitoring results concerning the content of the chemical substance in different fractions of waste supplied to landfills (cf. comments included in the subsection on biological treatment plants and Box A2)

- Various discharges (air, wastewater, leaching to groundwater) of the chemical substance from landfills.

It will probably be difficult to carry out mass balances for landfills due to the lack of reliable monitoring data concerning the content of the chemical substance in the waste supplied to the landfill. Moreover, the significance of possible degradation of the chemical substance during treatment (only relevant for organic substances) should be taken into account.

The only possible way to achieve an estimate of the supply of the chemical substance to waste deposits will most likely be to make an estimate on the basis of a source assessment (cf. biological treatment plants and waste treatment plants). In this assessment, it is important to include waste products such as sewage sludge and residual products from biological treatment plants, waste incineration plants etc. The assessment will probably be subject to a certain degree of uncertainty and can hardly be cross-checked.

It must be stated how effluents from landfills are treated and discharged.

3.5.3 '3.3 Turnover with Chemical Waste'

This section aims at evaluate the discharges to the environment by treatment of chemical waste in Denmark and to carry out cross-checks on the estimated loss of the chemical substance to chemical waste carried out for each field of application in Chapter '2. Application in Denmark'.

The section should thus cover:

- Supply of the chemical substance to chemical waste

- Volumes of chemical waste received by Kommunekemi (the national treatment facility for chemical waste in Denmark) etc.

- Emissions and substance flows by treatment of chemical waste

The section should not cover chemical waste processed or exported for recycling of the chemical substance. These issues will be covered in Section '3.1 Recycling of the Substance'.

Types and amounts supplied to waste

Based on the assessments undertaken in Chapter '2. Application in Denmark', a list is made (in the form of a table) of all supplies of the chemical substance to chemical waste. In principle, this list should indicate the source and type (pure substance, chemical compound etc) as well as the quantities (tonnes/year). Furthermore, indication may be made of the facilities to which the relevant type of chemical waste is delivered or at which final disposal takes place (Kommunekemi or others).

Reception

To the extent possible, data should be obtained from Kommunekemi and other disposal facilities about the quantities of waste received by types of waste. Kommunekemi may not have such detailed information, however. In that case, information should be obtained from Kommunekemi about possible imports/exports of waste, about discharges to air and water and about the quantities deposited in the form of ash, slag and filter cake. On this basis, it should be possible to make an estimate of the total amounts received. It should be considered whether degradation of the chemical substance will take place during treatment. Anyhow, it is important to consider whether there is reasonable accordance between the expected amounts received and the amounts, which can be registered by Kommunekemi. Possible discrepancies should be explained.

It should be noted that Kommunekemi might also receive polluted soil and that other disposal channels exist for some substances - some of which are approved, and some are not. By way of example oil is widely incinerated at other approved plants than Kommunekemi.

3.5.4 '3.4 Turnover with Wastewater and Sewage Sludge'

This section should include an assessment of the content of the chemical substance in sewage sludge as well as the size of discharges and substance flows by wastewater treatment and disposal of sewage sludge and other residual products. At the same time, the assessment will constitute a cross-check to verify the amounts of the substance estimated to end up in wastewater.

To what extent the assessment can be carried out depends on the existence of monitoring data concerning the content of the chemical substance in wastewater and sewage sludge. Data will typically be available for the most common heavy metals and persistent organic compounds. However, for many chemical compounds no data are available. If the available data are inadequate, the substance flow analysis will either have to be abandoned at this point, a special monitoring programme will have to be initiated or the estimates has to be based on theoretical models.

Assuming that adequate data are available to carry out the evaluation, it should include:

- Total annual discharged volumes of wastewater and rainwater (urban run-of) in Denmark

- Existing monitoring data concerning the content of the chemical substance in wastewater, rainwater and sewage sludge as well as the efficiency of treatment facilities

- Assessment of sources of the chemical substance in wastewater and rainwater

- Total amounts of sewage sludge and disposal hereof

Quantities

The total annual amount of wastewater in Denmark should be indicated as a basis for further evaluations. A minor part of this amount will be discharged to soil via infiltration plants and the rest is supplied to wastewater treatment plants or discharged directly to the aquatic environment. Moreover, some rainwater is discharged directly to the recipient. The extent to which these conditions should be taken into consideration depends on the level of detail of the analysis.

Existing monitoring data

Data on the content of the chemical substance in wastewater, rainwater and sewage sludge should be collected and specified (if possible). Such data may be obtained by personal contact to wastewater treatment plants or from literature. It is important to make sure that these data are representative. Furthermore, the literature should be consulted to obtain information about the typical efficiency of treatment at wastewater treatment plants aimed at the chemical substance and an assessment should be made as to whether there is reasonable concordance between these data and the registered concentrations contained in wastewater and sewage sludge.

Modelling

If monitoring data do not exist, this part of the analysis must be excluded or 'best estimates' may be obtained by modelling on the basis of e.g. physical chemical properties of the substance, experiences with analogous substances or experiences from other countries. It should be clearly noted in the report if emissions are estimated on the basis of models. For instance, the concentration of the substance in effluents from wastewater treatment plants may be estimated if the concentration in influents, the efficiency of treatment facilities and the physical/chemical properties of the substance is known.

Source evaluation

A list should be drawn up of the expected sources of the chemical substance in wastewater and rainwater. This list should be based on the estimates of loss to wastewater made in Chapter '2 Application in Denmark', and the other sections of this chapter.

Subsequently, an evaluation should be made as to whether there is reasonable concordance between this list (total amount supplied) and the actual monitoring results concerning the content in wastewater, rainwater etc. and to what extent inconsistencies can be explained.

Assuming that there is reasonable concordance, it should be possible, at this point, to make a qualified estimate of the total content in wastewater and of the substance flow through wastewater treatment plants.

Sewage sludge

If some of the chemical substance is likely to end up in sewage sludge, indication should be made of the ways in which sewage sludge is disposed of (landfilling, agricultural soil or incineration) and of the loss to the environment thus taking place. It would be relevant to make a distinction between losses to air, soil and solid waste and, if relevant, destruction.

3.5.5 '3.5 Summary'

This section sums up all types of waste disposal in Denmark. The section is based on a table indicating, for each disposal way, the annual loss of the substance to air, soil and water as well as the quantities estimated to be incinerated, deposited or recycled/stocked in society in new products. This summary helps the reader maintain an overall view of the situation. At the same time, the summary is valuable to the author, as it serves as a checklist (have all relevant issues been dealt with?).

3.6 '4. Evaluation'

3.6.1 '4.1 Fields of Application and Consumption in Denmark'
This section sums up the available information and estimates concerning the consumption of the chemical substance for different purposes in Denmark.

It is recommended to base the section on a table listing the different fields of application in as much detail as possible. For each field of application the consumption in absolute (tonnes/year) and relative figures (%) as well as the trend in consumption (downward/upward/stagnant) should be indicated.

The text in this section will focus on the conclusions that can be drawn from the table, i.e. total consumption, main fields of application and development trends. Moreover, the uncertainty on the consumption should be indicated.

In the case of updates of previous analyses, the results of such analyses should also be shown and the trends in consumption commented on.

3.6.2 '4.2 Discharge to the Environment in Denmark'
This section should sum up the available information and estimates concerning discharges to the environment of the substance in Denmark.

As in the case of Section '4.1', it is recommended to base the section on a table listing the different sources of discharge in as much detail as possible. For each source the discharges in absolute figures (tonnes/year) to air, water, soil and landfills should be indicated. As a footnote to this table, it should be indicated how much of the volumes deposited that is utilised for construction works.

The text in this section should focus on the conclusions, which can be drawn from the table, i.e. total discharge to air, soil and water and the amount deposited as well as the main sources of these discharges and losses. Moreover, the uncertainty of the data should be addressed.

In the case of updates of previous analyses, the results of such analyses should also be indicated and the development commented on.

3.6.3 '4.3 Substance Balance for Denmark'
This section aims to provide a general view of the main flows of the substance in Denmark. Here, it is recommended to base the section on a figure similar to that shown in Figure A2.

An important element of the figure is the calculation of the stock building of the chemical substance taking place in the Danish society. This stock building is calculated on the basis of a mass balance including all imports and exports to/from the Danish society. The stock building will most often be positive, but for e.g. 'sunset chemicals' negative stock building are seen.

Apart from this, a brief explanation of the main elements of the figure is sufficient.

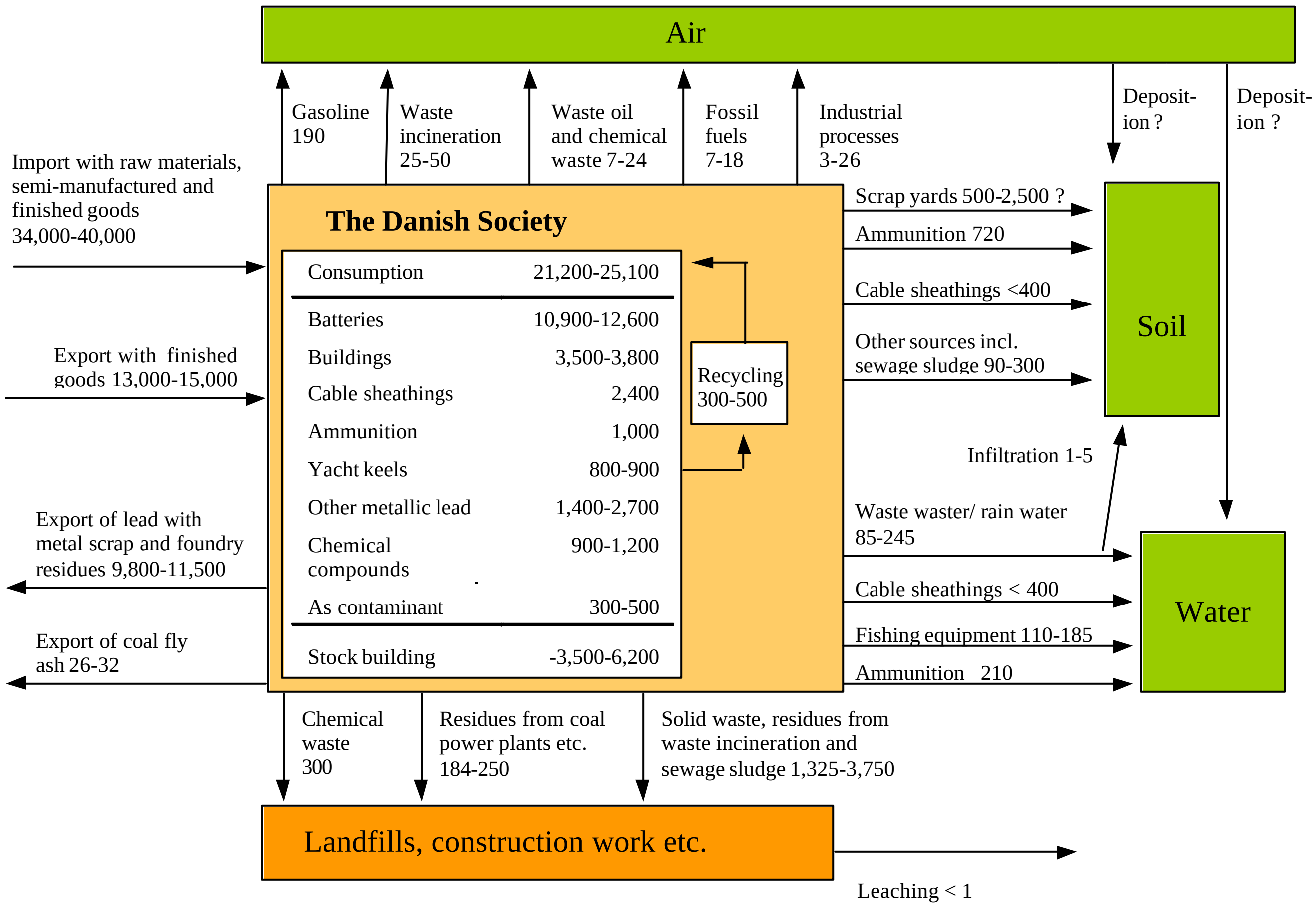

Figure A2
Mass Balance for Denmark - example (lead balance in Denmark 1985 - tonnes/year /1/)

3.7 'References'

References are indicated in accordance with normal practise for scientific reports. Based on the reasons stated in the main report, it would, however, be appropriate only to indicate the names of enterprises, from whom consumption figures have been obtained in a specific appendix entitled 'Enterprises Contacted '.

3.8 'Appendices'

The report should at least include the following appendices:

- Enterprises contacted

- Statistical information about imports, exports and Danish production of raw materials and semi-manufactured goods containing the substance. The list should include data for a period of at least 5 years in order to disclose random variation and incorrect registration and show possible trends in consumption.

Apart from these appendices the following optional extensions will be discussed in the following:

- Scenarios for future loss of the substance
- Occurrence and fate in the environment
- National and international regulation on the use of the substance
- Assessment of substitutes
- Recycling, downcycling and material deterioration

The titles of these appendices should only be considered suggestions.

Other appendixes may of cause be included as well if necessary.

3.8.1 Scenarios for Future Loss of the Substance

The appendix is an optional extension to the SFA.

The analysis can be carried out at two levels:

- Simple scenarios
- Detailed scenarios

The core SFA includes an assessment of the actual loss of the substance to the environment and landfills. The analysis, however, does not include any forecast of the potential losses of the substance in the future. For many substances, there is at the moment a continuous accumulation of the substance in the society and the losses are consequently lower than the present input of the substance into the society.

By way of example the consumption of aluminium profiles for wood window frames has increased markedly during the last years, but due to the durability of the windows only small amounts of aluminium profiles are at the present disposed of with the windows.

Discussion of models for prediction of future emissions and examples of application of the models to case studies can be found in Voet *et al.* 1999.

The object of the appendix is to study the sustainability of the present recycling and disposal of the substance and to analyse the future effect of different regula ting actions.

By the initiation of the SFA is will be necessary to define which application areas should be covered by the appendix and the space of time for the scenarios.

Simple scenarios

Simple scenarios can be developed by presuming that the present consumption and disposal pattern continues until a steady state is attained. At that moment, the sum total of loss and recycling will counterbalance the consumption. Such a simple 'business as usual' scenario can provide very useful information regarding the sustainability of the current consumption and disposal pattern, but often more exact scenarios are demanded.

Detailed scenarios

A more detailed scenario for the future loss of the substance imply for each product covered by the assessment the following:

- Information about the present loss of the substance by use and disposal of the products

- An assessment of the life-time distribution of the product

- An assessment of the annual consumption of the substance with the product within a historical period covering the whole range of the life-time distribution

- Scenarios for the future consumption of the product (the space of time will be dependent of the space of time of the loss scenario)

- Scenario for the future disposal of the product

Information about the loss of the substance by use and disposal of the products will most often based on the present use and disposal of the products.

Life-time distributions

Information on life-time distributions of the products can be obtained from the technical literature, producers, distributors and users of the products. It should, however, be emphasised that the actual life-time of the products may be different from the technical life-time. After use the products may be stored for some time in lumber-rooms and lofts or the product may be used in summer houses etc. where it is actually only used for a short time of the year. These effects have had a significant influence on *inter alia* the life-time distribution of electronic products, where the amount of discarded products has been significantly lower than expected from the technical life-time distributions.

Historical figures

Historical consumption figures can be obtained from Statistics Denmark, if the products can be unequivocally identified by relevant commodity numbers. Most often this is not the situation and it will be necessary to combine statistical information with information from obtained from previous consumption assessments and persons with years of experience in the relevant line of business.

A similar approach may be used within the core SFA for estimation of the amount of the substance accumulated in the society and the total loss of the substance with specific products with e.g. solid waste. The approach is however more time consuming than usually allocated for the assessment of the accumulated in the society.

An example of the application of this approach can be found in SFA for cadmium 1999 where the actual disposal of cadmium with NiCd batteries to solid waste is calculated from life-time distributions and historical consumption figures of NiCd batteries for different applications /Drivsholm et al, in press/.

Scenarios for the future disposal

Development of scenarios for the future disposal pattern will include considerations about the extent of recycling of the products in the future. The recycling rate will depend on the development in recycling technology, market mechanisms and governmental regulation of recycling and recovery. It is recommended to develop more scenarios where one of the scenarios is the "Business as usual" scenario.

Input

The input will depend on the number of application areas covered by the scenarios. It should be noted that each application area might cover many product types with different life-time distributions. The simple scenarios will take approximately three to six man-week for all application areas. It is estimated that the detailed scenarios for the first application area will approximately take one to four man-weeks dependent on the number of different product types; the following application areas will take less.

3.8.2 Occurrence and Fate in the Environment

The appendix is an optional extension to the SFA.

The object of the appendix is to provide an overview of the occurrence of the substance in the environment in Denmark. This information is aimed to be used in combination with other studies to provide a basis for decisions regarding the need for further minimisation of emissions of the substance to the environment.

For the discussion of the distribution of the substance in the environment, physical/chemical properties and fate of the substance in the environment is shortly described.

It should be emphasised that the appendix should not include data on the toxicity and do not contain a risk assessment or risk evaluation. If a risk assessment is needed it is recommended to carry it out as a separate project.

The assessment should at least include:

- Monitoring data for the substance in the environment in Denmark
- Discharges to the environment (from main report)
- Fate of the substance in the environment

An example on organotin compounds can be found in Stuer-Lauridsen *et al* 1998. This study, however, includes both occurrence and fate in the environment and a hazard and risk evaluation.

Monitoring data

The assessment should include a comprehensive summary in tabular form of existing monitoring data from Denmark covering the following compartments:

- **Atmosphere**
  - Air
  - Rainwater
  - Deposition
    - Background deposition
    - Deposition near point sources and in cities

- **Terrestrial environment**
  - Soil
    - Agricultural soil
    - Soil near point sources an in cities
    - Other soils
  - Terrestrial organisms

- **Groundwater**

- **Freshwater and marine environment**
  - Water, sediment and aquatic organisms
    - Open sea (background)
    - Coastal environment
    - Harbours
    - Near point sources

The table should be based on published and unpublished data (if possible) from the National Environmental Research Institute, the Environmental Protection Agency, the National Forest and Nature Agency, GEUS, County Environment Departments and Universities. Literature should be searched in relevant databases; ASFA among others.

Monitoring data on the concentration of about 100 substances in sediments will from the mid 2000 be available in the ATLAS database of the Danish EPA.

If monitoring data from Denmark do not exist or are scarce the summary may include literature data from other countries; in order of priority: the Nordic countries, EU Member States, OECD countries, Global.

The table should include both mean values and minimum/maximum values to indicate the range of concentration of the substance in the environment. If the range is wide, it is relevant to discuss the basis for the variation: data quality, point sources, hotspots, etc.

Discharges

Discharges to the environment identified in the SFA should be summarised in tabular form. The table should include both discharges that have been quantified and discharges that only qualitatively have been identified.

Fate of the substance

An assessment of the fate of the substance in the environment can be a rather extensive study, but will here be limited to a listing of relevant physical/chemical properties in tabular form and a short review of environmental chemical properties of the substance. The aim of the review is to form a background for a discussion of the observed distribution of the substance in the environment.

