Survey of sources of unintentionally produced substances

A report to the Swedish Government, 31 March 2005
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Preface

Many processes, both industrial production processes and other activities, can result in the unintentional formation of different substances. Such substances may arise as by-products or contaminants during the processes concerned, or through the chemical transformation or degradation of other compounds, produced intentionally or unintentionally. Combustion and other thermal processes are among the ones that can give rise to unintentionally formed substances of this kind. There has been a particular focus on compounds with properties such as high resistance to degradation (persistence), an ability to undergo long-range (transboundary) transport, a tendency to accumulate in humans and animals (bioaccumulation) and an ability to affect biological systems. Substances with these characteristics (‘POP characteristics’) are the subject of international agreements such as the Stockholm Convention and the POPs Protocol to the UN ECE Convention on Long-Range Transboundary Air Pollution (LRTAP-POP).

Sweden has signed and ratified these two agreements, which came into force on 17 May 2004 (Stockholm Convention) and 23 October 2003 (LRTAP-POP).

The substances specifically mentioned in the terms of reference for the study presented in this report (dioxins, polychlorinated biphenyls and hexachlorobenzene) are the ones dealt with in Article 5 of the Stockholm Convention, which sets out ‘Measures to reduce or eliminate releases from unintentional production’. The POPs Protocol to the UN ECE Convention also addresses these substances, with a focus on their propensity to undergo long-range transport and contaminate environments, often in the Arctic, far from known emission sources.
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Executive summary

The Swedish Environmental Protection Agency was commissioned in 2002 to undertake a survey of sources of unintentionally produced substances such as dioxins, polychlorinated biphenyls (PCBs) and hexachlorobenzene. The study carried out was also to cover the management of waste containing such substances and the occurrence of contaminated sites where they might be present. In addition, the Agency was to identify any further measures required to reduce or eliminate releases of these substances, to propose future arrangements for environmental monitoring and monitoring of releases, and to make a projection concerning the state of the environment in the light of the changes decided on and proposed.

Table 1: Magnitude of a number of dioxin sources, as estimated around 1993 and today. Quantities of dioxins have been estimated using different systems, and are shown in grams TEQ (toxic equivalents). The purpose of the table is to give an idea of the relative order of magnitude of the different types of sources. For some sources, the estimates for 2004 may seem higher than those made just over ten years ago. This is mainly because a lack of reliable data in the form of representative measurements has created a greater degree of uncertainty now than before. The range within which the ‘true’ release figure lies has therefore sometimes increased. A dash in a cell means that no reliable data are available.

<table>
<thead>
<tr>
<th>Source</th>
<th>Releases to air g TEQ/yr</th>
<th>Releases to water g TEQ/yr</th>
<th>Products and wastes, g TEQ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel works and pellet plants</td>
<td>2–20</td>
<td>5.9–8.6</td>
<td>–</td>
</tr>
<tr>
<td>Non-ferrous metal works and foundries</td>
<td>5</td>
<td>5.6–10.3</td>
<td>–</td>
</tr>
<tr>
<td>Cement industry</td>
<td>3–6</td>
<td>0.2–0.3</td>
<td>–</td>
</tr>
<tr>
<td>Pulp and paper industry</td>
<td>1</td>
<td>1.2</td>
<td>1.5–5</td>
</tr>
<tr>
<td>Chlor-alkali industry</td>
<td>–</td>
<td>–</td>
<td>0.28–0.6</td>
</tr>
<tr>
<td>Fossil fuel-fired boilers</td>
<td>0.7–3</td>
<td>&lt;4</td>
<td>–</td>
</tr>
<tr>
<td>Small-scale wood burning and large-scale burning of biomass fuels</td>
<td>3.5–18</td>
<td>&lt;14</td>
<td>–</td>
</tr>
<tr>
<td>Waste incineration</td>
<td>3</td>
<td>1.1</td>
<td>–</td>
</tr>
<tr>
<td>Landfill fires</td>
<td>2.8–30</td>
<td>0.4–65</td>
<td>–</td>
</tr>
<tr>
<td>Road transport</td>
<td>0.2–1.4</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Shipping to and from Swedish ports</td>
<td>0.2–0.5</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
The survey has been confined to the three groups of substances specifically mentioned in the terms of reference. Source data relating to unintentional production of PCBs and hexachlorobenzene have never previously been systematically collected in Sweden. In the case of dioxins, an extensive survey was carried out between 1988 and 1992 (de Wit & Strandell 2000). A comparison between that study and the situation today is presented in table 1.

Several of the figures in the table involve a wide range of uncertainty, as different measurements and other attempts at accurate quantification have yielded widely diverging results. This underscores the need to produce more reliable data that will enable the real situation to be assessed, for example in the context of self-monitoring and licensing.