The relevant properties depend on whether the substance is an element or an organic chemical. For organic chemicals relevant physical/chemical properties would be: Solubility, Henry's Law constant, octanol-water partition coefficient, pK_a and distribution coefficient.

For elements relevant properties are less well defined but relevant properties will be: Solubility, speciation in various media (water, soil, sediment, air) and physical/chemical conditions (pH, O_2 concentration, alkalinity). Attention should be paid on soluble or immobile species.

In addition the fate of the substance in the environment should be described as regards bioconcentration, degradation, biodegradation and biotransformation.

The data sources for this part of the assessment are numerous including databases as HSDB (Hazardous Substances Data Bank), IUCLID (International Uniform ChemicaL Information Database), ENVICHEM (Environmental Properties of Chemicals). For this reason it is for each assessment necessary clearly to define the strategy of data retrieval; which databases are searched and which properties are evaluated? The strategy of data retrieval will be closely connected to the level of detail and reliability of the assessment.

As minimum, it is recommended to search HSDB, ENVICHEM, IUCLID and SAX's Dangerous Properties of Industrial Materials.

Mackay distribution

If the substance is an organic chemical a Mackay level 3 distribution is calculated /Mackay & Patterson 1991/. The distribution represents the steady state distribution of the substance between air, soil, water and sediment when the actual discharges to the compartments are used as input-parameters.

Discussion

The properties concerning distribution and bioaccumulation should finally be discussed in relation to the concentrations actually found in water, sediment and aquatic organisms.

Input

The input for this appendix will be very dependent on whether the SFA covers a single element or a large group of chemicals. If the SFA covers a large group of chemicals, it may be most appropriate to report this assessment in a separate publication. The input for a single substance will approximately be a half to two man-month.

3.8.3 National and EU legislation on Use Restriction

The appendix is an optional extension to the SFA.

The object of the appendix is to give an overview over the current legislation on use restriction in Denmark and the EU.

The appendix should not include information on other regulation concerning the substance, e.g. limit values for the substance in wastewater, municipal sludge, etc.

Outline

The current Danish regulation of the use of the substance is chronologically gone through. For each act or statutory order the following is stated:

- The name of the regulation
- A short description of the of restriction of the use of the substance lain down in regulation (10-50 lines)
- Relevant EU directives if the Danish regulation is an implementation of EU directives

EU directives not implemented in Danish legislation should shortly be described by the end of the appendix.

Information on legislation can be found in:

- Legal Information (http://www.retsinfo/)

- Schultz legislative information (http://www.schultz.dk/)
- EUR-lex of the European Commission (http://europa.eu.int/eur-lex/)

Input

The input for this appendix will be approximately between a half and one man-week.

3.8.4 Assessment of Substitutes

The appendix is an optional extension to the SFA.

The object of the appendix is to provide detailed information about possible substitutes to the substance in question. The assessment of substitutes may only cover some of the applications of the substance and it is by the initiation of the assessment necessary to define which applications are covered.

Outline

For every fields of application covered by the appendix possible substitutes are described. The substitutes are described at different levels (see below). The levels included in the assessment should be defined by the initiation the assessment. For each substitute technical advantages and disadvantages should be described. Obstacles for substitution e.g. that new machinery and tool are needed if the substance is to be substituted should also be described.

The assessment is summarised in a table listing the substitutes at the different levels.

Levels of substitution

It assessment of substitutes are included in the SFA a short summary of the substitution assessment may be included for each application area within the main part of the report.

Substitution may take place at three different levels:

A: Substance level substitution: The substance can be replaced with another substance

B: Composite or compound level substitution: The substance makes part of a composite/compound material, which can be replaced by other composite/compound.

C: Service level substitution: The service provided by the substance (or composite/compound) can be obtained by a totally different solution.

For instance brominated flame retardants used for flame retardancy in computer monitor housings may be replaced by other flame retardants (A), the plastic compound/flame retardant system may be replaced by another plastic compound/flame retardant system (B), or fire safety may be obtained without the use of flame retardants by changes in the construction of the monitor (C) /Lassen et. al 1999 B/.

In the following the term substitutes will also include alternative solutions.

The substitutes can be described at four levels and it should be defined whether the assessment is to cover only some of the levels. For each of these levels, substitution may take place at the three levels of substitution mentioned above. The resulting matrix is shown in the following table.

	Substance level	Composite or compound level	Service level
Potential alternatives not technically approved			
Technically approved alternatives not commercial available			
Commercial available alternative raw materials and semi-manufactures			
Commercial available finished products with alternatives			

Information sources

The information on substitutes can be obtained from technical literature, technical experts and suppliers of raw material, semi-manufactures and finished products.

It will often be necessary to make direct contacts to technical experts in development departments and laboratories of foreign companies e.g. the large chemical companies. The contact can be established through the Danish branches or agents of the companies.

It should be noted that discussion at the first level, 'potential alternatives not technically approved' often will be very difficult and requires that the authors have an extensive technical knowledge about the subject.

Price of alternatives

An assessment of the economic feasibility of substitution includes beside an assessment of the prices of alternatives also e.g. costs of new machinery and tools for processing of the alternatives and is a quite extensive study. The price of the alternative is only on aspect and could solitary described be misleading. If a comprehensive substitution feasibility assessment is carried out it is proposed to report the assessment in a separate publication. It is therefore proposed not to include any economic considerations in this appendix.

A new paradigm for assessment of the economic feasibility of substitution has recently been developed by the Danish EPA.

Input

Input will be dependent on the number of applications and levels covered by the assessment. The input for an assessment at all levels for one application will approximately be one to three man-weeks.

It is proposed by the initiation of the project to define the number of applications covered by the assessment and for each application to fill in the matrix shown above to define the included levels.

3.8.5 Recycling, Downcycling and Material Deterioration

The appendix is an optional extension to the SFA.

There is at the moment a tendency toward a more widespread technically optimisation of materials by composing the materials of many different elements, minerals or chemical compounds. This applies for polymers, metal alloys and composites and mineral composites; in the following all designated 'composites'. In addition, the components are often covered by inseparable surface layers of other materials.

For example, aluminium is optimised for different specific applications by alloying the aluminium with a large number of other metals. The aluminium products may in addition be surface treated with thin layers of metals or other materials /Lassen et al. 1999 A/.

When the materials are collected for recycling they are often mixed resulting in secondary materials with a more limited application range than the primary materials and problematic components (e.g. heavy metals) may be spread to materials where they do not have any explicit function.

Issues related to the recycling of the materials are discussed in this appendix.

Outline

The appendix should include (the order illustrates the lineout of the appendix):

- Description of the composites and surface treatments used for the application areas covered by the assessment

- Description of material collection and recycling, including:
  - actual practice for sorting of collected materials
  - actual practice for recycling and downcycling
  - grades of secondary materials

- Description of material deterioration by recycling; both during a single and many material life cycles

- Loss of the material by each material life cycle

- Procedures for improved collection and recycling of the materials as regards mixing of grades

- The potential for and costs of upgrading secondary materials to a quality similar to primary materials

- The potential for separation of the composites into pure elements

The appendix is closed by a summary including a discussion of the assessment.

It should be noted that "downcycling" in the analysis should be put in two perspectives: a resource perspective and a contamination perspective. For problematic substances as heavy metals "downcycling" is a way the substances are dispersed in the technosphere to areas where they are undesired. In addition, the "downcycling" makes a "decontamination" of the technosphere more difficult. For problematic substances the analysis should include considerations about the time perspective of the "downcycling" helix; when can the substances introduced into the technosphere be expected to be disposed of as waste or discharged to the environment?

Information sources

The information on collection and recycling can be obtained from recycling companies, technical literature and technical experts.

It will often be necessary to make direct contacts to recycling companies and technical experts in foreign countries. The contact may be established through the Danish recycling companies or technical experts. The companies' web-sites at the Internet may also be an entrance.

Input

The input will be dependent on the number of application areas covered. By the initiation of the SFA is should be defined which application areas are covered by the appendix. There is only very limited experience with this extension in SFA's and the input has to be estimated separately for each substance.

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Appendix 2

Approximate Man-hour Inputs

In the table below the input of man-hours for the core SFA and optional extensions is summarised. The proposed inputs should be considered as reference values, and the actual input has to be determined specifically for each substance in question.

Core SFA, detailed	Approximately 3-5 man months per substance. For 'sun-down chemicals' extra input must be expected if the consumption assessment are to reach the level of a detailed analysis.
Core SFA, overview	Approximately 1 man-month per substance if more substances are analysed in the same project.
International market and trends in consumption, detailed	Approximately 1-3 man-week per substance or substance group. The use of international market analyses reports should be specified in the budget. The cost of these reports is 10,000-30,000 DKK.
Qualitative description of the exposure of man by use and disposal of finished products	Approximately 1-4 man-week per substance.
Scenarios for future emissions and loss of the substance, simple "business as usual" model	The input will depend on the number of application areas covered by the scenarios. It should be noted that each application area might cover many product types with different life-time distributions. It is estimated that the simple scenarios will approximately take in total three to six man-weeks for all application areas dependent on the number of different product types.
Scenarios for future emissions and loss of the substance, detailed model	The input will depend on the number of application areas covered by the scenarios. It should be noted that each application area might cover many product types with different life-time distributions. It is estimated that the detailed scenarios will approximately take one to four man-weeks for the first application area dependent on the number of different product types, and less for the subsequent application areas.
Occurrence and fate in the environment	The input for this appendix will be very dependent on whether the SFA covers a single element or a large group of chemicals. If the SFA covers a large group of chemicals, it may be most appropriate to report this assessment in a separate publication. The input for a single substance will approximately be a half to two man-month.
National and international regulation on the use of the substance	Approximately between a half and one man-week per substance.
Assessment of substitutes	The input will be dependent on the number of applications and levels covered by the assessment. The input for an assessment at all levels for one application will approximately be one to three man-weeks.

Recycling, downcycling and material deterioration	The input will be dependent on the number of application areas covered. By the initiation of the SFA is should be defined which application areas are covered by the appendix. There is only very limited experience with this extension in SFAs and the input has to be estimated separately for each substance.

The specification of focus areas is estimated not to influence the total budget, as inputs are allocated from one area to another.

Appendix 3

SFA System Definiton Table

The System Definition Table at the next page is meant to facilitate the delimitation of the analyses when SFA projects are initiated. In the following a number of questions that may be helpful for the delimitation is listed.

SFA or consumption assessment?	Is it actually a substance flow analysis that is needed or would information on the consumption of the substance in Denmark be satisfactory?
Level of detail	Is the aim of the analysis to provide a basis for action plans and regulation of the substance or is it to provide a preliminary overview?
Extensions *-international perspective*	Is it expected that imported finished products account for the main part of the Danish consumption of the substance? Is it expected that the Danish consumption of the substance will be significantly different from the consumption in other EU Member States?
- *exposure*	Is there a limited knowledge about the exposure of man by use and disposal of finished product? Is it expected that the substance will be released at significant levels during use?
- *future emissions*	Is it expected that emissions and loss of the substance in the near future will be significantly different from the emissions and loss today? Would this influence the decisions to be taken now?
- *national and international regulation*	Is there a need for an overview over national and international regulation on the use of the substance?
- *assessment of substitutes*	Could the lack of substitutes be an obstacle for the regulation of the substance? Should development of substitutes be financially supported?
- *recycling and downcycling*	Is the present recycling of the substance or the materials containing the substance in fact a downcycling? Does the present procedures for collection and recycling of the materials containing the substance lead to deterioration of the materials?
-occurrence and fate in the environment	Is there a need of an overview of the occurrence of the substance in the environment?
Focus areas - *marginal applications*	Does considerable knowledge already exist about the main fields of application and is there a need for very specific information on marginal applications e.g. because regulation of the use of the substance is under consideration?
- *specific compounds*	Are there particular environmental or health problems in connection to the use of specific substances within the substance group?

- *chemical state of emitted compounds* — Are there specific environmental or health problems, which are dependent on the chemical state of the emitted compounds?

- *parts of the life cycle* — Are there specific environmental or health problems connected to a particular stage of the life cycle: Production, use, or disposal?

Table 2
SFA System Definition Table

Substance:		
Type of analysis	Substance flow analysis	
	Consumption assessment	
Level of detail and reliability	Detailed analysis	
	Overview analysis	
	Other level of detail and reliability	
Extensions	International market and trends in consumption, derailed analysis	
	Qualitative description of the exposure of man by use and disposal of finished products	
	Scenarios for future emissions and loss of the substance	
	Simple scenarios	
	Detailed scenarios	
	Number of application areas covered	
	Occurrence and fate in the environment	
	National and international regulation on the use of the substance	
	Assessment of substitutes	
	Number of application areas covered	
	Specification of levels [1)]	
	Recycling, downcycling and material deterioration	
	Other extensions	
Focus areas	Specific compounds within the substance group	
	Consumption with marginal applications	
	Chemical state of emitted compounds	
	Consumption with finished goods	
	Disposal with solid waste	
	Emission from products in use	
	Danish production	
	Other parts of the life cycle	

[1)] A table for specification of the levels of the substitution assessment is included in Appendix 1, section 3.7.4

Appendix 4

List of Danish Substance Flow Analyses

In the following, a comprehensive list of national level SFAs carried out in Denmark is included. The list is organised into **metals** and **organic substances.**

All the SFA's except the analysis for brominated flame retardants are in Danish. Most of the reports include an English Summary.

Substance	Reference year	Level of detail	Reference
Metals			
Aluminium	1994	Detailed	/1/
Arsenic	1982	Overview	/2/
Cadmium	1990	Detailed	/3/
Cadmium	1998	Detailed	/4/
Chromium	1982	Overview	/2/
Cobalt	1982	Overview	/2/
Copper	1994	Detailed	/5/
Lead	1985	Detailed	/6/
Lead	1994	Detailed	/7/
Mercury	1992/93	Detailed	/8/
Mercury	1982/83	Detailed	/9/
Nickel	1982	Overview	/2/
Nickel	1994	Detailed	/10/
Tin	1994	Detailed	/11/
Organic substances			
Azo colorants	1998	Overview	/34/
AMPA	1996	Detailed	/12/
Brominated flame retardants	1997	Detailed	/13/
CFCs, HCFCs, HFCs	1984	Consumption assessment	/14/
CFCs, HCFCs, HFCs	1990,1993, 1994, 1995, 1996, 1997	Consumption assessment	/15-22/

Substance	Reference year	Level of detail	Reference
Chlorine and chlorinated products	1987	Detailed	/23/
Chloroparaffins	1992	Consumption and emission assessment etc.	/24/
Chlorophenols	1984	Detailed	/25/
Dichloromethane	1995	Detailed	/26/
Dioxins	Ongoing	Detailed	/27/
Organotin	1994	Detailed	/11/
Fluorocyclobutane Fluoroethane Fluorohexane Fluoropropane	1995	Consumption and emission assessment	/28/
Formaldehyde	1984	Consumption assessment	/29/
Methylbromide	1993-1997	Consumption assessment	/15-22 /
Nonylphenols and Nonylphenolethoxylates	1995	Consumption and emission assessment	/30/
PCB/PCT	1981	Detailed	/31/
Phthalates	1982	Consumption assessment	/32/
Phthalates	1994	Detailed	/33/
Sulphur-hexafluoride		Consumption and emission assessment	/34/
Tetrachloro-ethylene	1995	Detailed	/26/
Trichloroethylene	1995	Detailed	/26/

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Appendix 5
Summaries of Selected Danish Substance Flow Analyses

English summaries of selected Danish substance flow analyses are presented in the following appendix. The summaries are identical to the summaries in the reports, but minor layout changes have been carried out.

Substance Flow Analysis for Copper

Carsten Lassen, Thomas Drivsholm, Erik Hansen, Benthe Rasmussen & Kim Christiansen. 1996. Environmental Project no. 323.

The Danish EPA, Copenhagen

English Summary

This report presents a relatively detailed analysis of copper consumption and emission to the environment in Denmark. The report is prepared according to the Danish Environmental Protection Agency's paradigm for substance flow analysis /1/.

The present knowledge is acquired through information from the Danish National Agency of Statistics, the Product Database of the Danish Environmental Protection Agency, technical literature, private companies and governmental institutions.

Copper balance

Copper balance for the Danish society is summarized in figure 2.2.

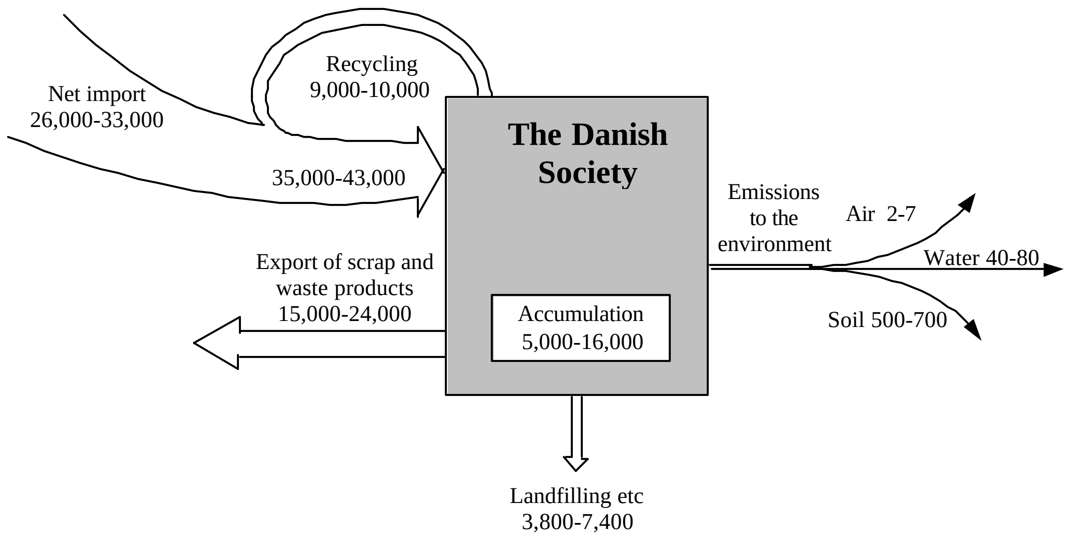


Figure 2.2
Copper balance for the Danish society (tonnes Cu/year)

The net supply of copper to the Danish society with raw materials, semi-manufactured and finished goods, inclusive unintended use of copper as contaminant in other products, amounted to 26,000-33,000 tonnes Cu/year (Figure 2.2). The net import of copper with raw materials and semi-manufactured goods made up 28,000-29,000 of this. About 25% of the raw materials were recycled as chips and stumps from the manufacturing of goods. Scrap containing about 10,000 tonnes copper was in 1992 in Denmark melted down to refined copper (mainly brass bars).

The copper balance in figure 2.2 only gives a simplified illustration of the total circulation of copper in Denmark as an exact determination of import and export of copper with manufactured goods has not been possible. In the analysis information on the total copper content of produced and consumed industrial products was retrieved from the Product Database of the Danish Environmental Protection Agency. From these data only the net import of copper with industrial products could be determined. In broad outline the total copper content of produced products balanced the total content of consumed products. Considering the uncertainty on the estimates, the net export with industrial products is estimated to (-2,000) - 4000 tonnes Cu/year. With valves and fittings there was a considerable net export, whereas there was a net import of copper with wires, electronics, lighting devices, and domestic electric appliances.

Copper consumption

The consumption differentiated on uses is presented in table 2.3 (summarised from table 5.2)

Table 2.3
Copper consumption with manufactured goods in Denmark 1992 [1)]

Application	Consumption Tonnes Cu/year	% of total [2)]
Copper and copper alloys:		
Cables, wires, switch-boards etc.	7,400-11,200	26
Electronic products	1,400-2,200	5
Lighting devices	900-1,300	3
Electric machines	3,200-4,600	11
Valves, fittings, coins, and copper castings	5,100-7,100	17
Building materials (roofs, sheets, pipes, etc.)	3,800-5,700	13
Means of transport (vehicles, trains, ships, etc.)	3,000-5,600	12
Other uses as metal	1,100-1,600	4
Chemical compounds:		
Pressure impregnation chemicals and pesticides	200-250	0.6
Antifouling paints	27-40	0.1
Pigments and dyes	100-200	0.4
Additives to feeding stuff and fertilizers	425-540	1.4
Plating	40-80	0.2
Other uses as chemical	2-15	0.2
As natural contaminant:		
Steel	1,000-1,800	4
Coal and oil	44-127	0.2
Other uses	60-110	0.3
Total	28,000-42,000 [1)]	100

Notes:

1) Only consumption with manufactured goods are represented and the estimates should not be confused with the total copper flow through the society presented in figure 2.2 which includes raw materials for the industry.

2) Percentages are calculated from averages.

Electric conductors and equipment for the main system of transmission lines (switchboards, transformers, etc.), constituted about 26% of the total copper consumption (electric conductors in electronic and machines are not included). Other key fields of application were valves, fittings and copper castings (17%), building materials (13%), means of transport (12%) and electric machines (11%). Electronics (computers, audio visual apparatus etc.) only constituted about 5% of the total consumption.

The nutritive effect of copper on plants was utilized by addition of copper compounds to fertilizers (1.4%), whereas the toxicity of copper to microorganisms, algae and fungi was utilized in pressure impregnation chemicals (0.6%), anti fouling paints (0.1), fungicides, and agents to prevent damage caused by game. Copper in pigments and dyes was used for a wide range of paints and inks (0.4%).

Copper as contaminant

A considerable amount of copper was circulated as alloy (most frequently unintended) in steel (4%). Copper as natural contaminant in other products amounted to about 0.5% of the total copper consumption.

Emission to the environment

Emission of copper to the environment and solid waste disposal are represented in table 2.4 (summarized from table 5.3).

Air

Foundry processes and energy production were the principal sources of copper emission to air, but it is emphasized that emissions to air were relatively small compared to the intentional spread of copper to soil and aquatic environments.

Water

The principal source of copper to the aquatic environment was antifouling paint on ships (about 38%). Discharge from municipal sewage plants and loss of copper slag from sand blasting comprised about 33% and 6%, respectively, of the total emission to the aquatic environment. It is emphasized that these contributions are estimated with considerable uncertainty. Corrosion of copper roofs, sheets, wires and pipes are considered to be key sources of copper to municipal waste water. However, nothing definite is known about total emissions from these sources.

Soil

Copper predominantly was released to soil with fertilizers (about 80%). Manure was the principal source as copper added to feeding stuff was transferred to the manure. Municipal sewage sludge comprised 5% of the release, and fungicides inter alia pressure impregnation chemicals comprised another about 5%.

Based on analysis of disposal of consumer products it is estimated that 3,000-5,800 tonnes copper in 1992 was disposed of with municipal solid waste (MSW). The sources of copper to MSW were wires and power cords used in the home, electronics, domestic appliances, lighting devices, furnishings, locks, keys, clothing, leather goods and a number of other products. Copper as natural contaminant in products (e.g. wood, paper, and plastic) which can be considered as the MSW background level only comprised 1% of the total disposal.

Disposal of solid waste

The bulk of the MSW was incinerated and copper was disposed of with residues. The available analysis for copper content in these residues indicate that the MSW contains less copper. The object of these analysis, however, has been to evaluate the potential leaching from the residues and metal pieces were sorted out before analysis, and consequently the total copper content was presumably underestimated.

Table 2.4
Emission of copper to the environment and solid waste disposal in 1992.

Process/source	Emission (tonnes Cu / year) Air	Water	Soil	Deposits etc.	Total
Industrial processes:					
Iron and steel production	0.07			4)	0.07
Casting	0.6-3			4)	0.6-3
Sand blasting		3-5	3-5	4)	6-10
Other processes	<0.2	1)		4)	<0.2
Energy production:	1.1-2.2		0.1-0.4	41-118	42-121
Uses of products:					
Pressure impregnation chemicals			10-35		10-35
Pesticides			8-11		8-11
Fertilizers and feeding stuff			425-540		425-540
Antifouling paints		18-28			18-28
Other uses		5-20 [1)]	16-47		21-67
Waste disposal:					
Scrap handling		1)	<1	8-12 [5)]	8-12
Solid waste incineration and deposit [4)]	0.5-1.0		1-1.5	3,600-7,100	3,600-7,100
Chemical wastes	<0.1	0.03-0.05		133	133
Discharge of waste water and storm water		17-25 [2)]	2-3		19-28
Sewage sludge	<0.2		32	15	47
Total [3)]	2-7	40-80	500-700	3,800-7,400	4,300-8,200

Notes:

1) Discharge of copper with waste water to the municipal sewage system is included in 'Discharge of waste water and storm water'.

2) Discharge to recipient.

3) Totals are rounded.

4) Exclusive of industrial wastes which are quoted under 'Solid waste incineration and deposit'.

Iron and steel

About 430-850 tonnes copper, mainly in small parts, ended up in scrap iron, which was melted down to new steel containing the copper as alloy (contaminant). About 97% of discarded iron and steel is recycled and consequently - despite the addition of virgin iron to the melt - the steel contains still more copper for each remelting. In total 1,000-1,800 tonnes copper was circulated with steel in 1992.

Recycling

There is a comprehensive trade with scrap copper. Wastes from the production of industrial products are nearly 100% recycled. It is estimated that 23,000-32,000 tonnes copper in 1992 was recycled. Taking account of that 4,800-9,000 tonnes Cu was deposited, lost or ended up as unintended alloy in steel, the recycling percentage (the percentage of discarded copper which was recycled) was roughly estimated 80%.

Stock building

The stock building in the Danish society in 1992 is estimated to 5,000-16,000 tonnes copper. The standing stock in the Danish society are presumably in the order of 200,000-1,000,000 tonnes copper.

Trends

A detailed analysis of trends in consumption for all uses of copper has not been possible within this scope of this study. The consumption of copper wire has declined to about 30% of the consumption in the early seventies presumably owing to substitution of copper with aluminum for electric conductors and substitution of copper wires with fibre-optic cables for telecommunication. For most other uses of metallic copper the consumption has increased.

The consumption of copper with pressure impregnation chemicals is expected to decrease in the next few years and the consumption of copper with fertilizers has a downtrend too. On the other hand the supply of copper with chemical compounds seems to be increasing and it has not been possible to give a satisfactory explanation of this increase.

Conclusion

In short, the conclusion is that unintended emissions to the environment are small compared to the intended spread of copper. The production of copper-containing industrial products caused only minor emissions to the environment.

The recycling percentage of copper was considerably lower than the recycling percentage of iron in spite of relatively high prices on scrap copper. The explanation is that copper in small amounts form part of a wide range of composite products, from which it today is not profitable to recover the copper.

About 20% of the used copper is lost to the environment or deposits and the quantities of copper deposited (including clinkers used for construction works) seems to be higher than formerly supposed in Denmark.

Substance Flow Analysis for Phthalates

Leif Hoffmann. 1996. Environmental Project no. 320.

The Danish EPA, Copenhagen

English Summary

A detailed analysis of phthalates, their use in production, as a final product and their emission into the environment in Denmark in 1992 has been carried out. The analysis is based on information obtained from Statistics Denmark, the National Institute of Occupational Health (Product Register), public institutions, private companies and literature.

A simplified phthalate balance is shown in figure 2.1. The balance is described in detail in chapter 6.3

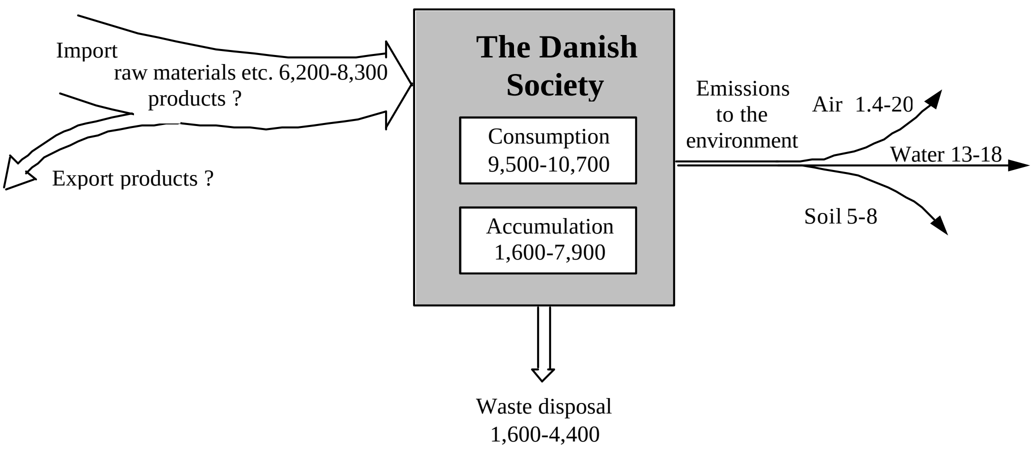


Figure 2.2
Phthalate balance for Denmark 1992.

Use

The import of phthalates in Denmark is estimated at 11,500 - 14,000 ton/year. The estimate is based on import of phthalates, compounded PVC and semi-manufactured articles. Imports consist of 6,500 ton phthalates, 3 - 5,000 ton phthalates with compounded PVC, 2 - 2,500 ton phthalate with semi-manufactured products. The import of lacquer, paint, printing ink, adhesives, fillers, denaturation substances and semi-manufactured products/products in other areas of application has not been investigated in detail, since the use of these products is primarily covered by production in Denmark.

The use of phthalates is divided into areas of application as shown in table 2.1.

Table 2.3
Survey of estimated consumption of phthalates in Denmark in 1992 in different areas of application.

Area of application	Phthalates		
	Consumption (ton/year)	Distribution (%)	Tendency
PVC			
- medical utilities	240 - 350	2.8	increasing
- packaging	200 - 350	2.6	decreasing
- construction and installations			
- cables	3,000	29	decreasing
- fittings	80	< 1	constant
- floor and wall covering	1,500	14	constant
- other applications	4,190	40	increasing
PVC, total	9,200 - 9,500	89	
Lacquer, paint and printing ink			
- lacquer and paint	45 - 225	1.3	decreasing
- printing ink	90 - 270	1.7	decreasing
Lacquer, paint and printing ink, total	130 - 500	3	
Adhesives	160 - 220	1.8	decreasing
Fillers	< 400	< 3.8	?
Denaturants	< 5	< 0.1	?
Other applications	< 50	< 0.5	?
Total	9,500 - 10,700		

Emission to the environment

The total emission of phthalates to the environment in 1992 may be estimated at:

- 1.4 - 20 ton phthalates/year to air
- 13 - 18 ton phthalates/year to water from wastewater treatment plants
- 5 - 8 ton phthalates/year to soil with compost and sludge from waste-water treatment
- 1,600 - 4,400 ton phthalates/year to waste disposal

A simplified survey of disposal and emission of phthalates to the environment in 1992 is shown in table 2.2; a more detailed survey is presented in chapter 6.2, table 6.3.

Air

Emission of phthalates to air primarily occurs during the manufacturing process of PVC since this is carried out at 130 - 210 °C leading to a potential risk of evaporation of phthalates. The highest emission comes from manufacturing of plastisols, i.e. coating of textiles, rotational and injection moulding. Other production processes are primarily carried out at room temperature and, therefore, do not normally result in significant emissions to air. Emission from products containing phthalates is less investigated. Literature on the subject shows that most tests are carried out as accelerated tests and, therefore, estimation of emission factors is difficult.

Emission to air is estimated at 1.4 - 20 ton phthalates/year. The most important sources are estimated to be:

- extrusion of cables: 0.5 ton phthalates/year
- calandering of foils: 0.2 - 4 ton phthalates/year
- extrusion of tubes and profiles: 0.3 - 0.5 ton phthalates/year
- production of other products: < 7 ton phthalates/year
- use of cables : 0.3 - 3 ton phthalates/year
- use of other products of PVC: 0 - 2 ton phthalates/year
- use of cosmetic products: < 2 ton phthalates/year

The estimates of air emissions are based on estimated emission factors and the uncertainty of the estimates is expressed in the width of the intervals. The estimate of the emission from use of cables is considered to be the most uncertain estimate. Air emissions during the user phase and waste disposal are considered negligible compared to emissions from production of PVC.

Water

Emission of phthalates to (waste)water is primarily caused by the use of plastiziced products, e.g. flexible PVC, lacquer, paint and printing ink and also adhesives. Only production of adhesives contributes significantly to the emission as products containing phthalates are manufactured in processes not often involving water (except use of cooling water or production of water-based adhesives). Therefore, the possibility of emission of phthalates to the aquatic environment from manufacturing is considered minimal. Emissions to the wastewater system are estimated at 5 - 80 ton phthalates/year. The most important sources are considered to be:

- cleaning of machines and other (adhesives): 1 - 40 ton phthalates/year
- washing of printed textiles (PVC print): 1.3 - 13 ton phthalates/year
- wall and floor sheets: 0.1 - 11 ton phthalates/year
- use of "other products": 0 - 4 ton phthalates/year
- use of tubes and profiles: 0.03 - 0.45 ton phthalates/year
- lacquered floors, etc.: 0.02 - 0.8 ton phthalates/year
- production of adhesives: 0.2 - 2.2 ton phthalates/year
- production of flexible PVC products: < 1 ton phthalates/year

There is also an unknown contribution from atmospheric deposition.

The estimates are based on estimated emission factors and the uncertainty of the estimates is expressed in the width of the intervals. The estimate of the emission from use of adhesives is considered to be the most uncertain estimate. Emissions to water during production processes are considered to be negligible compared to emissions from use of different products containing phthalates.

It should be stressed that documentation for some of the estimated emissions are missing, e.g. emission of phthalates during production and use of water-based adhesives. Therefore, it is recommended that such emissions should be subject to close investigation through specific measurements.

Table 2.4
Disposal and emission of phthalates to the environment in Denmark in 1992.

Process/source	Emission (ton phthalates/year) to:				
	Air	Water[4]	Soil[4]	Disposal	Total
Industrial processes				-[3]	
PVC	1 - 12				1 - 12
Lacquer, paint and printing ink	?				
Adhesives	?				
Fillers	?				
Use of products					
PVC	0.4 - 5.5			-[3]	0.4 - 5.5
Lacquer, paint and printing ink	0.01-0.05				0.01 - 0.05
Adhesives	÷				
Fillers	(+)				
Denaturants	< 2.5				< 2.5
Other applications	÷				
Recycling					
PVC	+			?	-
Waste treatment					
Waste incineration[1]	0.2	< 0.001	(+)	1.6	1.8
Composting[1]	< 0.001	?	0.2	-	< 0.001
Disposal of solid waste[1]	< 0.001	< 0.005	-	1,600 - 4,400	1,600 - 4,400
Treatment of hazardous waste	+	+	-	+	+
Wastewater (treated)[2]	-	13 - 18	-	-	13 - 18
Sludge from wastewater treatment[2]	-	-	5 - 8	1 - 1.5	6 - 10
	1.4 - 20	13 - 18	5 - 8	1,600 - 4,400	1,600 - 4,400

Notes:

+ Emission to the specific recipient may occur; the quantity is unknown.

÷ Emission to the specific recipient is not expected.

\- Not relevant

1. The values are based on measurements of DBP, BBP and DEHP.
2. The values are based on measurements of BBP, DBP, DEHP, DOP and DNP.

3. The amount of phthalates is counted as disposal of waste.

4. Atmospheric deposition is expected but the quantity is unknown.

Wastewater treatment

The amount of phthalates in the inlet to wastewater treatment plants has been estimated at 115 ± 82 ton phthalates/year as the sum of 31 ± 34 ton DBP/year, 52 ± 74 ton BBP/year and 32 ± 4 ton DEHP/year. The amount of other phthalates and one single adipate (DEHA) was equal to or below the detection limit. The estimated emission of phthalates from production and use of products containing phthalates is seen to explain the lower part of the level found in inlet to wastewater treatment plants.

Only DEHP could be detected in significant amounts in sludge and outlet water from wastewater treatment plants. The levels were 7 ton DEHP/year in sludge and 13 ton DEHP in outlet water. The total amount of phthalates in outlet water is estimated at 13 - 18 ton/year. The total amount of phthalates in sludge is estimated at 7 - 12 ton/year and 5 - 8 ton/year is spread on agricultural soil, 1 - 1.5 ton/year is deposited and 1.5 - 2.5 ton/year is incinerated.

The reduction in wastewater treatment plants has been measured for DBP, BBP and DEHP, and the reduction of DBP and BBP is approximately 100 % while the reduction of DEHP is 25 - 75 %. 20 - 45 % of DEHP in inlet is found in sludge.

Recycling

Recycling of phthalates as a product does not take place. Recycling is not considered technically possible. Through recycling of flexible PVC, phthalates are indirectly recycled.

Substance Flow Analysis for Nickel

Carsten Lassen, Thomas Drivsholm, Erik Hansen, Benthe Rasmussen & Kim Christiansen. 1996. Environmental Project no. 318.

The Danish EPA, Copenhagen

English Summary

This report presents a relatively detailed analysis of nickel consumption and emission to the environment in Denmark. The report is prepared according to the Danish Environmental Protection Agency's paradigm for substance flow analysis /1/.

The present knowledge is acquired through information from the Danish National Agency of Statistics, the Product Database of the Danish Environmental Protection Agency, technical literature, private companies and governmental institutions.

Nickel balance

Nickel balance for the Danish society is summarized in figure 2.2.