Based on existing knowledge about the situation today, the following overall conclusions can be drawn:

**Present situation**

- Unexpectedly few studies and analyses have been carried out in Sweden since 1992 with the aim of identifying new and quantifying known sources of unintentionally produced substances such as dioxins, PCBs and hexachlorobenzene. In several sectors more recent analyses are completely lacking, while in others only a few have been performed and it is uncertain how representative they are of current conditions.
- Unintentional production can make only a very small contribution to the overall occurrence of PCBs in the environment.
- Compared with the situation for PCBs, a larger proportion of hexachlorobenzene probably originates from unintentional production.
- As releases from primary sources have abated, secondary sources, including long-range transport and atmospheric deposition, have become more important in relative terms.
- Levels of PCBs and hexachlorobenzene in the environment have fallen since the 1970s. This can be attributed partly to the bans that have been introduced, and partly to a decrease in the unintentional formation and release of these substances, resulting from measures taken to reduce the formation and release of dioxins.
- These decreases may also be a result of measures of a more or less far-reaching character implemented in different sectors. Such measures have often had the aim of curbing emissions and discharges more generally. Improved particulate control, for example, is one measure that has also led to reduced releases of dioxins, PCBs and hexachlorobenzene.
- Most of the dioxin sources identified in the 1980s are now responsible for appreciably lower emissions. The reductions since the beginning of the 1990s are less clear-cut, but available data are very limited and generalizations can easily give rise to misleading results.
• The decline in dioxin and PCB levels in the environment has become less and less pronounced in many areas in recent years. In some parts of the environment the decrease has probably levelled off, or even given way to an increase.
• Despite the measures introduced, the average Swede’s exposure to dioxins and dioxin-like PCBs is currently only marginally below the highest tolerable daily intake (TDI) set by the EU. This also means that, for some 10% of Sweden’s population, the TDI is exceeded.
• Further efforts to reduce the formation and release of dioxins and dioxin-like PCBs are therefore called for.
• In today’s society there may still be a legacy of timber treated with dioxin-contaminated pentachlorophenol, which could contain a total of 30 kg of dioxins (as TEQ).

Further action required
Improved knowledge
The Swedish Environmental Protection Agency considers the most important aim for subsequent work in this area to be to obtain better data generally concerning the formation, release, dispersion and cycling of the groups of substances in question, as a basis for determining the scale of the problems and their component elements.
• The Agency also wishes to see a larger number of systematic studies of industrial sources: self-monitoring by companies with regard to unintentionally produced substances should be improved across the board, for example, and the need for measurement data should be emphasized in conjunction with operational changes and licensing.
• The relative significance of long-range transport for current loadings is probably considerable, and the scale of this process should be studied more closely.
• We need a better understanding of the long-term risks of environmentally excessive leaching of unintentionally produced substances from landfills and contaminated sites, and of the relative significance of different exposure pathways, both now and in the future.
• The environmental monitoring programme needs to be strengthened, partly to provide better monitoring of the effects of measures introduced.

Control measures
The Agency proposes a range of measures in this report with the aim of further reducing and eliminating releases, in particular of dioxins.
• Industries and other relevant sectors should continue to develop and refine technical solutions to avoid the formation and reduce the release of environmentally harmful substances, including those produced unintentionally. This question should receive careful consideration in licensing and other contexts.
• Similarly, measures to reduce releases from secondary sources need to be developed.
• Efforts to manage unintentionally produced substances cannot be confined to Swedish sources alone. Sweden should therefore continue to pursue these issues, above all in the framework of international conventions and the EU, but also in other international contexts, e.g. in the elaboration of BAT reference documents (BREFs) under the IPPC Directive.
• Measures should be introduced to encourage the replacement of small, outdated wood-fired boilers with environmentally approved ones.
• There is a need for further efforts to disseminate information on what should and should not be burnt in small wood-fired boilers and on environmentally beneficial operating techniques to minimize emissions. The same goes for open fires in private gardens.
• Greater resources should be devoted to supervisory and advisory initiatives in certain areas. For example, efforts to avoid fires in landfills and on waste holding sites should continue and be stepped up.
• A study of pentachlorophenol should initially focus on assessing the feasibility of identifying where in society timber treated with this chemical is to be found and how it could be recovered and disposed of.
1 Working methods and organization

In the initial phase of this project, the primary focus was on assembling existing information about sources of the unintentionally produced substances in question. This was done by means of an inventory of the data held in different units of the Swedish Environmental Protection Agency. In parallel with this process, introductory enquiries regarding relevant data were made to sectoral organizations and individual industrial plants, and to university and college departments. The results of these enquiries were presented in the project’s pilot study report in December 2002.

On the basis of the results obtained in the pilot study, much of the subsequent work of gathering facts, performing measurements, estimating costs and assessing different alternative measures was undertaken by consultants and other third parties. The majority of this work was done at the Environmental Chemistry Section of Umeå University’s Department of Chemistry. As part of the process, over 150 analyses of dioxins, PCBs and hexachlorobenzene were performed on samples from contaminated sites, ships, large- and small-scale burning of biomass fuels, and ‘backyard burning’, i.e. simulated small-scale burning of garden waste, household refuse etc. The results of these efforts are summarized in the background reports listed in the references section of the present publication.

The project was supported by a steering group from the Environmental Protection Agency and the National Chemicals Inspectorate, and by an external and an internal reference group. The external group included representatives of various sectoral organizations, the research community, central government agencies and consultants.

This report was prepared by Malin Gunnarsson, Mikaela Gönczi and Niklas Johansson, project manager. In addition, Helene Lager was involved in writing the pilot study report. The present report includes only a few references to primary sources of data. For a complete list of references, readers should consult the background reports, except where otherwise indicated, and primarily the one from the Environmental Chemistry Section in Umeå.
2 Background

Substances that can harm living organisms by affecting their natural vital processes are said to be toxic. When such substances find their way into the environment they can be referred to as toxic pollutants. There are a great many pollutants of this kind, and new ones are constantly being discovered. A number of them have never been deliberately manufactured, but are the unintentional result of a wide range of industrial processes and other human activities. Unintentionally formed substances may arise as by-products or contaminants during a process, or through the transformation or degradation of other compounds, produced intentionally or unintentionally. Combustion processes, along with other thermal processes, have been found to be capable of giving rise to unintentionally formed substances. At present we probably know of only a fraction of the substances produced unintentionally in modern-day society.

Particular attention needs to be paid to unintentionally produced substances with properties such as high resistance to degradation (high persistence), a tendency to be taken up by and accumulate in humans and animals (bioaccumulation), and an ability to affect natural bodily functions and other biological systems (toxicity).

Persistence is a critical property in this context, since it has the following consequences:

- Persistent substances remain in the environment for a long time.
- During that time, they are able to disperse over great distances via different media and to become distributed in the environment in a manner reflecting their inherent properties.
- If the substances concerned are bioavailable, they can be taken up by organisms and become more concentrated as they pass through food chains.
- Organisms at higher levels of food chains will then be exposed to greater concentrations than those at lower levels.
- Under such circumstances, exposure will be chronic in character, which means that the internal dose will increase over the lifetime of an organism.
- We have to be prepared for a considerable delay before emission reductions and other measures produce appreciable beneficial effects in the environment.

Reactions between persistent compounds and other substances are slow. The biological effects we need to watch for in connection with such compounds are therefore long-term in character. They include effects on reproduction, the immune system and behaviour, and also cancer.
Humans are primarily exposed to persistent organic pollutants, or POPs, via their diet. This is because of the ability of such substances to become concentrated through food chains, and they reach humans chiefly in animal-based food products. Most POPs are lipophilic, i.e. have a tendency to accumulate in fatty tissues. Higher concentrations therefore often occur in organisms with high levels of fat than in those with less fat.

The lipophilic properties of POPs also mean that they do not readily dissolve in water. This in turn has the consequence that, unlike many other substances, they do not accompany water as it circulates through the environment, but are often to be found more or less tightly bound to particles in soils and sediments. Since this binding can be strong, the movements of these compounds in soil and water will be slow. Being bound to particles and other solids also makes them less bioavailable. There may therefore be considerable differences in the amounts of a substance an organism is able to take up, depending on whether or not the substance is bound to solid material. How great a risk there is of effects in any individual case also depends on a host of other factors. Apart from the inherent properties of the substance, these include the dose (exposure time x quantity of the substance) and the sensitivity, age, sex etc. of the species/individual in question.

Unintentionally produced substances can be of many kinds. Combustion processes generate complex mixtures of compounds, the more precise composition of which is rarely known. Various organic compounds, such as polyaromatic hydrocarbons (PAHs), can form as a result of incomplete combustion or through what is known as de novo synthesis during the cooling phase. Other substances, such as metal compounds, may be transformed during combustion into more bioavailable forms. Substances that have received attention as products of unintentional formation include PAHs, a complex group of compounds, some of which have been investigated in some detail. Groups which as yet have been less closely studied include brominated dioxins, dioxins containing both bromine and chlorine, chlorinated and brominated thiophenes, and the relatively recently discovered perfluorinated compounds, which may unintentionally be converted into even more stable forms in a number of different processes. Clearly there is a need to identify and quantify more precisely the significance of different processes for the formation and release of a great many groups of unintentionally produced substances. This report deals primarily with three such substances or groups of substances: dioxins, PCBs and hexachlorobenzene.

*Dioxins* is used here as an umbrella term for polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans. Dioxins have never been deliberately manufactured, other than for testing and reference purposes. In all there are 210 (75 + 135) different compounds, or congeners, belonging to this group. Of these, 17 have been found to be particularly toxic. As all of these 17 substances usually occur together, but in widely varying proportions, ‘toxic equivalency’ schemes have been developed to express the total quantity of different dioxins in a sample, weighted for...
their toxicity. The most carefully investigated and probably also the most toxic of the 17 highly toxic dioxins is 2,3,7,8-tetrachlorodibenzo-p-dioxin, also known as TCDD. The toxic equivalency schemes are based on a comparison of the toxicity of the other 16 with TCDD, which is assigned a toxicity factor of 1. All the others are given a toxic equivalency factor (TEF) of between 1.0 and 0.0001. The quantity or concentration of each of the 17 congeners is multiplied by its TEF, and the products are then summed. The figure arrived at provides a measure of the toxicity of the sample, expressed as if all its toxicity derived from TCDD alone.