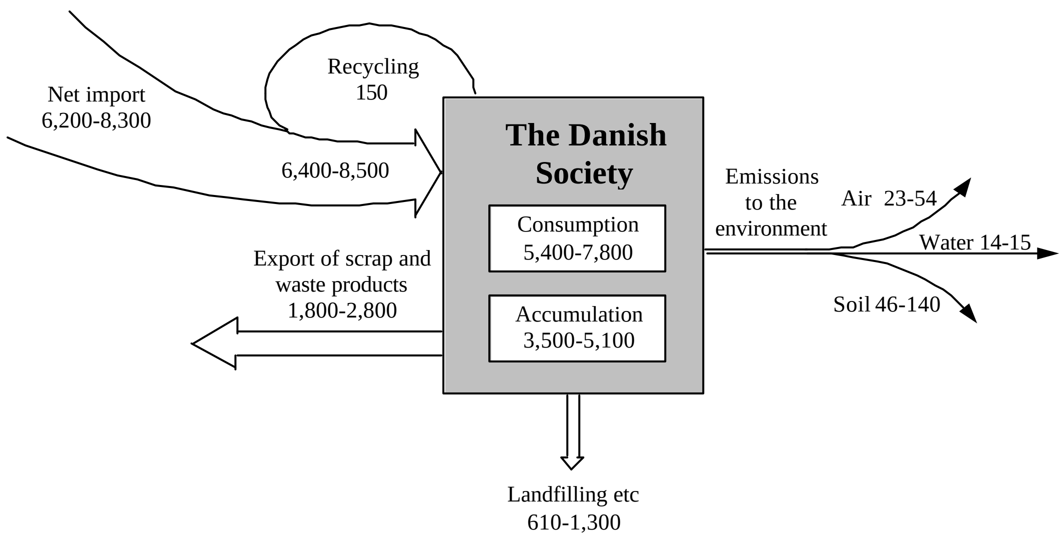


Figure 2.2
Nickel balance for Denmark 1992/93 (tonnes Ni/year)

The supply to the Danish society in 1992 with raw materials, semi-manufactured and finished goods, inclusive nickel as natural contaminant in other products, amounted to 6,400-8,500 tonnes nickel (Figure 2.2). A part of this - roughly estimated 1,000 tonnes nickel - was reexported as production residues and, consequently, the nickel consumption within the society can be estimated to 5,400-7,800 tonnes.

The consumption differentiated on uses is presented in table 2.3 (from table 5.1).

Stainless steel products comprised 80% of the total nickel consumption. The principal application of stainless steel was as pipes and containers which alone made out 40% of the total nickel consumption.

Table 2.3
Consumption of nickel with manufactured goods in Denmark 1992/93.

Product	Consumption Tonnes Ni/year	% of total
Nickel and nickel alloys:		
Stainless steel	4,600-6,000	80
Other steels and cast irons	70-300	3
Nickel plating	70-130	2
Nickel-copper	220-300	4
Other uses as metal	86-330	3
Chemical compounds:		
Catalysts	50-100	1
Nickel-cadmium batteries	43-59	<1
Pigments	60-100	<1
As natural contaminant:		
Coal and oil	102-205	2
Fertilizers, agricultural lime and feeding stuff	38-111	1
Other uses	90-161	2
Total	5,400-7,800	100

Emissions to the environment and release to waste deposits are summarized in table 2.4 (from table 5.3).

Emission to air

The emission to the air was mainly caused by burning of oil products - particularly fuel oil - which contributed to the total emissions by 90%. Solid waste incineration comprised about 5% of the total emission to air.

Emission to water

Wastewater/stormwater was the principal source of nickel emission to the aquatic environment. The principal sources of nickel in municipal wastewater were wear of nickel platings, natural content of nickel in ground water, and road dust containing nickel from bitumen in the asphalt. Nickel plating was the only industrial process which contributed significantly to the total emission to wastewater. Road dust and atmospheric deposition were probably the primary sources of nickel in storm water. It has not been possible to quantify the release of nickel by cleaning of stainless steel products (e.g. pipes and tanks) which might be significant.

Release to soil

The release of nickel to soil was primarily due to the use of phosphate fertilizers, feeding stuff and agricultural lime. The agricultural soils were supplied with 38-111 tonnes Ni/year by these sources of which feedstuff was the principal. The nickel content of feed is regulated by mid 1995.

Disposal of solid waste

The present estimated discards of nickel in solid waste significantly exceeds former estimates based on analysis of solid residues from solid waste incinerator plants. The principal source of nickel in solid waste was products containing stainless steel and other nickel alloys. Nickel in these alloys are not included in the former presented analyses of residues from incinerator plants as metal pieces have been sorted out before the chemical analysis.

Table 2.4
Emission of nickel to the environment and solid waste disposal in 1992/93.

Process/source	Emissions (tonnes Ni/year) to: Air	Water	Soil	Deposits [1]	Total
Industrial processes:					
Iron and steel production	0.5			[3]	0.5
Other processes	<0.43	0.5-1 [2]		[3]	0.5-1.43
Energy production:					
Coal	0.2-1			40-95	40-96
Oil, wood and straw	21-50		0.1-0.3	[3]	21-50
Application of products:					
Wear of roads (asphalt)		[2]	2-7		2-7
Fertilizers, feeding stuff, and agricultural lime			38-111		38-111
Loss of coins			1-10		1-10
Other applications		[2]			
Waste disposal:					
Solid waste incineration and deposit	1.5-2.5		0.8-5.8	525-1,170	527-1,178
Chemical wastes	0.02	0.01		44	44
Discharge of wastewater and stormwater		13-14	1.3		14-15
Sewage sludge	<0.02		2.6	2.6	5.2
Total [4]	23-54	14-15	46-140	610-1,300	690-1,500

Notes:

1) Includes residues used for construction works.

2) Discharge of nickel with wastewater to the municipal sewage system is included in 'Discharge of wastewater and stormwater'.

3) Deposit of nickel from these activities is included in 'Solid waste incineration and deposit'.

4) Totals are rounded.

The principal part of nickel disposed of in solid waste derives from household uses (e.g. cutlery, keys and nickel-cadmium batteries) or from industrial products (e.g. tires) where the nickel-containing part only comprise a minor part of the product.

From March 1995 regulations are laid down for recycling of tires from automobiles.

The dominant part of the nickel consumption in the society is related to stainless steel used for production equipment, which after its useful life will be dismantled and exported through scrap merchants for reprocessing.

The consumption of nickel significantly exceeded the disposal (incl. scrap export) indicating that a substantial part of the consumed nickel accumulates in the society in production equipment and households.

Substance Flow Analysis for Lead

Carsten Lassen & Erik Hansen. 1996. Environmental Project no. 327.

The Danish EPA, Copenhagen

English Summary

This report presents a relatively detailed analysis of lead consumption and emissions to the environment in Denmark in 1994. The report is prepared according to the Danish Environmental Protection Agency's paradigm for substance flow analysis.

The present knowledge is acquired through information from the Danish National Agency of Statistics, technical literature, private companies and governmental institutions.

Lead balance

Lead balance for the Danish society is summarised in figure 2.2.

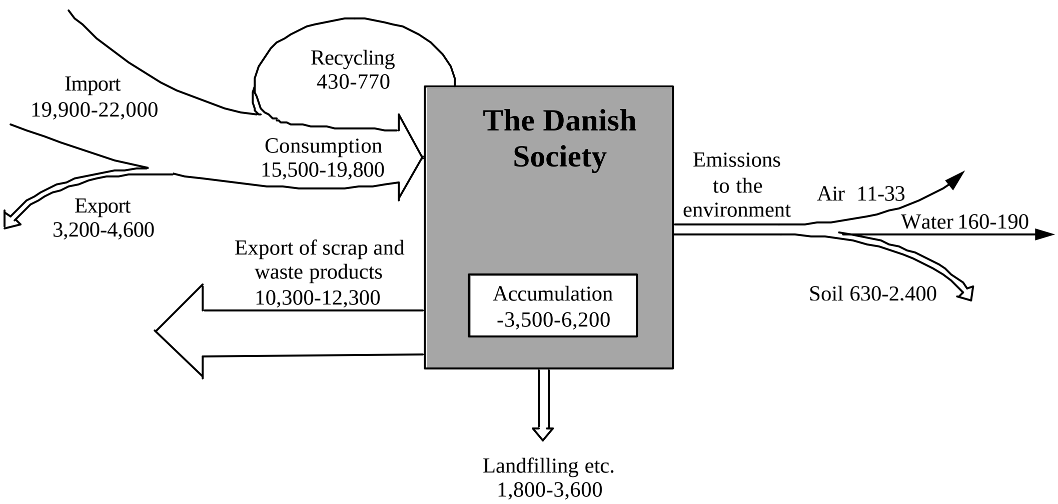


Figure 2.2
Lead balance for Denmark; 1994. (tonnes Pb/year)

The total lead consumption with manufactured goods in Denmark in 1994 is estimated at 15,500-19,800 tonnes/year. The turnover of lead in the society was somewhat higher as there aside from this was an import of lead with raw materials which were manufactured and re-exported with manufactured goods. The total import in 1994 is estimated at 19,900-22,000 tonnes lead.

The export covered batteries, keels, cables, and factory-mounted flashing on roof lights and chimneys.

Additionally 430-770 tonnes lead was recycled and used in Denmark for casting of lead sheets for roofs, sinkers and lead lines for fishing, seals, counterweights, and home-cast fishing tackle.

Lead consumption

Lead consumption, differentiated on uses, is shown in table 2.3 (summarised from table 5.1).

Batteries accounted for about 48% of the total consumption. Other significant fields of application was lead roofs and flashing (about 20%) and cable sheaths mainly on deep sea cables (about 12%). About 2.5% of the total consumption was used for the fishing trade while tackle for angling (mainly jigs and sinkers) made up about 0.5 % of total consumption.

Table 2.3
Consumption of lead with manufactured goods in Denmark; 1994 [2)].

Application	Consumption tonnes Pb/year	% [1)] of total
Metallic lead		
Batteries	8,100-8,900	48
Building materials	2,800-4,100	20
Cable sheaths	2,000-2,300	12
Fishing-tackle and nets	380-730	3
Ammunition	350-465	2
Keels	50-150	0.6
Other uses as metal	700-1,200	5
Chemical compounds		
Glass	620-990	5
PVC stabilisers	300-400	2
Pigments in plastics and paints	35-110	0.4
Other uses as chemical	60-240	0.9
Natural contaminant		
Fuels	40-130	0.5
Other uses as contaminant	24-60	0.2
Total [2)]	15,500-19,800	100

Notes:

1) Based on mean values.

2) Totals are rounded.

Other uses as metal cover solder for radiators, electronics and light bulbs, vehicle wheel weights, miniatures (e.g. tin soldiers), cones for flower decorations, radiation shields, sheets for corrosion protection of industrial equipment, seals for gauges, counterweights, curtain weights, weights for vibration and sound damping, and a number of other minor uses.

Chemical compounds

The consumption of lead with chemical compounds in 1994 is estimated at 1,000-1,700 tonnes or about 8% of the total consumption. About half of this was lead in crystal glass (Pb_3O_4) and cathode ray tubes (PbO) in television sets and computer monitors (about 5%). Lead silicate was used for glazing on ceramics (about 0.7% of total consumption). Lead stabilisers in PVC represented about 2% of the total consumption while lead pigments in paints and plastic represented 0.4%. Other uses as chemical cover red lead for corrosion protection (0.2%), petrol additives, drying agents in paint, brake lining, and lubricants.

Lead as natural contaminant

Unintended uses of lead as natural contaminant comprises trace amounts of lead in coal and oil, wood, fertilisers, agricultural lime, cement, feeding stuff etc. which totals 70-190 tonnes (1% of the total lead consumption).

Emissions to the environment

Emissions to the environment and release to waste deposits are shown in table 2.2 (summarised from table 5.3).

Emission to the air

The total emission of lead to the air is estimated at 11-33tonnes lead per year.

Emissions to the air was mainly due to burning of leaded petrol (about 33% of total emission) and solid waste incineration (about 20% of total emission). The emission from burning of petrol is expected to further decrease in 1995, where leaded petrol only is used in some types of aviation petrol. Beyond this lead was emitted in significant amounts from energy production (about 17% of total emission), production of steel (about 10% of total) lead casting (about 16% of total), and production of ceramics and tile (5% of total). The emissions from lead casting is determined with high uncertainty and was mainly due to casting in the open air without improved flue gas cleaning.

Discharge to aquatic environments

The total discharge to aquatic environments is estimated at 50-300 tonnes lead per year. The main source was loss of sinkers used by anglers and the fishing trade which is estimated to contribute at about 51% of total discharge. Angling is estimated to contribute to the same extent as the fishing trade to the discharge. Cables left at the sea floor made up about 47% of the total discharge. The quantity does not represent the release of lead from the cables to the sea water, but the total quantity left on the sea floor (estimated annual mean).

Storm water drained directly to recipients represented the main part of lead discharge with waste water/storm water (about 1% of total discharge), whereas more than 90% of the lead entering sewage disposal plants was retained with the sludge. The predominant source of lead to municipal waste water is estimated to be lead oxides corroded from lead flashing and roofs.

Release to soil

The most significant source of lead release to soil was sheaths on cables left in the ground. Since 1945 about 150,000-200,000 tonnes of lead have been used for underground cables in Denmark. When the cables are taken out of service they are either dug up or left to slowly disappear by corrosion. There is no registration of the total quantity left and the quantity given in table 3.4 is estimated with high uncertainty (estimated annual mean).

Recycling

About 420-570 tonnes lead was in 1994 exported with ashes and dust from steel production and foundries. In total 10,400-12,700 tons lead with scrap and wastes was recycled in Denmark or exported including scrapped lead batteries (7,900-8,600 tonnes lead), sheets used for flashing (600-1,200 tonnes lead), and cables sheaths (550-800 tonnes lead). Recycling of lead within the Danish society is estimated at 430-770 tonnes

The scrap was predominantly exported for recasting abroad. However, a significant part of the cables were reprocessed in Denmark as there was an import of cables for reprocessing. The product of the reprocessing was mainly exported.

Table 2.2
Emission of lead to the environment and solid waste disposal; 1994.

Process / source	Emission (tonnes Pb/year) to:				
	Air	Water	Soil	Deposits	Total
Industrial processes:					
Lead casting	0.1-6.8	-	-	3)	0.1-6.8
Iron- and steel production	2-2.5	-	-	3)	2.0-2.5
Other processes	0.3-2.3	-	-	3)	0.3-2.3
Energy production:	2.2-5.4	-	0.2-0.4	25-80	27-86
Use of products:					
Building materials	-	1)	3-12	-	3-12
Ammunition	-	?	195-270	-	195-270
Petrol additives	2-10	-	-	-	2-10
Fishing equipment	-	105-275	-	-	105-275
Other uses	-	1-5	20-60	-	21-65
Waste disposal:					
Left cable sheets	-	50-300	400-2,000	-	450-2,300
Solid waste incineration and deposit	3.4-5.4	-	0.4-0.5	1,700-3,400	1,704-3,406
Chemical waste	0.4-0.6	0.01	-	99-101	99-102
Waste water and sewage sludge	0.1-0.2	5.4-7.9	9.1	13	28-30
Scrap	-	1)	7-26	3)	7-26
Total 2)	11-33	160-590	630-2,400	1,800-3,600	2,600-6,600

Notes:

1) Discharge of lead with waste water to the municipal sewage system is included in 'Waste water and sewage sludge'.

2) Totals are rounded.

3) Deposit of lead from these activities is included in 'Solid waste incineration and deposit'.

Depositing

About 1,800-3,600 tonnes lead was deposited (including construction work etc.). The main sources were residues from solid waste (800-1,200 tonnes lead), shredder waste (200-1,000 tonnes lead), electronics including cathode ray tubes (350-580 tonnes lead), and fishing equipment (230-300 tonnes lead).

Stock building

On the present basis it is estimated that (-3,500)-6,200 tonnes lead annually is accumulated in the society (a negative accumulation means that the stock in the society is decreasing). The stock comprises lead in cables (100,000 - 200,000 tonnes lead), roofs and flashing (80,000-120,000 tonnes lead corresponding to 30 years consumption), and batteries (30,000- 40,000 tonnes corresponding to four years consumption). Additionally 10,000-50,000 tons is accumulated in keels, X-ray laboratories, electronics, PVC, glass and other products. In total, the accumulation is estimated at 220,000- 410,000 tonnes lead.

Trends in consumption

Trends in consumption in the recent ten years appears from a comparison of the present analysis with a previous substance flow analysis from 1985 (Table 5.2 and 5.4).

The consumption of lead shot was, due to legislative restraints on the use, reduced from 870 tonnes lead in 1985 to about 130 tonnes in 1994. Lead consumption with petrol additives has likewise decreased from 250 tonnes lead in 1985 to less than 10 tonnes in 1994 due to substitution of lead additives.

The consumption of lead with keels has decreased due to declining sales of new sailing-boats.

The consumption of lead batteries seems to have declined, but a part of the apparent decline may be due to an overestimation of the consumption in 1985.

The consumption of lead with cables and construction works, which next to batteries represent the principal fields of application, has in broad outline been stagnant during the last ten years.

Within some minor fields of application the consumption has decreased considerably. Consumption of lead with seals for gauges, wine bottle seals, tubes and fittings, corrosion protection in chemical industry, and soldering of tins is considerably reduced or ceased.

Mainly due to working environment problems, the use of lead with drying agents for paints and lead pigments in glazing, paints and yellow road lines has decreased and seems gradually to cease. Red lead is today only used for repair work on old iron constructions and fishing boats.

Lead consumption with glass has increased due to an increase in consumption of cathode ray tubes in television sets and computers which comprise the main part of the consumption of lead glass. In crystal glass produced in

Denmark, lead is substituted with other metal oxides, but this seems not to be the case for most of the imported crystal glass.

The consumption of lead stabilisers in PVC is increasing too.

Red lead and pigments used for ceramics and tile is nearly phased out whereas the consumption of lead silicates for ceramics is stagnant.

Trends in emission and disposal

While the total consumption of lead in the recent ten years has been nearly stagnant, emissions to the environment has declined considerably due to legislative restraints and improved cleaning technology.

Emission to the air has been reduced from 250-300 tonnes lead in 1985 to - tonnes in 1994. The reduction is due to substitution of lead additives to petrol and reduced emissions from solid waste incineration, power plants, battery production, and burning of waste oil.

Discharge to aquatic environments was reduced mainly as a result of the ban on use of lead shot in wetlands and improved treatment of waste water. Additionally, the contribution from red lead released by repair work is estimated to be lower than in 1985.
Both in 1985 and 1994, release of lead from cable sheaths is estimated to be a considerable source of lead contamination of soil and aquatic environment although the released quantity is estimated with a high degree of uncertainty. Generally deep sea cables are left at the sea floor when the cable is taken out of service. As regards underground cables it seems to be common to dig up old cables if a new cable is placed in the same track. If not, the old cable seems generally to be left in the ground. Today lead sheaths are mainly used for deep sea cables.

An important part of the release of lead to soil in 1985 was caused by loss at scrap dealers. This release has decreased considerably mainly due to a better handling of batteries. Scrap batteries are today statutory stored and exported in closed acid resistant containers. Additionally many scrap yards has been consolidated and roofed to minimise the losses. On the other hand, fragmentation of scrap of composite products, especially cars, generate large amounts of lead containing waste which is landfilled.

Release of lead to soil with ammunition is reduced by legislative restraints, but the decrease is not as significant as the decrease in lead shot emission to aquatic environments, partly because use of lead shot in forests is still legal, partly because the use of ammunition for rifles and military applications has been unchanged.