The procedure described has gained very wide acceptance, and the results of virtually all types of dioxin analysis are now expressed in this form. The major problem with this is that, over the years, a dozen different schemes have existed, comprising different numbers of dioxins (12–17) and assigning different TEFs to them. Depending on the origin of the sample, the choice of equivalency scheme can significantly affect the results. There are no methods of converting from one scheme to another, unless results are available for each of the 17 congeners. All too often, dioxin results are reported in the open literature with no indication of the toxic equivalency scheme used to calculate them. These factors combined make for considerable uncertainty when different analyses are compared, e.g. in temporal studies. The schemes used most frequently in Sweden are known as ‘Eadon’, I-TEQ, N-TEQ and WHO-TEQ. The last three of these include all 17 congeners and only differ in terms of two or three TEFs. Eadon (of which two versions exist) diverges considerably from the others, in that it only includes 12 congeners and assigns six of them different TEFs compared with the other systems. Among the congeners excluded from Eadon are the most highly chlorinated ones. For several types of sample these are often the dominant dioxins, which means that the Eadon scheme gives lower TEQs than the more modern ones. WHO-TEQ differs from I-TEQ and N-TEQ by a power of ten for the fully chlorinated variants.

To bring some sort of order to the situation, it would be helpful if current standards defining emission limits or maximum levels of dioxins in different media were expressed in terms of one of the most recently accepted systems (currently WHO-TEQ and I-TEQ). And to permit future conversions to other systems, all 17 congeners should be reported separately.

Research has shown that continuous, low-dose exposure to dioxins in food can cause a wide range of toxic effects, including cancer, immune suppression, and reproductive and developmental disturbances. In 1997 the most toxic dioxin congener, TCDD, was classed as a human carcinogen by the International Agency for Research on Cancer (IARC) of the WHO. The reproductive disturbances observed in laboratory animals affect both female and male fertility and development of the fetus and offspring. Many studies, moreover, show that the fetus is highly sensitive and that the effects of fetal exposure may not emerge until adulthood, in the form of damage to sexual organs (or their functioning), the immune system, or brain development and behaviour.
In 2001, the EU’s Scientific Committee on Food (SCF) performed an assessment of the health risks of dioxins. This resulted in the tolerable daily intake (TDI) being cut to 2 pg TEQ/kg body weight (including all dioxin-like compounds covered by the TEF scheme, which includes dioxin-like PCBs – see below). It should be noted that this TDI is calculated on the basis of lifetime exposure. Short-term exceedances of it are considered to be of no or very little consequence for the risk of adverse effects. Since the average daily intake of dioxins among adults (in Sweden, around 1 pg TEQ/kg body weight) is in the vicinity of this TDI, and since children are exposed to more dioxins than adults (per kilogram of body weight), dioxins are a priority area for the EU. Furthermore, Sweden’s National Food Administration estimates that 12 per cent of the adult population have an intake exceeding the TDI of 2 pg/kg body weight. In an attempt to reduce exposure to dioxins, the EU has set limit values for different foods. In oily fish from significant areas of the Baltic Sea, concentrations exceed the defined limits. The National Food Administration has issued dietary advice on the fish species concerned, with a view to limiting people’s exposure to dioxins and other substances in their diet.

PCBs are complex mixtures of up to 209 different congeners. They have been used extensively in a wide range of applications. Their most important area of use is as dielectric (insulating) fluids in transformers and capacitors, but they have also been widely employed as hydraulic fluids, flame retardants, stabilizers and plasticizers. Global production has been estimated at over a million tonnes. PCBs are now prohibited across much of the world, and it is uncertain whether they are still being produced. At all events, though, large quantities of PCBs are still to be found in the ‘technosphere’, in electrical equipment, in plastics, sealants and so on. In Sweden, virtually all the PCBs used in the electrical industry have been removed and destroyed in an environmentally acceptable manner. The more diffuse presence of these substances in buildings and contaminated sites often persists, however, giving rise to a slow but continuous release into the atmosphere and into surrounding soil and water.

More recently it has emerged that PCBs can also be formed unintentionally during various high-temperature processes such as combustion. As yet, the scale on which this occurs has been very poorly studied and documented, and the same is true of such issues as the mixtures of congeners formed.

As with dioxins, there are several different ways of calculating the quantity of PCBs in a sample. One is to use the sum of all the individual PCBs found in an analysis. Another, commoner method is to report the total quantity of a specific number of individual congeners. A few other, more or less well-established approaches also exist. The major problem in this context is that either in the original report, or when it has been cited a number of times, everything is referred to as ‘PCBs’, ‘sum PCBs’ or ‘total PCBs’. This creates enormous difficulties and uncertainties when it comes to comparing different results.
The PCB group includes a subgroup of congeners that differ from the others in that they can give rise to the same toxic effects as dioxins. These compounds are accordingly referred to as dioxin-like PCBs, and a TEF scheme has been established for them which, as in the case of dioxins (cf. above), is based on the toxicity of TCDD. For this quantitatively small group within the PCB family it is possible to make a quantitative risk assessment based on the risk assessment for dioxins. Not only that: it is assumed that the two toxicity values arrived at can be combined directly into a single value, providing us with an overall measure of the dioxin-like toxicity of a sample. Since levels of PCBs in foodstuffs, for example, are much higher than the concentrations of dioxins, PCBs contribute roughly as much as dioxins in toxic equivalent terms, even though individual PCBs are less toxic than dioxins. The basic assumption underlying the TEF concept is that these compounds have the same mechanism of action, i.e. via the Ah (or dioxin) receptor, and thus give rise to identical effects. A study at the Institute of Environmental Medicine (IMM), at the Karolinska Institute in Stockholm, shows that children generally are more exposed to dioxins and PCBs than adults. The highest intake per kilogram of body weight (apart from in breastfed infants) is found in the youngest children, who are estimated to have an intake 3–4 times that of adults. This intake then gradually falls with increasing age. The main reason it is higher is that children eat larger amounts than adults (including of foods containing dioxins and PCBs), relative to their body weight.

As from 2005, the EU will also be introducing limit values for dioxin-like PCBs. There is no up-to-date quantitative risk assessment on which a TDI for non-dioxin-like PCBs could be based. The European Food Safety Authority (EFSA), however, is currently studying the basic data for a risk assessment of these substances, and hence the feasibility of setting a TDI.

*Hexachlorobenzene* is a chlorinated aromatic hydrocarbon that was previously used as an industrial chemical in the synthesis of other compounds, but which was also manufactured for use as a pesticide. Production has now largely been discontinued. However, this compound also forms as a by-product in the manufacture of other chlorinated hydrocarbons, such as tetrachloroethylene, trichloroethylene and carbon tetrachloride. As a result of restrictions on the use of these chlorinated solvents, formation of hexachlorobenzene as a by-product has largely ceased. At the beginning of the 1970s it was estimated that up to 2,000 tonnes were produced every year, solely as a by-product/contaminant in the manufacture of other chlorinated compounds. Hexachlorobenzene also forms in the majority of combustion processes.

### 2.1 Earlier national surveys

Beginning in April 1988 and over the next five years, the Environmental Protection Agency’s Laboratory for Special Analysis, subsequently the Institute of Applied Environmental Research at Stockholm University, undertook – on the initiative of the Environmental Protection Agency and in collaboration with Umeå University...
and other partners – a project known as the Swedish Dioxin Survey. It was a very wide-ranging study. No fewer than 900 samples of varying types were analysed for dioxins: biological samples from a large number of species, including humans, and from different food products, together with samples of sediments, different types of sludge, soil, waste water, air, and flue gases and wastes from various industrial processes. Compared with that project, the study on which the present report is based must be described as a very modest undertaking.

The results of the Dioxin Survey have been followed up in certain respects as part of the Environmental Protection Agency’s Environmental Monitoring Programme (see chapter 5).

2.2 International activities

Many countries have made national inventories of their sources of dioxins and other unintentionally produced substances in recent years. One such study that is highly relevant to the situation in Sweden is the one conducted by Denmark’s National Environmental Research Institute in 2002. That study, too, was undertaken partly to meet the requirements of the Stockholm Convention (Hansen & Hansen 2003). Between 2000 and 2002, a wide range of investigations were carried out in Denmark to determine the quantities of dioxins in different media and in releases from industrial plants and waste incinerators. The report cited summarizes the results of the measurements performed in the study, but also presents older data, and where measurements are not available an attempt is made to estimate emissions from the sources in question. The report thus describes the quantities released from different industries and the energy sector, in products, and from transport, waste incineration and landfills. Estimates are also made of exports and imports of dioxins, in products or as a result of long-range transport. By way of a summary, a flow analysis is presented, describing the various flows of dioxins between ‘Danish society’, air, water, soil, landfills and exports/imports. Many of the values presented are very uncertain, however, as is indicated for example by the wide ranges sometimes given. In the context of the present project we have explored the possibility of performing a similar flow analysis. However, since it has emerged in the course of our work that great uncertainty attaches to the release figures for Sweden too, and that other data needed to estimate several of the flows concerned are simply not available or else of uncertain representativeness in relation to the present-day situation, we have not felt that a flow analysis would serve any useful purpose.