The total discard of lead to deposits (including landfills) has in broad outline been unaltered. The main sources of lead to solid waste has not changed, except for batteries, which today is considered to constitute a minor part of lead in solid waste.

Substance Flow Analysis for Mercury

Jacob Maag, Carsten Lassen & Erik Hansen. 1996. Environmental Project no. 344.

The Danish EPA, Copenhagen

English Summary

A detailed assessment of the consumption of mercury divided on use areas in Denmark has been carried out. Disposal and emissions to the environment has also been quantified. The assessment is based mainly on data from 1992-1993.

Mercury balance

The established picture on consumption and emissions to the environment for mercury in Denmark is illustrated in figure 2.1.

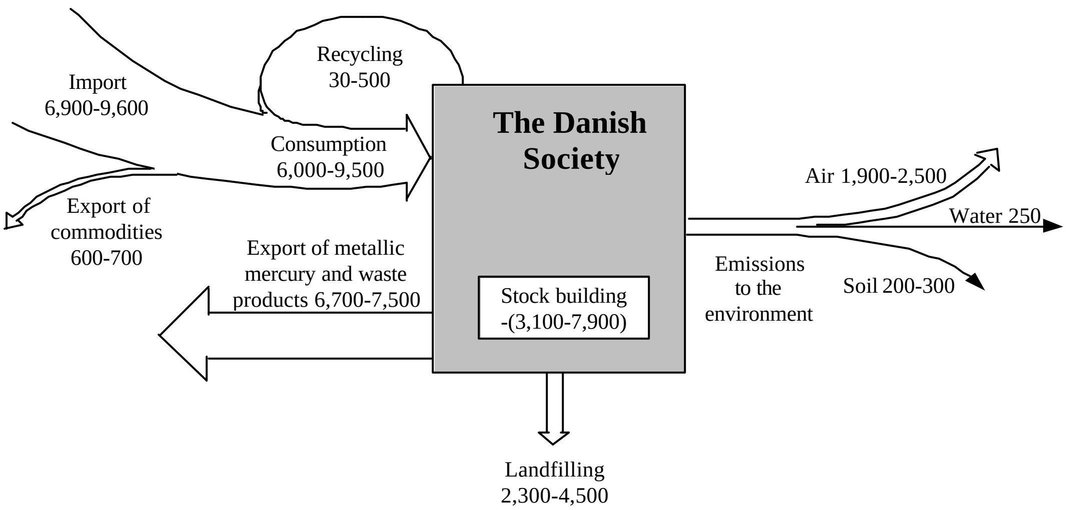


Figure 2.1
Mercury balance for Denmark 1992/93 (all figures in kg/year)

As stated in figure 2.1 the consumption of mercury is calculated to 6,800 - 9,500 kg/year, while the import of mercury as raw material and with commodities containing mercury amounted to approximately 7,000-10,000 kg/year, and the export with commodities came up to approximately 1,000 kg/year. The export comprised batteries, thermometers and flashing lights for rail road crossings.

A more detailed presentation of the use areas for mercury is given in table 2.1.

Uses

The most important intended uses include catalyst for electrolysis, mercury amalgam for dental fillings and batteries (mercuryoxide batteries, alkaline batteries and button cells types as alkaline, zinc-air and silveroxide). Together these uses count for approximately 61% of the total consumption.

Less important uses include monitoring equipment (measurement of blood pressure, manometers etc.), electrical switches and relays (floating switches for submerged pumps, flashing lights for railroad crossings, sensors for airbags and other purposes in cars etc.), lamps (fluorescent tubes and the like), thermometers (fever thermometers and thermometers for monitoring of ship engines etc.), chemicals for laboratory purposes (COD-analysis etc). Together these uses count for approximately 16% of the total consumption. Unintended use of mercury due to, that mercury will exist as contaminant in coal and other commodities is estimated to count for approximately 23 % of the total consumption

Table 2.1
Mercury consumption in Denmark 1992/93.

Use areas	Consumption 1992/93 ***1**		
	kg/year	***2**	Trend
Intended uses:			
Electrolysis	2500	31	Stagnating
Dental purposes	1800	23	Decreasing
Batteries	400-860	7	Decreasing
Monitoring equipment / education	500	6	Decreasing
Electrical switches and relays	200-400	4	Decreasing
Other uses ***3**	380-490	6	Stag./Decrea.
Uses as contaminant:			
Coal	500-1300	11	
Other uses ***4**	100-1700	12	
Total	6400-9500	100	

Notes:

*1 Consumption is to be understood as "net"-consumption, i.e. the consumption of mercury with different industrial products and for different purposes in the Danish society. Mercury consumed in Denmark for manufacturing of finished goods and exported with such commodities is not included in the figures (reference is made to figure 2.1).

*2 Calculated based on the average of the intervals stated.

*3 "Other uses" includes thermometers, lamps, laboratory chemicals and other minor uses (<50 kg mercury/year) for which detailed investigation has not been undertaken.

*4 "Other uses" include oil products, wood and straw used as fuel, fertilizers, agricultural chalk, cement and other products, in which mercury exists as naturally contaminant or pollutant in small concentrations (ppb-level). The consumption of mercury for these purposes can only be estimated with significant uncertainty.

Trends in consumption

The consumption of mercury is generally on retreat. In the period from 1982/83 to 1992/93 the total consumption of mercury in Denmark has been by and large halved. This development is related to, that the consumption for several important use areas (batteries, dental fillings, thermometers etc.) has been significantly reduced, while for other purposes the use of mercury has completely or almost disappeared (fungicides for seed, Kjeldahl-analysis). The regulation on mercury use in Denmark established in 1994, will most likely enhance this development.

Also with respect to the use of mercury for electrolysis the mercury consumption has decreased in this period. This fall was caused by, that the chlorine-alkali plant belonging to Dansk Sojakagefabrik was closed by the beginning of the 1990'ties, resulting in, that today only one plant using mercury for electrolysis is operating in Denmark.

Emissions/losses to the environment

Emissions/losses of mercury to the environment is quantified in table 2.2.

Table 2.2
Emissions/losses of mercury to the environment in Denmark 1992/93, (kg/year.

Process/source	Emission/loss to - (kg/year)				Total (kg/year)
	Air	Water	Soil	Landfills	
Industrial processes					
Cement manufacturing	60-220	<1			60-220
Other industrial activities	70-90				70-90
Coal and other fuels *4	220-560		3-9	160-520	380-1080
Use of products					
Dental clinics		150-200 ***1**			150-200 ***2**
Thermometers	2,5	100-250 ***1**	<100		100-250 ***2**
Other activities		<110 ***1**			2-210 ***2**
Waste disposal					
Solid waste incineration/landfilling	1100	2.5	1	1700-2400	2800-3500
Chemical waste/Kommunekemi	110			400-1600	500-1700
Municipal waste water/sludge	50	250	140	60 ***3**	500 ***2**
Other activities	270-340		50? ***5**	130 ***3**	330-380?
Total	1900-2500	250	200-300?	2300-4500	4600-7500

Notes:

*1 The amount indicated has been included in the figures for "municipal waste water/sludge", and is for that reason not included in the figure for "water, total" (to avoid double counting).

*2 The amount indicated is only included in the figure for "total" to the extent, that it is not covered by other topics items (to avoid double counting - reference is made to note 1 and 3).

*3 The amount indicated has been included in the figure for "landfills, Solid waste incineration/landfilling", and is for that reason not included in the figure for "landfills, total" (to avoid double counting).

*4 Other fuels cover oil products, wood and straw.

*5 It is not possible to quantify the loss of mercury to soil, that most likely will take place at metal scrap dealers dealing with recycling of iron- and metalscrap containing mercury switches (chest freezers, cars).

Emissions to air

The most important source for emission of mercury to air is solid waste incineration, which is assessed, in particular, be to due to the supply of mercury with batteries (most likely especially mercuryoxide batteries from photo equipment) and with dental fillings (in particular fillings in children's milk teeth). However, it should be noted, that it is difficult exactly to explain the supplies of mercury to incineration plants, as the supplies estimated are somewhat short of, what is actually registered at the incineration plants.

The second most important source for emission of mercury to air is coal fired power plants, which are estimated to count for 200-500 kg of mercury per year. Other emissions are mainly related to waste treatment and disposal.

Emissions to water

Emissions to water are due to waste water (treated) from municipal sewage treatment plants, which are receiving mercury from dental clinics and the use of mercury for thermometers and monitoring equipment.

Emissions to soil

Emissions to soil are due to, in particular, sewage sludge from municipal sewage treatment plants (dental clinics, thermometers, monitoring equipment), churchyards (dental fillings) and mercury as natural contaminant in fertilizers and agricultural chalk. It is noted, that most likely loss of mercury to soil will take place by recycling of iron- and metalscrap containing mercury switches (chest freezers, cars). It is, however, not possible to quantify this loss.

Trends

Also with respect to emissions of mercury to the environment significant reductions have taken place within the period from 1982/83 to 1992/93. This is the case for emissions to air, water as well as to soil.

This development follows naturally from the decline in consumption. The reduced consumption of mercury with batteries has naturally lead to reduced emission from incineration plants, just like the stop for the use of mercury fungicides for seed heavily has reduced emissions to soil. The regulation on mercury use in Denmark established in 1994, will without doubt enhance this development.

Improved cleaning has contributed as well. This is especially the case for incineration plants, as the introduction of cleaning for acid gasses has resulted in, that approximately 50% of the content of mercury in the flue gas is separated with residual products from the flue gas cleaning process. It should be noted, that this assessment deals with the 1992/93-situation, and that acid flue gas cleaning first was fully established at all incineration plants in Denmark in 1995. The consequence is, that the emission to air from incineration plants in 1996 - everything else equal - is likely 200 kg/year lower than indicated in table 2.2.

Today, all dental clinics are equipped with filters, that partly retain particles containing mercury from the clinics sucking system and sinks. Such filters has reduced the emission of mercury from dental clinics to the sewage system. However, the efficiency of never and older filter types differs widely. Thereby, a potential exist for further reduction of emissions.

Collection and disposal/ /recycling

The ongoing collection of mercury and waste containing mercury is considerable. The yearly collection includes approximately 3,000 kg of metallic mercury (incl. surplus amalgam from dental clinics) and 4,200-6,200 kg of mercury with chemical waste.

Collected metallic mercury is no longer recycled in Denmark, but exported for recycling in other countries. Chemical waste containing mercury are partly deposited in Denmark and partly exported for depositing or recovering of mercury abroad.

Stock building in the society

As stated in figure 2.1 these activities result in a negative stock building of mercury in the Danish society of 3,100-7,900 kg/year. These figures illustrates, that the consumption of mercury is decreasing and that the existing stock of mercury in the Danish society (e.g. in monitoring equipment and at institutions for education) is being reduced.

The total stock of mercury in the Danish society (i.e. the mercury in use in miscellaneous products) was for 1982/83 estimated to 100-300 tons /5/. The amount of mercury removed from the stock in the period up to 1992/93 is not known precisely, but may be roughly estimated to approximately 50 tons. Thus, the existing stock of mercury may likely be estimated to around 50-250 tons.

Substance Flow Analysis for Tin
- with Focus on Organotin

Carsten Lassen & Erik Hansen. 1997. Working Report no.7/1977.

The Danish EPA, Copenhagen

English Summary

This report presents a relatively detailed analysis of tin consumption and emissions to the environment in Denmark 1994. The report is prepared according to the Danish Environmental Protection Agency's paradigm for substance flow analysis.

The present knowledge is acquired through information from the Danish National Agency of Statistics, the Danish Productregister Database, technical literature, questionnaire to the PVC industry, private companies, and governmental institutions.

Tin balance

Tin balance for the Danish Society is summarised in figure 2.2.

Tin consumption

The total tin consumption with manufactured goods in Denmark in 1994 is estimated at 740-1,280 tonnes. The turnover of tin in the society was somewhat higher as there aside from this was an import/re-export of tin with packaging, copper-tin alloys, and solders in electronics and auto radiators.

Metallic tin

In total the consumption of metallic tin was 640-1,000 tonnes tin. The most significant fields of consumption were tinplated containers (33% of total consumption), solder used in electronics, plumbing and sheet metal joining, auto radiators, and container seaming (32%), and copper-tin alloys (bronze) used in switches, valves and bearings (10%). Apart from uses of copper-tin alloys it was characteristic that tin was used in consumer products which were disposed of with municipal solid waste and there was hardly no recycling of tin from discarded consumer products.

Chemical compounds

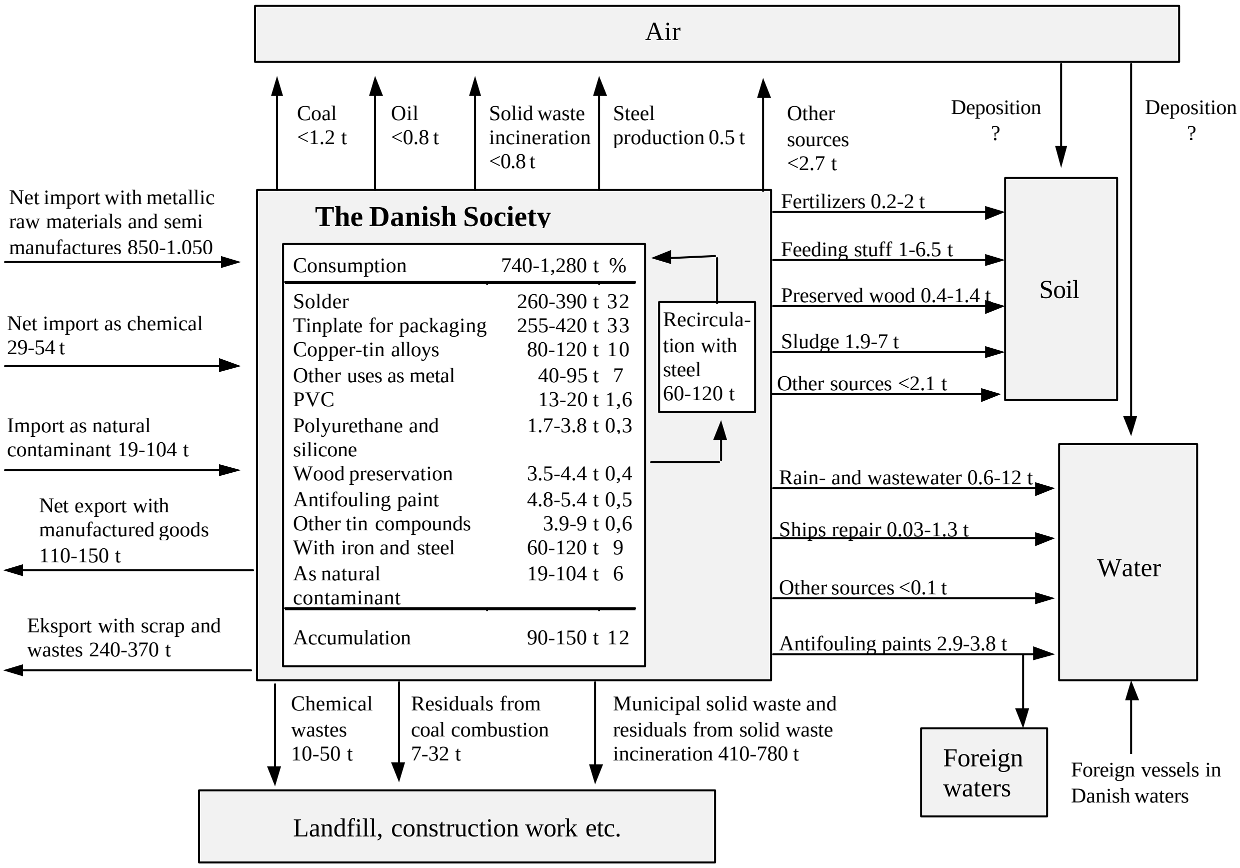
The total tin consumption with chemical compounds in 1994 was 13-21 tonnes Sn. Organotin compounds constituted the main part.

Organotin compounds are defined as compounds which contain one or more organic functional groups attached to the tin atom with a relatively stable tin-carbon bond. The compounds are dependent on the number of tin-carbon bonds divided into four classes: the mono-, di- tri- and tetraorganotins. Only mono-, di- and triorganotin compounds are used in Denmark and the consumption of the three classes is summarised in table 3.

The major use of mono- and diorganotin compounds was for UV and heat stabilisers in PVC. The main uses of tin stabilised PVC were transparent rooflight sheets, tarpaulins, bottles and packaging. The consumption of tin

stabilisers has had a downward trend due to substitution of PVC packaging with other materials.

Figure 2.2
Tin balance for the Danish Society (tonnes tin/year)



Beside this, diorganotin compounds were used in low concentrations as catalysts for silicone, polyurethane foam and for a broad range of glues and paints. The total consumption with these uses is relatively small, but diorganotin compounds are used in a range of semi-manufactured goods for consumer products such as electronics, footwear, vehicles, and furniture.

Triorganotin compounds are used as a biocide in antifouling paint and as fungicides in surface and vacuum preservation of wood. In 1994 only a single organotin pesticide was used in Denmark.

The total consumption of inorganic tin compounds is estimated at 2.7-7.1 tonnes Sn. Inorganic tin compounds were used for electroplating tin-lead alloys in the electronic industry and electroplating of tin or tin-nickel on equipment for the food industry, scientific instruments etc. Moreover inorganic compounds were used for glass and ceramic glazes.

Emissions to the environment

Emissions of tin to the environment in Denmark and release to waste deposits are shown in figure 2.2.

Emissions to the air

There are only a few available measurements of tin emissions to the air in Denmark. Emissions from the different sources are consequently estimated from emissions factors from the literature. The total emission to the air is estimated at 0.5-6 tonnes Sn. The main sources were production of iron and steel, glass, cement, ceramics, and castings, burning of coal and oil and incineration of municipal solid waste.

No data on organotin emission to the air has been available but a modest emission from solid waste incineration and glass production is expected.

Table 2.1
Consumption of organotin compounds with finished goods in Denmark; 1994.

Uses	Consumption of organotin compounds				% of consumption (tin) [6)]
	Monoorganotin [1)] Tonnes/year	Diorganotin Tonnes/year	Triorganotin Tonnes/year	Total Tonnes/year	
PVC	0.5-0.8	60-89		13-20	60
Polyurethane [2)]		3-4.5		0.6-0.9	2.7
Silicone		0.9-3.4		0.1-0.7	1.5
Wood preservation [3)]			13-16	3.5-4.4	14
Antifouling paint			17-20	4.8-5.4	19
Other paintings		1.5-2.5		0.3-0.6	1.6
Pesticides			0.11	0.02	0.07
Other uses [4)]		0.2-0.9		0.04-0.2	0.4
Total [5)]	0.5-0.8	66-100	30-36	22-32	100

Notes:

1) Only tin compounds used in finished goods are included. About 6,5 tonnes monobutyltin dichloride used as precursor for tin oxide coatings on glass is thus not included.

2) The most common catalyst used for flexible polyurethane foam is the non-organotin compound stannous octoate.