Various unintentionally produced substances are referred to in a number of international conventions that seek to limit the formation of such substances and their release into different environments. The substances mentioned in our own terms of reference (dioxins, PCBs and hexachlorobenzene) are for example the same ones as are addressed in Article 5 (Measures to reduce or eliminate releases from unintentional production) and Annex C of the Stockholm Convention. Under Article 5, each party is required, as a minimum, to take certain measures to reduce the total
releases from anthropogenic sources of the chemicals listed in Annex C, with the goal of their continuing minimization and, where feasible, ultimate elimination. More specifically, each party is to develop an action plan within two years of the entry into force of the Convention, and subsequently to implement it with a view to identifying, characterizing and addressing the release of the substances in question. The action plan is to incorporate, among other things, an evaluation of current and projected releases, including the development and maintenance of source inventories and release estimates, taking into consideration the source categories listed. In addition, each party is expected to undertake a five-yearly review of the strategies it has adopted and of its success in meeting its obligations under the Convention. The parties are also to promote the development of modified processes to prevent the formation and release of the chemicals in question, and to require the use of best available techniques for new sources within source categories which each party has identified as warranting such action in its action plan. In any case, the requirement to use best available techniques for new sources in the categories listed in Part II of Annex C must be phased in as soon as practicable, but no later than four years after the entry into force of the Convention. For these categories, the parties are to promote the use of best environmental practices. Release limit values or performance standards may be used by a party to fulfil its commitments concerning best available techniques. The substances listed in Annex C of the Stockholm Convention are also dealt with in Article 6, which is concerned with measures to reduce releases from stockpiles and wastes. More specifically, parties to the Convention are required to develop strategies to identify products and wastes containing the substances in question. In addition, they have to ensure that wastes of this kind are handled, collected, transported and stored in an environmentally sound manner. To achieve this, parties are to endeavour to develop appropriate strategies to identify sites contaminated by chemicals listed in Annex C, and if remediation of such sites is undertaken it must be performed in an environmentally sound manner. The Protocol to the Convention on Long-Range Transboundary Pollution on Persistent Organic Pollutants (LRTAP-POP) includes a similar body of rules.

To assist in the identification and quantification of dioxin sources, UNEP has published a manual, *Dioxin and Furan Inventories, National and Regional Emissions of PCDD/PCDF*, with the help of which it is possible to obtain a rough estimate of releases of dioxins from different industrial processes, based on production or energy consumption data. This manual has come to be known as the ‘UNEP Toolkit’. It is based on a number of studies, mainly in Germany, in which formation and releases were related to different production and energy consumption variables etc. It has turned out to be difficult to obtain reliable data using this method, partly because of the very large number of individual processes involved and because processes work differently in different environments. The Toolkit is currently being revised and updated, and will therefore, it is hoped, be able to provide more reliable data for future work.
3 Sources of unintentionally produced substances

Unintentionally produced substances can arise, on the one hand, as by-products or wastes from different processes and, on the other, as degradation products of intentionally manufactured compounds. By-products and wastes arise in a great many industrial processes of varying kinds. To mention just a few examples, these include combustion processes, chemical processes, and high-temperature processes generally, such as those involved in the production and processing of metals. In a significant proportion of cases, the structures of these unintentionally formed substances are probably unknown. This is true of many compounds which break down relatively rapidly into more stable forms, and of substances belonging to complex groups such as the polyaromatic hydrocarbons (PAHs). To what extent unintentionally produced substances can have adverse effects on health and the environment depends on several different factors. The persistence of a substance, i.e. its ability to resist degradation, and its tendency to become more concentrated as it passes through food chains, along with its toxicity, are major determinants of whether or not it will be regarded as a toxic pollutant. Other factors of great significance are how much of a particular substance is released, and in what form and by what pathways it enters the environment.

It may be appropriate at this point to clarify the concept of ‘release’. Sometimes there is a tendency to equate the formation and the release of a substance, which can be misleading, not only when it comes to determining the true scale of a problem, but also in terms of understanding where and when different measures may be called for. In this report, we use the concept of ‘release’ (or ‘emission’) to refer to that portion of a substance formed which, for one reason or another, has irrevocably escaped into the environment. That is to say, it is not possible to recover or collect the substance from the environment using known methods or at a reasonable cost. Contaminated sites occupy a special position in this context, in that they may be the result of an intentional or unintentional release, but may sometimes be amenable to remediation.

What all sources of unintentionally produced substances have in common is that the substances concerned can leave their site of origin by different routes. From combustion processes whose purpose is to generate energy, sometimes combined with the destruction of various forms of waste, unintentionally formed compounds may be released directly into the surrounding environment via air and water. Another portion of the substances formed may be found in the waste from the process, which in the case of combustion processes consists mainly of ashes. For other processes in which substances can be formed unintentionally, the same potential release pathways exist. In addition, there is in this case the possibility of such
substances accompanying the final products. This means that products may act as sources of emissions when in use and/or when they become waste.

As more action has been taken to reduce releases from several major primary sources, such as waste incineration and elemental chlorine-based bleaching in the paper industry, secondary sources have assumed growing importance.

The general downward trend in levels of PCBs and dioxins in Baltic Sea biota observed between 1970 and 1990 has slowed and even come to a halt in certain areas. This is particularly true of dioxins. There may be several reasons why a decrease in concentrations levels out. One possibility is that, the lower concentrations become, the greater is the relative impact of sources such as long-range transport and ‘past sins’.

In Gävlebukten and the southern Bothnian Sea, however, levels in fact seem to be rising, which is more difficult to explain without reference to new sources or a change in the character of old ones. At present we have no definite clues as to the factors behind these observations. There is every reason to take such indications of rising concentrations very seriously. The Environmental Protection Agency is currently funding a study in the area in question to obtain a clearer picture of the situation.