3) Represents the consumption of antifouling paint in Denmark subtracted the losses during painting.

4) Includes organotin in catalysts for polyethylene and in repellents for moulding.

5) Totals are rounded

6) Calculated from mean values. Represents the percentage of tin consumption with organotins.

Discharge to aquatic environments

The total discharge to the aquatic environment is estimated at 4-17 tonnes Sn/year. Of this, organotins constituted 2.9-4.6 tonnes Sn/year. The main sources were municipal waste water, release of organotin from antifouling paints on ships, and emission of organotin from shipyard activities.

The emission of organotin from antifouling paints can either be estimated as the emission from ships built or repaired in Denmark or as the total emission from vessels to the Danish waters. Based on the consumption of antifouling paint in Denmark, the emission is estimated at 2.9-3.8 tonnes Sn/year. The total emission to the Kattegat and the Belt Sea from vessels calling at Danish and Swedish ports or passing through the Belts in 1994 is with high uncertainty estimated at 0.2-1.4 tonnes Sn. Danish vessels are estimated to be responsible for 12-35% of this emission.

Based on preliminary studies of organotin in municipal waste water it is estimated that triorganotin in waste water constituted at most 5% of the total triorganotin discharge to the aquatic environment while at least 95% directly or indirectly was due to the use of antifouling paint.

Discharges of organotin with waste water from ship yards has been significantly reduced due to effective waste water treatment. But it is still unclear to which extent organotin is emitted with aerosols from spray-painting and dust from sand blasting. The present information indicates that these activities could contribute significantly to the total discharge of organotin compounds to the aquatic environment.

Release to soil

The total release to soil is estimated at 3-19 tonnes Sn/year. Release of organotin was due to the use of municipal waste water sludge on agricultural soil (0.1-0.9 tonnes Sn), leaching and spill of wood preservatives (0.4-1.4 tonnes Sn), use of pesticides (0.02 tonnes Sn) and emissions of dust and aerosols with antifouling paint from ship yards (0.03-0.3 tonnes Sn). The compounds which are released may be degradation products as the organotin compounds are degraded within and at the surface of the products where they are used.

Recycling

There is hardly no recycling of tin with used products. In 1994, 220-270 tonnes tin were recycled with scrap - principally from manufacturing of products. The scrap was exported. Indirectly organotin was recycled with transparent PVC sheets, but compared to the total consumption of organotin compounds recycling was rather insignificant.

Aluminium
- Substance Flow Analysis and Loss Reduction Feasibility Study

Carsten Lassen, Erik Hansen, Torben Kaas & Jørgen Larsen. 1999.
Environmental Project no. 484.

The Danish EPA, Copenhagen

English Summary

Menu
The total consumption of aluminium metal with finished goods in Denmark 1994 is estimated at 72,000-105,000 tonnes. The same year, 40,000-60,000 tonnes was discarded, of which about 60% was recycled whereas the remainder was disposed of with solid waste or emitted to the environment. Solid waste disposal of aluminium in packaging made up about half of the lost aluminium metal. Some 7,300-13,000 tonnes aluminium metal ended up in refuse incineration leading to the formation of 14,000-25,000 tonnes slags. Beside aluminium metal 1.000-2.400 tonnes aluminium was consumed with chemicals and 110,000-340,000 tonnes aluminium was consumed with minerals; mainly clay minerals and coal. The major part of discarded aluminium is recycled, but the recycling process results in general in a quality deterioration of the aluminium. For selected uses the report reviews the feasibility of quality preservation and the possibilities of a reduction of the loss of aluminium from the material cycle.

Background and Aim of the Project
The present analysis made part of a project which beside this analysis includes an assessment of environmental profiles of aluminium in a life cycle perspective and an assessment of the “ecological scope” for the use of aluminium.

The background for the project is that the Danish Environmental Agency’s Action Programme for Cleaner Technology 1993-1997 designated aluminium as one of the materials for each of which a survey of the environmental load in the whole life cycle of the material is to be carried out. Aluminium was designated because the metal is used in large quantities, consumption is increasing, and because parts of the material cycle have substantial environmental impact.

The Survey
The project is carried out according to the Danish Environmental Protection Agency’s paradigm of substance flow analyses. The present knowledge is based on information from the Danish National Agency of Statistics, the Product Database of the Danish EPA, technical literature, private companies and governmental institutions. In the analysis all information is hold together to form an image of the total aluminium mass flow through the Danish

society. An important purpose of the analysis is to point out applications which result in losses of the substance to the environment, wastewater, refuse incineration and landfills respectively. By drawing up the mass balance, independent data on sources and sinks are compared, e.g. sources of aluminium to wastewater are compared to actual analyses of the substance in wastewater and municipal sludge.

The assessment of aluminium disposal and emissions to the environment focuses on losses and emissions from uses of aluminium as metal or with chemicals, whereas the turnover of aluminium with minerals and as natural contaminant is only analysed summarily. With respect to this the analysis deviates from the paradigm.

The survey was carried out in 1996 using data representing the 1994 situation.

Main Conclusions

- The consumption of aluminium metal with finished goods in Denmark 1994 is estimated at 72,000-105,000 tonnes Al, whereas aluminium consumption with chemicals is estimated at 900-2,400 tonnes Al.

- Some 14,000-25,000 tonnes aluminium metal was lost to the environment or deposits.

- Aluminium in packaging made up more than half of the loss of aluminium metal with waste.

- A reduction of the loss of aluminium with thin packaging foils can in particular be obtained through a more differentiated view on the necessity of diffusion barriers and as a consequence eventually substitute other materials for aluminium.

- It is recommended to investigate the feasibility of collecting aluminium packaging with other metals from the households.

- Anodes for cathodic protection of ships and harbours were the principal source of non-mineral bound aluminium release to the aquatic environment, whereas he main sources of non-mineral bound aluminium to wastewater were precipitants and nonphosphatic detergents.

- Only about 60% of discarded aluminium was recycled. Due to mixing of alloying elements almost all scrap aluminium was recycled for casting alloys with a high content of alloying elements.

- If a major part of the total aluminium consumption is to be based on secondary aluminium, an increased grade of scrap aluminium will be requisite to avoid the limitations of applications of secondary aluminium caused by the mixing of alloy constituents.

Aluminium Consumption

The total aluminium consumption in Denmark is represented in table 1. The aluminium metal consumption of 72,000-105,000 comprises less than a third of total consumption of aluminium. With respect to this aluminium consumption differs markedly from most other metals. This is due to the fact that aluminium occurs in high concentration in many common minerals. Aluminium in coal comprises about a third of the total aluminium consumption, and the high aluminium concentration in the residues makes coal a possible future aluminium resource.

Table 1
Aluminium consumption with manufactured goods in Denmark 1994.

Product	Consumption Tonnes Al	% of total consumption
Aluminium metal	72,000-105,000	28
Chemicals	990-2,400	0.5
Minerals (mainly clays)	47,000-159,000	33
Unintended uses (mainly coal)	60,000-178,100	36
Total consumption	180,000-445,000	100

From an energy and resource viewpoint, the consumption of aluminium metal is not comparable to the consumption of aluminium with minerals, as extraction of the metal from the clay minerals involves a high energy consumption. The aluminium consumption with minerals and unintended uses is consequently only assessed summarily and included, as the uses with minerals influence on the drawn up balances.

Aluminium metal consumption differentiated on uses is presented in table 2. Aluminium is used for a large number of applications and there is no main application that makes up a predominant part of the consumption.

Table 2
Aluminium metal consumption with manufactured goods in Denmark 1994.

Product	Consumption Tonnes Al	% of Al metal consumption
Packaging	7,300-11,200	10
Building materials	19,100-25,800	25
Electric and electronic appliances	14,200-20,700	20
Transportation	19,000-26,400	26
Other uses as metal	12,700-20,400	25
Total consumption	72,000-105,000	100

Mass Balance of Aluminium

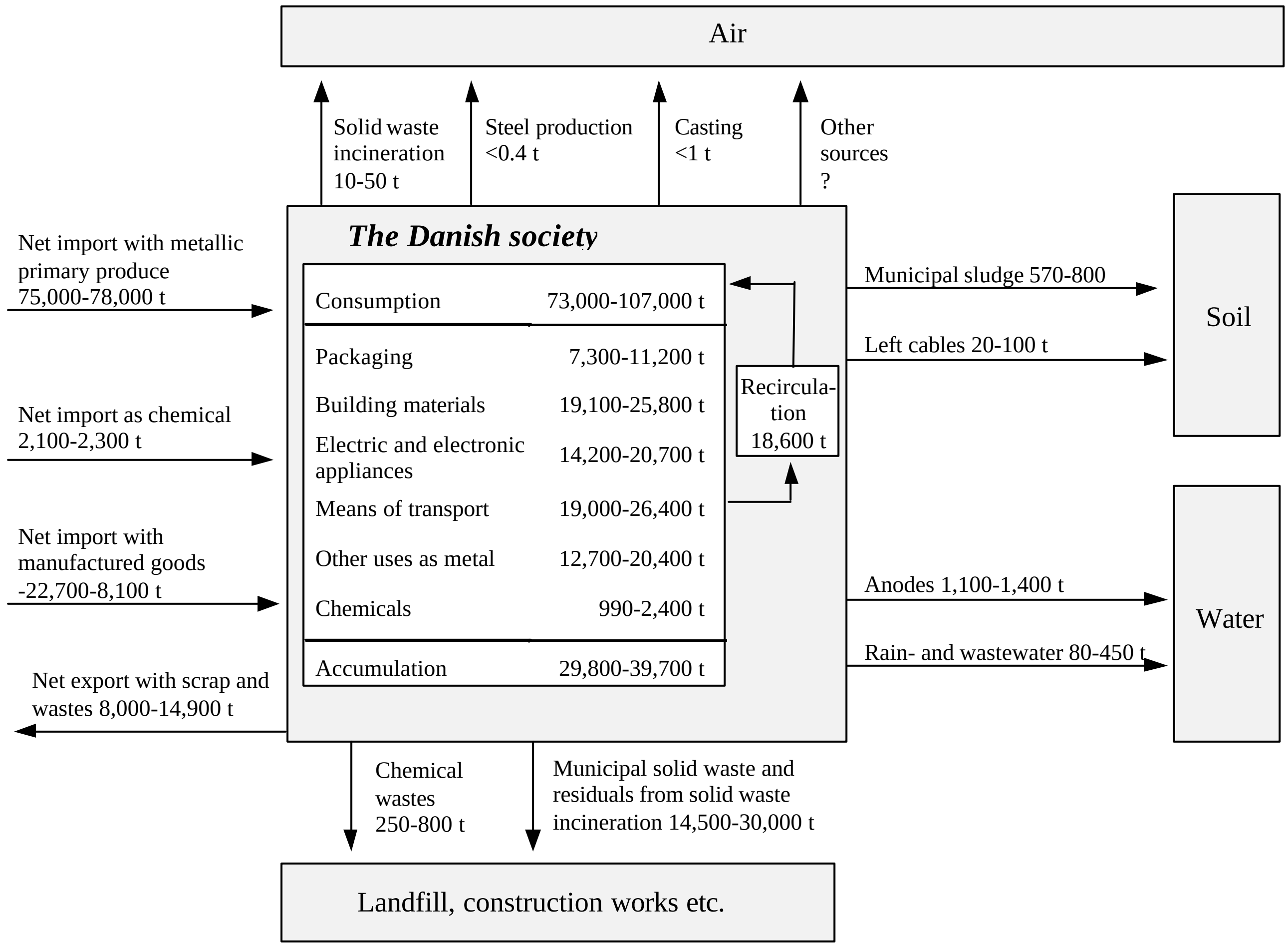
The national mass balance of aluminium is shown in figure 1. The balance only comprises uses of aluminium as metal and with chemicals.

There is no primary production of aluminium in Denmark and the country is dependent on supplies from abroad. Commodity trade across the border is represented in the left part of figure 1.

The net supply of metallic aluminium or aluminium in chemicals to the Danish society with both raw materials and manufactured goods in 1994 is estimated at 54.000-88.000 tonnes. Of this, the net import of metallic aluminium with raw materials and semi-manufactures made up the main part which based on the trade statistics can be determined relatively precisely. The total import and export with finished goods could only be estimated with high uncertainties, and the net balance is in between a net export of up to 23,000 tonnes and a net import of up to 8,000 tonnes.

In 1994 about 18.200 tonnes secondary aluminium was produced from remelted scrap in Denmark. The produced secondary aluminium was exclusively used for casting alloys and deoxidiser for steelworks.

Figure 1
Aluminium mass balance for the Danish society 1994. The production of secondary aluminium is illustrated in a simplified way as a recycling within the boundary of the country, although there is an intensive import and export of scrap. All flows are in tonnes Al.



Emissions to the Environment
In the upper part of figure 1 emissions to the air are shown.

There are no limit values for emission of aluminium to the air in Denmark, and it has not been possible to procure any measurements of aluminium in flue gasses from refuse incineration, coal and oil combustion, aluminium casting or production of cement, tile or secondary aluminium. The total emission from Danish sources is roughly estimated at 40-320 tonnes Al, of which the main sources are supposed to be refuse incineration and coal combustion. Broadly <50 tonnes Al of these could be assigned to use of aluminium as metal or with chemicals.

In the right part of the figure the release of aluminium to soil and the aquatic environment is shown.

The turnover of acid soluble (i.e. not mineral bound) aluminium with wastewater is, based on measurements of aluminium in sewage sludge, estimated at 1.100-1.800 tonnes Al. More than 90% of this was retained with the sludge. The main sources of acid soluble aluminium (not mineral bound) are assumed to be aluminium containing precipitants and nonphosphatic detergents.

The principal source of aluminium release to the aquatic environment, representing 1.100-1.400 tonnes aluminium, was anodes used for cathodic protection of ships and harbours.

In 1994 570-800 tonnes acid soluble aluminium was disposed of to agricultural land with sewage sludge. Loss of aluminium with discarded underground cables left in the ground, is estimated at 20-100 tonnes Al in 1994, equivalent to about 1% of the current consumption for this purpose.

Loss of Aluminium with Solid Waste
At the lower part of figure 1, the loss of aluminium with solid waste is shown. Most of the aluminium metal that was lost was disposed of to refuse incineration where it was oxidised under liberation of energy and ended up in the residues. It is estimated that incineration of aluminium metal lead to the formation of 14,000-25,000 tonnes aluminium oxide in residues.

As shown in table 3, aluminium in packaging constituted about half of the total loss of aluminium metal in 1994. Intended loss of aluminium as deoxidiser for steel production and cathodic protection of harbours and ships constituted about 12% of the total loss. For both packaging and cathodic protection primary aluminium is used, and at present it is not possible to use less pure secondary aluminium for these applications.

Table 3
Loss of aluminium metal in Denmark 1994.

Source	Tonnes Al	% of total
Packaging	7,300-11,200	48
Electronics	370-1,300	4.3
Electric appliances	410-1,540	5
Building materials	40-210	0.6
Cables left in the ground	20-100	0.3
Other products	910-4,000	13
Waste from manufacturing processes	960-2,000	8
Waste from shredders	50-300	0.9
Waste from secondary aluminium production	880-1,200	5.4
Iron and steel scrap	500-700	3.1
Deoxidizer for steel production	1,100	6
Anodes for harbours and ships	1,100-1,400	6
Total	13,600-25,100	100

New Danish guidelines for the disposal of electric and electronic appliances will markedly decrease the loss of aluminium with these products, and the 1994 data shown in table 3 will not be representative for the present situation. However, there will still be a considerably loss of aluminium with smaller objects disposed of with municipal solid waste from households.

Industrial waste constituted about 8% of the total loss. A part of this waste was reused for production of precipitants, and there is a trend of increasing utilisation of the industrial waste.

Recycling of Aluminium
In 1994 40,000-60,000 tonnes aluminium metal was discarded or lost. Of this quite 60% was recycled. Compared to other metals like iron or copper the recycling rate of aluminium is relatively low. This is primarily due to the loss of aluminium with packaging. Of a total consumption of 7,300-11,200 tonnes with packaging it is estimated that less than 100 tonnes was collected for recycling in 1994. However, a number of collection system experiments are running at present, but efficient collection systems are difficult to realise because the aluminium is contaminated with food.

It is estimated that 27,100-37,200 tonnes aluminium was recycled in 1994. There was an intensive import and export of aluminium scrap with a net export of 8,000-17,500 tonnes Al. In Denmark 18,200 tonnes secondary aluminium was produced from aluminium scrap. Due to mixing of alloying elements broadly all scrap from discarded products was used for production of casting alloys or deoxidizer for steelworks, whereas process scrap to some extent was exported for remelting and production of new raw materials of the same composition. Due to the increasing aluminium consumption in Denmark as well as in the rest of the world the market for casting alloys can at present absorb all produced secondary aluminium.

Through repeated life cycles the quality of the aluminium alloys will deteriorate due to a mixing of alloy constituents. At present, when secondary aluminium is principally used for casting alloys, mainly iron and magnesium cause problems. If a major part of the total aluminium consumption is to be based on secondary aluminium, an increased grade of scrap aluminium will be requisite to avoid the application limitations of secondary aluminium caused by the mixing of alloy constituents.

Feasibility of reducing or avoiding the loss of aluminium
The aluminium consumption is increasing due to a number of good material characteristics as lightness, diffusion resistance, and corrosion resistance. In the present analysis no obvious uses where aluminium can be substituted by other materials have been identified.

Trade, material characteristics, recycling and substitution feasibility have been reviewed for four product groups: packaging, building materials, electronics and transportation. The following conclusions are drawn from the analyses:

Packaging: A reduction of the loss of aluminium with thin packaging foils can in particular be obtained through a more differentiated view on the necessity of diffusion barriers and as a consequence eventually substitute aluminium by other materials. Thicker foils, cans and containers are more suitable for recycling, but are collected to a very limited extent. It is recommended to investigate the feasibility of collecting aluminium packaging with other metals from the households.

Building materials: These materials are suitable for recycling, and the bulk part of aluminium from construction and demolition sites are recycled. The trend of using aluminium in more composite products in the building sector may impede recycling on the long view.

Electronics: Until now aluminium from electronics has mainly been disposed of to landfill and incineration plants or recycled via a shredding process. In the new electronic recycling plants these products are disassembled which makes sorting of the aluminium feasible. About 10% of electronic products is at present disassembled. Disassembling and sorting of the aluminium would be easier and more profitable, if the products were easier to disassemble.

Transportation: More than 95% of aluminium in cars is recycled. The alloys are in general mixed during the recycling process, and consequently characteristics are lost.

Substance Flow Analysis for Dichloromethane, Trichloroethylene and Tetrachlorethylene

Jacob Maag. 1998. Environmental Project no. 392.

The Danish EPA, Copenhagen

English Summary

This report

This report is presenting the results of a national substance flow analysis (SFA) for the three chlorinated hydrocarbons dichloromethane, trichloroethylene and tetrachloroethylene[1] for Denmark. The analysis was conducted in 1996 and 1997 and describes the situation in 1995. Investigations and reporting was undertaken by COWI Consulting Engineers and Planners AS for the Danish Environmental Protection Agency.