3.1 Primary sources
By primary sources of unintentionally produced substances such as dioxins, hexachlorobenzene and PCBs, we are referring in this report to processes whereby such substances are formed and released into the environment. Combustion and other high-temperature processes, for example in the metallurgical industry, are considered to make up the majority of primary sources. The fact that a process is regarded as a primary source does not mean that all of the unintentionally formed substances to which it gives rise are released at the source itself. A greater or lesser proportion of the quantity produced may be transferred from the primary source to another site, which may possibly act as a secondary source (see 3.2). In a combustion process, for example, various substances will be formed unintentionally and a certain proportion of them may escape directly into the atmosphere. This process then acts as a primary source of emissions to air. It will also generate ash, which may likewise contain various unintentionally produced substances. This ash may for instance be taken to a waste disposal site of some kind, where the substances concerned could in the long term be released to water or air. The waste site will then be acting as a secondary source.

Although major efforts have been made since the 1980s to reduce the formation and release of dioxins, in particular, at various primary sources, the current significance of these sources cannot be disregarded. The contribution made by primary sources today will, in terms of loadings, be added to the levels already
present in our environment, and current releases from primary sources will be part of the contribution from the secondary sources of the future.

In this report we will consider the following groups of primary sources: combustion, the metallurgical industry, the chemical industry, refineries and the cement industry, the forest products industry, and shipping.

3.1.1 Combustion

3.1.1.1 BACKGROUND AND PRESENT SITUATION

Table 2: Table summarizing releases to air and quantities in ash of dioxins, PCBs and hexachlorobenzene from different types of combustion in Sweden. Far and away the dominant amounts of dioxins and hexachlorobenzene from waste incineration under ‘ash’ below are to be found in fly ash (over 90% in the case of dioxins). In general, the figures in the table involve some degree of uncertainty. The data for landfill fires for example are, understandably, very uncertain. A dash in a cell means that no reliable data are available.

<table>
<thead>
<tr>
<th></th>
<th>Air Dioxins g TEQ/yr</th>
<th>PCBs g/yr</th>
<th>Hexachlorobenzene g/yr</th>
<th>Ash Dioxins g TEQ/yr</th>
<th>PCBs g/yr</th>
<th>Hexachlorobenzene g/yr</th>
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</thead>
<tbody>
<tr>
<td>Waste incineration</td>
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<td></td>
<td>1.1</td>
<td>&lt;60</td>
<td>–</td>
<td>~ 160</td>
<td>3,000–4,000</td>
<td>600–6,000</td>
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<tr>
<td></td>
<td>I-TEQ</td>
<td>PCB_{int}</td>
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<td>I-TEQ</td>
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<tr>
<td>Hazardous waste</td>
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<td>0.025</td>
<td>7–60</td>
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<td></td>
<td>I-TEQ</td>
<td>PCB_{int}</td>
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<td>Large-scale burning of</td>
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<td>&lt;10</td>
<td>1,000–7,000</td>
<td>20–300</td>
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<td>WHO-TEQ</td>
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<tr>
<td>wood</td>
<td>&lt;4</td>
<td>&lt;0.3</td>
<td>&lt;400</td>
<td>&lt;1</td>
<td>&lt;0.04</td>
<td>~ 30</td>
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<tr>
<td></td>
<td>WHO-TEQ</td>
<td>WHO-TEQ</td>
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<td>WHO-TEQ</td>
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<tr>
<td>‘Backyard burning’</td>
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<td>Fossil fuel-fired</td>
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<td></td>
<td>I-TEQ</td>
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<tr>
<td>Landfill fires</td>
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<td>0.4–65</td>
<td>300–4,000</td>
<td>100–2,500</td>
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<tr>
<td></td>
<td>I-TEQ</td>
<td>PCB_{int}</td>
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<tr>
<td>Crematoria</td>
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<td>0.1–0.3</td>
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<td>–</td>
<td>0.2</td>
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<tr>
<td></td>
<td>I-TEQ</td>
<td>–</td>
<td>–</td>
<td>I-TEQ</td>
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<td>–</td>
</tr>
<tr>
<td>Building fires</td>
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<td></td>
<td>0.02–0.3</td>
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<td>TEQ</td>
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</table>
Burning of organic matter in the presence of chlorine is one of the main causes of formation of a range of organic pollutants, including dioxins, PCBs and hexachlorobenzene. The high temperatures that arise in a waste incinerator, for example, result in the pollutants in the material breaking down. However, when the flue gases are cooled, conditions arise which result in *de novo* formation of these substances.

Atmospheric emissions from waste incineration plants used to be one of the biggest sources of dioxins. In recent years, however, these plants have appreciably reduced their emissions. Releases from other combustion processes combined are now judged to be significantly higher. However, Swedish data on such sources are scarce, and to some extent therefore releases have been estimated with the help of internationally published emission factors. As far as the formation and release to the atmosphere of PCBs are concerned, very few measurements have been made, making it difficult to draw any conclusions about concentrations or trends.

The few measurements that have been made of ashes and residues show that waste incineration gives rise to flue-gas cleaning residues containing large quantities of dioxins, PCBs and hexachlorobenzene. Ashes from the burning of pure biofuels exhibit much lower concentrations of dioxins and PCBs, but the available data are very uncertain.

Landfill fires, too, can result in the formation and release of various persistent organic pollutants. The mix of substances produced probably varies appreciably, depending on the waste deposited in the landfill, the temperature, oxygen supply etc. This, combined with the unpredictable occurrence of landfill fires, makes it difficult to quantify the annual amounts formed and released from this type of source.