Special attention has been given to the use of the three substances in preparations, meaning products consisting of mixtures of substances.

Trends in consumption: Industrial use mainly

The investigations has revealed that the consumption is concentrated on traditional industrial uses, particularly of the pure substances, but also on preparations such as paint strippers and solvents for processing printing plates for the flexo technique. All identified products are mainly used professionally.

Paint strippers for domestic use

The only major use of chlorinated hydrocarbons in the households are paint strippers containing dichloromethane.

Consumption of preparations

Only a minor share of the consumption of trichloroethylene and tetrachloroethylene in Denmark is used with preparations, 5% and 3% respectively . For dichloromethane the corresponding figure is approximately 26%, due to the relative large consumption of paint strippers.

Consumption and losses of the three substances are summarised in the tables 2.4-2.6.

Losses to the atmosphere dominates

As expected, available measurements describing the losses of chlorinated hydrocarbons to the environment in Denmark is scarce. However, the few results reported on concentrations in waste water has confirmed the magnitude of the estimated discharges by this route.

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[1] Dichloromethane: Cas.nr. 75-09-2, is also known as methylenechloride. Trichloroethylene: Cas.nr. 79-01-6, is also known as TRI and trichloroethene. Tetrachloroethylene: Cas.nr. 127-18-4 is also known as perchloroethylene, PER and tetrachloroethene.

The major part of the consumption is considered lost to the atmosphere by evaporation during the use. Measurements on rain water indicates that part of this will be deposited in the terrestrial and aquatic environments.

Direct discharges to waste water are deemed propable for only few uses of the substances. For all other uses, it is believed that no discharges to waste water will appear under normal circumstances.

Losses with waste

It has not been possible to quantify the losses of the chlorinated hydrocarbons to hazardous waste precisely . The presented figures are rough estimates based on general knowledge on chemical characteristics and standard routines of use and disposal in the application fields in question.

For domestic waste the situation is similar. A few measurements of emissions of trichloroethylene and tetrachloroethylene from waste management plants has been found, though.

The major contributions to hazardous waste originates from use in closed or semi-closed systems, such as dry-cleaning of textiles, medical industry, laboratories and flexo plate processing.

Alternatives available

In this investigation most of the information has been retrieved from product suppliers and only to a lesser degree from users. It is the clear impression from the conducted inquiries, that alternative preparations, not containing chlorinated hydrocarbons, are commercially available, and that such products hold considerable shares of the market for several applications. It must be noted however, that it has not been part of the purpose of this investigation to evaluate if the alternative products comply with the demands of the users for efficiency and low cost.

Pure substanses vs. preparations

In these investigations the turnover of each substance is quantified separately for the pure substance (traded as such) and for the substance contained in preparations.

In figure 2.1 the flows are shown in principle (simplified). "Net import" denotes the import minus the re-export of the substance as pure and and as contained in preparations manufactured outside Denmark (respectively). As such "Export" denotes the export with preparations produced in Denmark only. "Losses" includes losses to the environment (to air, water and soil), as well as destruction and degradation in waste treatments facilities.

Figure 2.1
Flow of chlorinated hydrocarbons as pure substances and with preparations of these in the Danish society (simplified, see text).

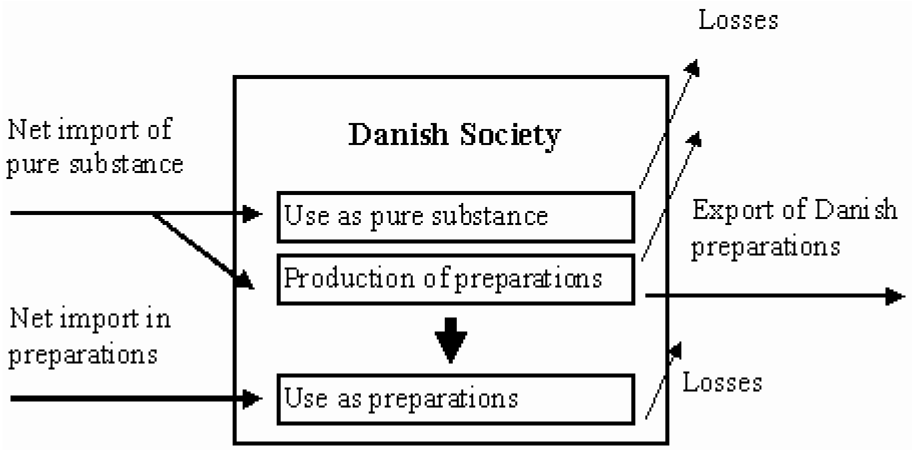


Table 2.2
Estimated consumption and losses of dichloromethane in Denmark.

Application	Consumption (tons/y)	% of consumption (mean)	Emissions to air (tons/y) *6	Emissions to waste water (tons/y)*3,*6	Disposal as hazardous waste (tons/y) *6	Recycling (tons/y) *5
Applications of pure dichloromethane *4	**390-430 *1**	**73 *1**	**260-320**	**0-1**	**90-120**	**5-15**
Ancillaries for production of plastic goods	25 *2	5	24	0	1	0
Plane glas industry	15-30	5	7-10	0	2-5	5-15
Pharmaceutical industry	30	6	0	0-1	30	0
Analysis of asfalt	20	4	19-20	0	0-1	0
Paint strippers manufactured in Denmark	46-50	10	44-50	0	0-2	0
Metal industries (shipyards etc.)	35	7	34-35	0	0-1	0
Other laboratory and research applications	35	7	9	0	26	0
Grafic industry	15-20	4	10-20	0	0-5	0
Other identified applications of pure dichloromethane	40	8	35	0	5	0
Unknown applications of pure dichloromethane	130-140	28	80-120	0	30-40	0
Applications in prepararions *4	**110-140**	**26**	**100-140**	**0-1**	**0-4**	**0**
Paint strippers	90-110	21	80-110	0-1	0-4	0
Ancillaries for production of plastic goods	1	0	<2 ***7**	0	0	0
Glues	2-7	1	2-7	0	0	0
Fillers	8	2	8	0	0	0
Cleaning agents	3-5	1	3-5	0	0	0
Other preparations	4-10	1	4-10	0	0	0
Total *1, *4	**450-510 *2**	**100**	**320-400**	**0-2**	**90-120**	**5-15**

Notes:

*1 Double counting of the consumption of preparations manufactured in Denmark is eliminated in the totals (paint stripper, sealer, glues, cleaning agents). Products for which the country of manufacturing is unknown are considered imported (deemed most likely).

*2 An additional 70-90 tons/year are used for Danish manufacturing of products for export (sealers for diecasting of plastics).

*3 Indirect exposure via evaporation to air and subsequent rainfalls are not included.

*4 Totals are rounded up.

*5 Recycling numbers does not include internal recycling integrated in manufacturing processes.

*6 The presented figures are rough estimates based on general knowledge on chemical characteristics and standard routines of use and disposal in the application fields in question.

*7 Part of this loss to air is caused by the danish production of ancillaries for export.

Table 2.3

Estimated consumption and losses of trichloroethylene in Denmark.

Application	Consumption (tons/y)	% of consumption (mean)	Emissions to air (tons/y) *6	Emissions to waste water (tons/y)*3,*6	Disposal as hazardous waste (tons/y) *6	Recycling (tons/y) *5
Applications of pure trichloroethylene *4	**690-870 *1**	**95 *1**	**640-830**	**0-10**	**0-10**	**30-40**
Degreasing in metal industries	660-830	91	610-790	0-10	0-10	30-40
Ancillaries for production of plastic and rubber goods	30-40	4	27-40	0	0-1	0
Cleaning agents manufactured in Denmark	0.7-0.9	0	0.7-0.9	0	0	0
Applications in preparations *4	**26-39**	**5**	**23-36**	**0**	**2-4**	**0**
Vulcanizers and glues	10-14	1	10-14	0	0	0
Cleaning agents	8-10	1	5-7	0	2-4	0
Paints and varnishes	4-5	1	4-5	0	0	0
Other preparations	4-10	1	4-10	0	0	0
Total *1,*4	**720-910 *2**	**100**	**660-870**	**0-10**	**2-14**	**30-40**

Notes:

*1 Double counting of the consumption with preparations manufactured in Denmark is eliminated in the totals (cleaning agents). Products for which the country of manufacturing is unknown are considered imported (deemed most likely).

*2 An additional 40-70 tons/year are used for Danish manufacturing of products for export (varnish and paint products).

*3 Indirect exposure via evaporation to air and subsequent rainfalls are not included.

*4 Totals are rounded up.

*5 Recycling numbers does not include internal recycling integrated in manufacturing processes.

*6 The presented figures are rough estimates based on general knowledge on chemical characteristics and standard routines of use and disposal in the application fields in question.

Table 2.4

Estimated consumption and losses of tetrachloroethylene in Denmark.

Application	Consumption (tons/y)	% of consumption (mean)	Emissions to air (tons/y) *6	Emissions to waste water (tons/y)*3,*6	Disposal as hazardous waste (tons/y) *6	Recycling (tons/y) *5
Applications of pure tetrachloroethylene *4	**740-800**	**97**	**350-500**	**0-1**	**270-390**	**7-11**
Dry cleaning of textiles	325-330	41	160-210	0-1	110-150	7-10
Pharmaceutical industry	50-65	7	8-10	0	42-55	0
Processing of flexo printing plates *1	0-10	1	0-7	0	0-2	0-1
Other identified applications of pure tetrachloroethylene	35-60	6	30-57	0	2-9	0
Unknown applications of pure tetrachloroethylene*2	330	42	150-220	0	120-170	0
Applications in preparations *4	**20-33**	**3**	**14-24**	**0**	**3-5**	**3-4**
Compound products for processing af flexo printing plates	17-26	3	11-17	0	3-5	3-4
Cleaning agents	0-0.1	0	0-0.1	0	0	0
Proofing agents	1.6	0	1.6	0	0	0
Other preparations	1-5	0	1-5	0	0	0
Total *4	**760-830**	**100**	**360-520**	**0-1**	**270-400**	**10-15**

Notes:

*1 The number only includes tetrachloroethylene sold as pure for subsequent mixing by the user. Tetrachloroethylene, which is mixed with other buthanol by the suppliers, is included under preparations.

*2 The net import is reported stabile while the consumption for the major applications is reduced. This indicates, that a considerable amount of tetrachlorethylen can not be accounted for in detail.

*3 Indirect exposure via evaporation to air and subsequent rainfalls are not included.

*4 Totals are rounded up.

*5 Recycling numbers does not include internal recycling integrated in manufacturing processes.

*6 The presented figures are rough estimates based on general knowledge on chemical characteristics and standard routines of use and disposal in the application fields in question.

Brominated Flame Retardants - Substance Flow Analysis and Assessment of Alternatives

Carsten Lassen, Søren Løkke & Lina Ivar Andersen. 1999. Environmental Project no. xxx.

The Danish EPA, Copenhagen

Including 'English Summary' and 'Summary and Discussion of Substance Flow Analysis'

English Summary

The consumption of brominated flame retardants (BFRs) with end products in Denmark in 1997 is estimated at 320-660 tonnes. Tetrabromobisphenol A (TBBPA) and derivatives accounted for about half of the consumption, and the consumption of these flame retardants is increasing. The more controversial compounds, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) accounted for approximately 1% and 9%, respectively, of the consumption with end products. A marked shift away from PBDEs has taken place in Danish production and for a part of the imported products. The knowledge on the emissions of the brominated flame retardants to the environment is still very limited. Model estimates indicate that the major source of brominated flame retardants lost to the environment is evaporation from products in use. No recycling activities are taking place for materials containing brominated flame retardants. Broadly all electronic equipment, as well as a major part of other electrical devices, contains brominated flame retardants. For two large application areas - TV sets and computer monitors - the trend of the recent years has been a shift away from the use of brominated flame retardants. This is partly due to the influence of ecolabels. Today, alternative flame retardants are available for applications that quantitatively account for the major part of the consumption of brominated flame retardants. The current knowledge of the environmental properties of the substitutes is limited, however. For a number of applications that account for a major part of the BFRs used for Danish production, substitutes are still at the developmental stage.

Background and Objectives

The term ‘brominated flame retardants’ cover a large number of different organic substances, all with bromine in their molecular structure. Bromine has an inhibitory effect on the formation of fire in organic materials. Flame retardants are added to plastics and textiles in order to comply with fire safety requirements.

The most widely used substances - among these TBBPA, PBDEs and PBBs - contain one or more carbon rings, making them very stable and efficient in a large number of plastics.

The chemical stability of the substances - particularly in the cases of PBBs and PBDEs - is also the reason why brominated flame retardants for years have been in focus in the international environmental debate. PBDEs and PBBs, which are the most stable of the described BFRs, are spread widely in the environment, are bioaccumulated and are accumulated in sediments, where they are only very slowly degraded.

With the aim of reducing the release of brominated flame retardants to the marine environment, Denmark has committed itself in the Esbjerg Declaration of 1993, to promote the substitution of brominated flame retardants with less problematic substances if such are available.

Recent research has revealed that some of the brominated flame retardants are emitted to the indoor environment from the products in use. Increasing concentrations of PBDEs have been observed in human breast milk.

Risk assessments on three PBDEs and HBCD have been carried out within the EU since the mid nineties. The results of the assessments of the PBDEs are expected to be presented in 1999.

No previous assessments of brominated flame retardants have been carried out in Denmark. It is the aim of this study to establish an overview of the use of these substances in products manufactured in, and imported to, Denmark. In addition the purpose of the project is to assess the possibilities of and limitation for substitution of brominated flame retardants.

Studies in other countries have shown that the use of flame retardants has an important role in saving lives. This issue - and more broadly the social advantages of the use of flame retardants - has not been covered by the present study.

The Study

This study has been carried out in accordance with the paradigm for substance flow analysis of the Danish Environmental Protection Agency. The knowledge presented is based on data from Statistics Denmark, the Danish Product Register, the literature, market analyses, public institutions as well as from private organisations and companies. In the analysis, all the information has been hold together to describe the total flow of brominated flame retardants through the Danish society.

Data on the import of brominated flame retardants with polymer raw materials for production in Denmark has been obtained through a questionnaire in co-operation with the Danish Plastic Federation.

An attempt has been made to collect information on the contents of brominated flame retardants in imported goods via trade companies and importers. This has proven difficult, as most vendors do not know, whether the products in question contain brominated flame retardants. As a consequence, the analysis for a number of product types has been based on data on the European market for flame retardants and flame retarded polymers. Based on such information, it has been possible to determine which flame retardants are likely to be used in the different types of end products.

No measurements of the concentrations of brominated flame retardants in Danish waste water and sewage sludge have been found. Similarly no measurements of emissions from production or products in use are available. No Danish studies have been made on the fate of brominated flame retardants in the waste treatment systems. Hence, it has been necessary to estimate the potential loss of brominated flame retardants to the environment considering the few available foreign analyses and model estimates. The presented estimates of losses to the environment are therefore to be considered as the author's best estimate based on the existing knowledge.

Information on alternative flame retardants, and products containing alternatives, has been obtained from suppliers of flame retardants and plastic raw materials, as well as searches on the Internet and direct contact to producers using alternatives. Brominated flame retardants account only for about 15% of the Western European market for flame retardants. For many purposes, for instance carpets and PVC, other types of flame retardants are generally used. For this reason, only the applications where brominated flame retardants are used today, have been included in the assessment of alternatives.

In order to give a first overview, potential risks related to alternative flame retardants were identified on the basis of existing reviews.

This study has been carried out in 1998/99, and the data represent the 1997-situation.

Main Conclusions

The main conclusions of the project are:

- The Danish consumption of brominated flame retardants with end products in 1997 is estimated at 320-660 metric tonnes. The consumption can be broken down to about 47% TBBPA and its derivatives, 12% PBDEs, 1% PBBs, 11% HBCD and 29% other brominated flame retardants. About 44% of the total were used as reactive constituents.

- Imported goods accounted for about 90% of the consumption with end products.

- Brominated flame retardants are used in almost all product types containing electronics, as well as in a significant part of other types of electrical equipment.

- Brominated flame retardants are not produced in Denmark. The total import of brominated flame retardants with chemicals, polymer compounds and plastic semi-manufactures for production in Denmark was 260-390 tonnes in 1997. Of this TBBPA accounted for about 54%, while PBBs and PBDEs in total accounted for only about 2%.

- For production of insulating materials in Denmark 83-130 tonnes HBCD and brominated polyetherpolyol were used.

- In Danish manufacturing of housing for electronics, the brominated flame retardants have been substituted with halogen-free flame retardants. The substitution has been driven by the purpose of avoiding antimony trioxide, which is often used in combination with the brominated flame retardants. Antimony trioxide is listed on the Danish list of hazardous substances. (brominated flame retardants are not).

- There has been a marked shift from PBDEs to TBBPA (and derivatives) in thermoplastics used in Danish production. This trend is also seen for housing of imported electronics, although PBDEs are still present in many imported products. Assessments on the overall European consumption do only indicate a decrease in the consumption of PBDEs in Northern Europe.

- Model estimates indicate that the emissions of brominated flame retardants to the environment are predominantly caused by evaporation from end products in use, whereas production processes may contribute with minor amounts. Little is known so far regarding the evaporation from end products. The actual emission rates and the fate of the evaporated substances are still uncertain.

- It is important to distinguish between additive and reactive uses. Brominated flame retardants used as additives are estimated to have a much larger tendency to evaporate to the surroundings, than substances chemically bound in the polymer structure. Examples of reactive use are the incorporation of bromine in epoxy based printed circuit boards and rigid polyurethane foam.

- Discharges to waste water from products and production processes are modest. A major part is estimated to originate from flame retarded textiles. This contribution is, however, rather small compared to other European countries, where the use of brominated flame retardants in textiles is more common.

- For a number of electronic products, no alternatives are currently available. This is reflected in the fact that the present ecolabels only have requirements regarding flame retardants for large plastic parts in the products.

- Alternatives exist for the major applications, printed circuit boards and housing.

- Most of the alternatives have been assessed only to a very limited extent. Several of the substances have been demonstrated to have undesirable environmental effects, and there is a need to establish a better overview of the environmental properties of the alternatives.

The results

The present study consists of two parts: a substance flow analysis of brominated flame retardants and an assessment of alternatives to brominated flame retardants.

Extended summary of the results and discussion of the substance flow analysis can be found in chapter 6.

The aim of the assessment of alternatives is to identify possibilities of and limitation for substitution of brominated flame retardants. Extended summary for the assessment of alternatives can be found in chapter 11.

6 Summary and Discussion of the Substance Flow Analysis

6.2 Consumption in Denmark

The total consumption of brominated flame retardants with end products in Denmark is summarised in table 6.1.

The total consumption is estimated at 320-660 tonnes.

The principal fields of application were:

- Electric and electronic equipment accounting for about 70% of the total
- Building materials accounting for about 15% of the total
- Transportation accounting for about 12% of the total

The consumption with electric and electronic equipment can be broken down to about 29% of the total consumption with printed circuit board assemblies, 21% with housing, 7% with other parts of electric appliances and machines, 2% with lighting, and 11% with products for wiring and power distribution.

The use of brominated flame retardants is very widespread. Brominated flame retardants are present in almost all products containing electronic components i.e. virtually all electronic products and means of transport and a large part of the electric products. Additionally brominated flame retardants are used in a significant part of plastics in contact with live parts in electric equipment. Switches, plugs, and sockets for lighting are only a few examples.

Unintended uses as contaminant

Natural occurrence of BFRs has not been reported. The total turnover of PBDEs with food is estimated at 0.4-0.8 tonnes per year. Fish is estimated to account for approximately half of the intake with food. The available data indicate that the turnover of TBBPA with fish is considerably lower than the turnover with PBDEs, but data on other BFRs than PBDEs and PBBs are scarce.

Specific substances

The consumption of the different groups of flame retardants is estimated with high uncertainty, as specific information on the content of flame retardants in imported products has been difficult to obtain. For some applications the actual flame retardants present in the products are estimated from more general information on the consumption of flame retardants in Western Europe and other parts of the World.

Table 6.1
Consumption of brominated flame retardants with end products in Denmark 1997

Product group	Total consumption of BFRs		Consumption of specific compounds (tonnes)				
	Tonnes	%	PBDE	TBBPA	PBB	HBCD	Other BFRs
Printed circuit boards	100-180	29	0.3-5.2	100-180			0-2
Epoxy laminates	*92-150*			*92-150*			
Paper/phenolic laminates	*3-4.8*		*0.3-1*	*2.3-3.8*			
Electronic component encapsulates	*6-22*		*<2.2*	*7.4-22*			
Other plastic parts	*<4*		*<2*	*<2*			*<2*
Housing of EE appliances and machines	80-130	21	3-10	56-89			25-49
PC monitors	*48-73*			*34-52*			*14-21*
Notebook computers	*3-4*			*2-3*			*1-1.4*
Other office machines	*20-31*			*17-25*			*3.7-5.5*
TV-sets	*3-4*		*1-3*	*1-2*			*2-4*
Other consumer electronics	*2-6*		*0.5-2*	*0.5-2*			*2-6*
Medical and industrial electronics	*2-14*		*1-4*	*1-4*			*2-10*
Small household appliances	*0.5-2*		*0.5-1*	*0.5-1*			*0.5-1*
Other parts of EE appliances and machines	20-50	7	5-14	3-8	0-2		16-43
Switches, relay parts etc.	*10-25*		*2-6*	*2-6*			*8-20*
Moulding fillers	*2-5*		*2-5*				*2-5*
Other plastic parts	*6-20*		*1-3*	*1-2*	*0-2*		*6-18*
Lighting	4-14	2	1-7	4-11			1-9
Sockets in lamps and fluorescent tubes	*4-7*		*1-3*	*4-7*			*1-3*
Plastic cover parts	*<3*		*<2*	*<2*			*<2*
Switches, electronic parts etc.	*<4*		*<2*	*<2*			*<4*
Wiring and power distribution	30-80	11	7-29	4-15	1-5	2-4	20-49
Rubber cables	*2-10*		*1-5*		*1-5*		
Other cables	*<5*		*0-5*				*0-5*
Wiring of houses	*11-26*		*2-7*	*2-7*		*2-4*	*7-14*
Contactors, relays, switches etc. for automation and power distribution	*15-35*		*4-12*	*2-8*			*13-30*
Textiles, carpets and furniture	2-11	1.3	0-5			2-9	0-5
Protective clothing	*<0.1*		*<0.1*			*<0.1*	*<0.1*
Curtains, carpets and tents	*<1*		*<1*			*<0.5*	*<0.5*
Furniture, Foam and stuffing	*2.2-9.7*		*<4*			*2.2-8.7*	*<4*
Building materials	50-100	15	1-5	0-2		13-36	41-66
Expanded polystyrene, EPS	*0.5-2.7*					*0.5-2.7*	
Extruded polystyrene foam, XPS	*11-29*					*11-29*	
Polyurethane foam	*40-60*						*40-60*
Other uses	*1-7*		*1-5*	*0-2*		*1-4*	*1-6*
Paint and fillers	0.6-1.7	0.2	0.1-0.5				0.5-1.2
Paint	*0.1-0.3*		*0.1-0.3*				
Fillers and wood proofing	*0.5-1.4*		*0-0.2*				*0.5-1.2*
Transportation	30-90	12	13-46	14-52		9.4-30	19-71
Cars, lorries and busses	*24-72*		*13-41*	*12-37*		*9.4-29*	*18-52*
Trains	*0.3-4*		*0.04-1.7*	*0.3-4*			*0.3-4*
Other means of transport	*1-15*		*0-3*	*1-11*		*0-1.5*	*1.5-15*
Other uses	<3	0.3	0-2	0-2		0-1	0-2
Total (round)	320-660	99	30-120	180-360	1-7	26-80	120-300

Notes

1) Include derivatives of TBBPA.

2) Some of the flame retardants are used reactively and the chemical substance *per se* is only present in the end product in trace amount. For some

applications the flame retardants are indicated as either/or (for instance either TBBPA or PBDE) and the sum total of BFRs is lower than the sum of the single groups.

TBBPA and derivatives are estimated to account for about 47% of the total consumption. TBBPA is mainly used reactively for printed circuit boards and additively for housing of electric and electronic appliances and engineering thermoplastics. TBBPA and derivatives are estimated to account for a larger part of the total consumption than they do at the global and W. European market cf. section 3.3. The reason is that TBBPA and derivatives are estimated to account for the major part of BFRs used for housing of electronics and this may be specific for Northern Europe.

PBDEs are estimated to account for approximately 12% of the total consumption. It should be noted that the uncertainty on this value is as high as ± 50%. Major application areas are housing and engineering thermoplastics of electric and electronic equipment and plastic parts of transportation.

PBBs account for approximately 1%. Areas where the use of PBBs has been identified are engineering thermoplastics and rubber cables.

HBCD accounts for approximately 11%. Major application areas are expanded polystyrene (EPS and XPS) and textiles for automotive interior.

Other brominated flame retardants accounted for approximately 29%. Specific information of other BFRs in imported products has been difficult to obtain. Major applications are polyurethane insulation (brominated polyetherpolyol), housing of electronics (e.g. tetrabromophtalimide), transportation (e.g. tetrabromophthalic anhydride). Other BFRs may, however, be used within all application areas.

Reactive vs. additive use

When the flame retardants are used reactively and built into the polymer structure, the chemical substance *per se* is only present in the plastic in trace amount. The product may rather be considered a brominated thermoset with properties that are significantly different from the properties of the flame retardant compound that is used as precursor.

TBBPA used reactively for printed circuit boards may accordingly in the end products be considered another substance than TBBPA used as additive flame retardant in housing. On a global scale additive use of TBBPA has traditionally only accounted for about 10% of the total consumption . Because of the substitution of TBBPA (and derivatives) for PBDEs in housing and other applications, the additive use is estimated to account for a considerably higher part of the consumption of TBBPA with end products in Denmark.

Other main applications by which the brominated flame retardants are used reactively are polyurethanes for insulation and technical laminates based on unsaturated polyester or epoxy.

The consumption of BFRs used as reactive flame retardants can roughly be estimated at about 44% of the total consumption.

Consumer applications of chemicals

Brominated flame retardants are not marketed for non-professional use. Sprays with flame retardants for self treatment of for instance textiles in cars are available, but to the knowledge of the authors the sprays do generally contain other flame retardants.

Trends in consumption with end products

There is no previous substance flow analysis of brominated flame retardants in Denmark.

For some of the traditional major applications, TV-backplates and housing of electronics, the trend in the consumption is downward. For TV-backplates the downward trend is general to all Europe. For the housing of electronics the trend is general to at least Northern Europe.

For other applications in electric and electronic equipment - for instance printed circuit boards - the consumption pattern has been unchanged during the last years, and the total consumption of BFRs for these applications is increasing due to an increase in the consumption of the end products.

The trend in the attitude to brominated flame retardants is that many producers are looking for substitutes for brominated flame retardants, but until now substitution has only had a minor influence on the total consumption of these compounds with end products.

Consumption for production processes in Denmark

Brominated flame retardants are not produced in Denmark. For production processes they are mainly imported with plastic compounds and laminates for production of printed circuit boards.

The total import of brominated flame retardants as chemicals and with semi-manufactures for production in Denmark is shown in table 6.2.

Table 6.2
Import of brominated flame retardants as chemicals and with semi-manufactures for production in Denmark

Product group	Total import of BFRs	Import of specific substances (tonnes)				
	Tonnes	PBDE	TBBPA and der.	PBB	HBCD	Other BFRs
Chemicals [1]	29	1	2.1			26
Plastic compounds and masterbatches	130-190	0.1-0.2	34-42	3.3-4.9	6.1-13	86-126
Other plastic semi-manufactures	2.6-7		2-5.2		0.1-0.3	0.5-1.5
Laminates for printed circuit boards [2]	100-160		100-160			
Total (round)	260-390	1.1-1.2	140-210	3.3-4.9	6.2-13	110-150

Notes:

1) The chemicals are predominantly used for production of semi-manufactures that are exported. The data are derived from the trade statistics.

2) Represent the amount used for print circuit board production in Denmark.

Consumption of plastic raw materials

TBBPA for thermoplastic polyester (PBT/PET) and brominated polyetherpolyol account for the major part of the consumption of BFRs with plastic compounds in Denmark. The thermoplastic polyesters are flame retarded with TBBPA (derivatives) or PBB, and are used for production of plastic parts for electric and electronic equipment, for instance switches, relays, parts of pumps and electromotors.

Brominated polyetherpolyol is used reactively for production of rigid polyurethane foam for insulation. HBCD is used for production of expanded polystyrene for export.

A minor part of TBBPA is used for housing of electronic equipment. BFRs are only used for a small part of the flame retarded polyamide. Polyamides with non-halogen flame retardants are widely used.

Trends in consumption for production in Denmark

A few years ago PBDE in plastics for housing of electronic appliances represented a major part of the total consumption for production in Denmark, but non-halogen flame retardants have replaced BFRs for most applications.

The consumption of PBDEs as chemical has decreased from about 20 tonnes in 1995 to about 1 tonne in 1997.

Comparison with an W. European average

In section 3.3 it was estimated that the Danish consumption of brominated flame retardants in 1997 should be approximately 600-800 tonnes if the consumption equalled the average W. European consumption. The estimated total in table 6.1 indicates that the consumption in Denmark in total may be a little lower than the average European consumption. The assessments are, however, not totally independent, as the Danish consumption within some application areas has been estimated with a sidelong glance to the W. European consumption figures.

This is in particular true with respect to the distribution of the single groups of flame retardants. A recent market analysis shows PBDEs to a large extent has been replaced by other brominated flame retardants; especially in The Netherlands, Germany and the Nordic countries. PBDEs are hardly used in Danish production and not used by large German suppliers of plastic raw materials. TBBPA and other BFRs have substituted for PBDEs in housing of electronic products on the N. European market and dominant producers of electronic products has a policy of avoiding PBDEs. Market analyses of the European flame retardant market did not show any significant decrease in the use of PBDEs from 1992 to 1996 and PBDEs accounted in 1996 for about 26% of the W. European BFR market (based on information covering 76% of the market). A recent market analysis estimates that the PBDEs only accounted for 11% of the W. European market for brominated flame retardants in 1998.

The is a very significant difference between the consumption of BFRs in Danish production of plastics parts and the distribution of BFRs on the W. European market. PBDEs in Danish production only accounted for about 2% of the total BFR consumption in 1997 in comparison to approximately 26% and 11% of the W. European market in 1996 and 1998, respectively.

6.2 Emission and Disposal to the Environment and Landfills

Based on model considerations, the total emissions from Danish sources in 1997 have been estimated as follows:

Emission to the air: 0.2-1.6 link tonnes
Discharge to aquatic environments: 0.005-0.07 tonnes
Release to soil: 0.03-0.3 tonnes

The estimated emissions to the environment and disposal to landfills are shown in table 6.3.

Table 6.3
Estimated emission of brominated flame retardants to the environments and disposal to landfills in Denmark 1997

Process/source	Potential emission/disposal in tonnes BFRs to:				
	Air	Water	Soil	Landfills	Incineration
Industrial processes:					
Manufacturing of plastic products	<0.05				
Uses:					
Emission from products in service	0.2-1.5				
Textile wash		1)			
Roofing		1)			
Human excretions		1)			
Other emissions					
Waste processing:	?				
Waste management:					
Effluent from waste water treatment		0.005-0.05			
Municipal sludge			0.03-0.3	0.006-0.06	0.008-0.09
Precipitation determined effluents		<0.015			
Chemical waste					
Solid waste incineration	<0.04			?	170-360
Landfilling				90-200	
Total (round)	0.2-1.6	0.005-0.07	0.03-0.3	90-200	170-360

Notes:

1) Brominated flame retardants are released to waste water from these uses. The amount is included in 'Municipal sludge' and 'Effluents from waste water treatment plants'.

Emission to the air

There are no Danish measurements of emission of brominated flame retardants. Hence, all estimates have been based on models and measurements from other countries.

The significance of the emission of brominated flame retardants from products in use has been demonstrated by chamber experiments and measurements in the indoor environment, but the actual rates are very uncertain. Similarly emissions from production processes have been demonstrated by environmental samples from the vicinity of production sites.

Based on model considerations evaporation from products in use and during production is estimated to be the major sources of emission of the flame retardants to the air. The emission of flame retardants used reactively is estimated to be insignificant, and PBDEs and other additively used flame retardants account for the major part of the emission.

When emitted the flame retardants will tend to adsorb to solid surfaces and particles in the air. The dust particles may be released to the environment by airing, end up in vacuum cleaning bags or attach to the interior of appliances. Dust attached to the interior of appliances may be released by dismantling of the appliances.

Discharge to waste water

Although the use of brominated flame retardants with protective clothing in Denmark compared to other countries is very limited, laundry of clothing with BFRs is estimated to be one of the major sources of brominated flame retardants to waste water.

Roofing foils and particles containing brominated flame retardants - initially evaporated to the air from production processes and products in use - are estimated to be other major sources of brominated flame retardants to waste water.

Discharge to the aquatic environment

Brominated flame retardants in waste water will tend to follow the sludge. The total discharge to the aquatic environment with waste water effluents is estimated to be <0,068 tonne. As is the case with other organic compounds following the solid phase, the occasional discharges by heavy rainfall bypassing the treatment plants may account for a significant part of the total discharge to the aquatic environment.

Compared to the potential deposition of BFRs from the air, the discharge with waste water is presumably small. The potential deposition of emitted substances will be dependent on the atmospheric stability of the substances. PBDEs seem to be much more stable in the atmosphere than TBBPA and PBDEs emitted to the atmosphere may be spread over long distances.

Emission to soil

The only identified source of release of brominated flame retardants to soil is spreading of municipal sludge on agricultural soil. The flame retardants may to some extent be degraded during the digestion of the sludge, but data are not available for a quantification of the degradation.

Solid waste incineration

In total 170-360 tonnes brominated flame retardants were disposed of to solid waste incineration. During the incineration the flame retardants will be destructed. Analyses of the fate of other organic compounds during incineration show that trace amounts of the compounds will pass the combustion chamber and end up in residuals from the incineration. For phthalates for instance up to 0.1% passes through the combustion chamber.

Flame retardants passing the combustion chamber may act as precursor for formation of brominated and mixed halogen dioxins and furans.

Landfilling

In total 90-200 tonnes brominated flame retardants were disposed of to landfills. Flame retardants in products disposed of to landfills may in the long term be released to the air or landfill leachate. Measurements of brominated flame retardants in landfill leachate have not been identified. It is not known to what extent the flame retardants will be degraded within the products or in the soil in the immediate vicinity of the products from where they are released.

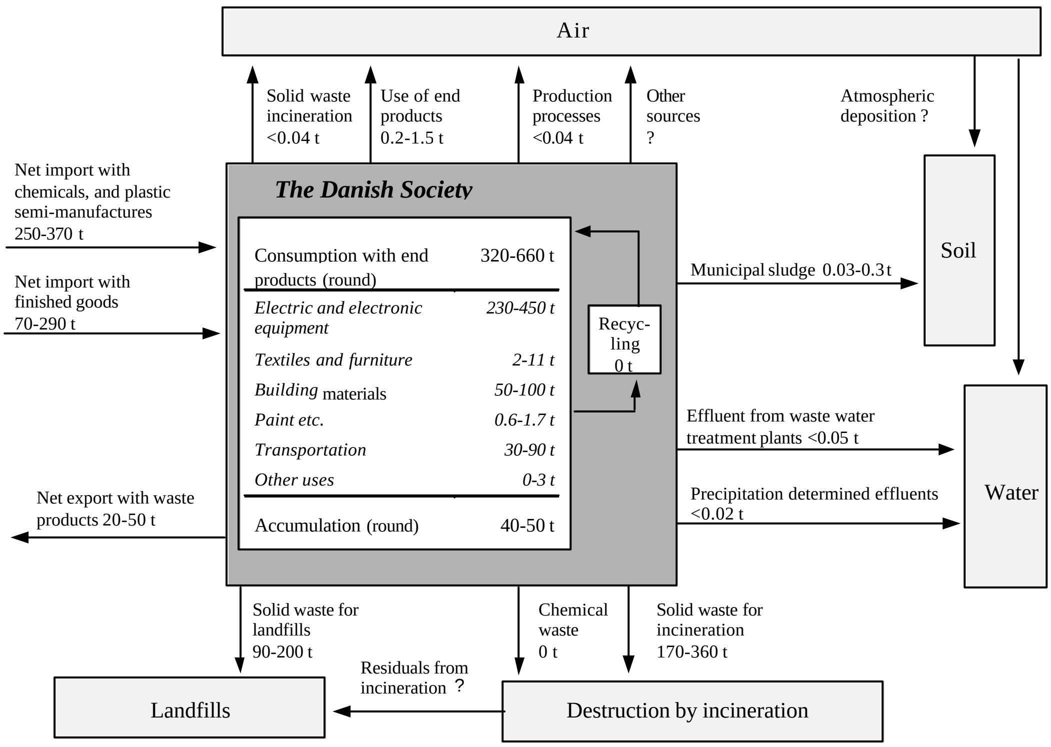
6.3 Substance Flow Balance for Brominated Flame Retardants

A schematic representation of the estimated flow of brominated flame retardants through the Danish society is shown in figure 6.1.

Import/export

Approximately 90% of the electronic products produced in Denmark are exported. Building materials is the only major application area of brominated flame retardants where domestic production accounts for a significant share of the consumption; and still the domestic production account for less than half of consumption. It is roughly estimated that imported products account for approximately 90% of the consumption of brominated flame retardants with end products.

Figure 6.1
The estimated flow of brominated flame retardants through the Danish society in 1997



Recycling

There is at present no recycling of brominated flame retardants with plastics from discarded products. Production scrap is recycled for the same applications as the primary materials.

Deposition

There are no Danish measurements of atmospheric deposition of brominated flame retardants. Data on atmospheric deposition have neither been identified in the literature.