*Waste incineration*

The earliest data on releases of dioxins to air are from 1985, when the atmospheric emission from waste incinerators was reported to be around 90 g I-TEQ. A significant proportion of the total came from small incinerators, such as hospital incinerators. When these were closed down at the end of the 1980s, at the same time as more advanced flue-gas cleaning equipment was installed and improved process control introduced at many incineration plants, emissions were substantially reduced. Today, most waste incinerators have fabric filters combined with activated carbon and/or advanced wet scrubbing of the flue gas, and at the majority of plants more than 99% of the dioxins formed in the flue gases are removed. The annual atmospheric emission of dioxins in 2002 was estimated by the industry at 1.1 g I-TEQ. This is despite a doubling of the quantity of waste incinerated since 1985. The emission per unit of energy is around 30 pg dioxins/MJ.

The annual release of PCBs to air from waste incineration has been estimated at some 60 g. This figure is extremely uncertain, however, as it is based on a single
flue-gas analysis performed in 1994. Presumably, moreover, emissions have fallen since then, as in the case of dioxins.

Hexachlorobenzene levels in waste incinerator flue gases were last analysed in the mid-1980s. On the basis of those measurements, the annual emission was 1–30 kg. The same measures as have reduced dioxin releases so dramatically have probably also brought down emissions of hexachlorobenzene, which means that current releases of the latter substance from waste incineration are probably well below the level mentioned.

Organic pollutants bind to a large extent to ash particles, with the result that the majority of them end up in residues from the flue-gas cleaning process. A small proportion can also be found in bottom ash. In the case of dioxins, over 90% of the total is to be found in flue-gas cleaning residues. Based on earlier studies and the industry’s assessments, the annual quantities of the substances of interest in fly ash and bottom ash from all of Sweden’s waste incinerators can be estimated at around 160 g I-TEQ of dioxins, 3–4 kg of total PCBs and 0.6–6 kg of hexachlorobenzene. The figure for dioxins corresponds to 5 ng per megajoule generated. Flue-gas cleaning residues are handled as hazardous waste and only disposed of to landfills that are approved for such waste. Various leaching experiments have been performed on residues of this kind, for example by the Swedish Association of Waste Management (RVF), and in these studies the leachability of dioxins was found to be low. A small proportion of bottom ash is reused as a secondary aggregate, e.g. for road construction or to cover landfills. The quantity recycled represents only a small fraction of all the ash generated each year, and as yet no evidence has been found of leaching of dioxins. Releases to water occur from installations with flue-gas condensation or wet scrubbing of flue gases. At present there is no general formal requirement to measure dioxin levels in outgoing condensate, but this will change when the Waste Incineration Ordinance and Regulations come into effect with respect to existing installations.

Fly ash from flue-gas filters at three different types of waste incineration plant was sampled in 2004 by Umeå University for the Environmental Protection Agency. Estimates of annual quantities of dioxins, PCBs and hexachlorobenzene in fly ash, based on these studies, have produced results in the same range as earlier investigations.

Hazardous waste
Dioxin releases from the incineration of hazardous wastes containing organic pollutants, like those from the burning of other wastes, have been substantially reduced in recent years and are now judged to be low, with a figure of 0.025 g I-TEQ in 2002. PCB emissions could amount to 7–60 g of total PCBs per year (2002). Hexachlorobenzene has not been analysed. The residues arising from incineration are disposed of in SAKAB’s own landfill for hazardous waste.
Large-scale burning of biomass fuels

Biomass fuels, or biofuels, is an umbrella term for plant-based fuels, including in particular felling debris from forestry, wood from energy forests, and industrial by-products, above all from the wood, pulp and paper industry. Biofuels and peat, often together, are used to generate electricity and heat in the energy sector and in certain industrial operations, especially in the forest products industry.

Previously only a few measurements have been made at plants burning pure biomass fuels in Sweden. Recent sampling (SP – Swedish National Testing and Research Institute 2005) at three Swedish biofuel-fired installations indicates, like isolated earlier measurements, that dioxin releases to air are below, or considerably below, the limit value that applies to waste incinerators.

Using these few measured data, and applying the UNEP Toolkit in combination with energy statistics on biofuel consumption, it is possible to get some idea of Swedish emissions to air from this type of source. The values arrived at suggest that a relatively large proportion of atmospheric releases of dioxins from combustion in Sweden today may be attributable to large-scale burning of biofuels. On the basis of the sources mentioned above, the Environmental Protection Agency estimates that dioxin emissions could be getting on for 10 g I-TEQ per year, but are probably lower. Per megajoule generated, this means a dioxin release of <35 pg/MJ. In the recent measurements mentioned, PCBs and hexachlorobenzene were also analysed. The results suggest that annual emissions total around 0.1 g WHO-TEQ of PCBs and <400 g of hexachlorobenzene.

A small number of studies have been made of dioxins, PCBs and hexachlorobenzene in ashes from biofuel-fired plants. Levels vary widely, but estimates of the annual production of these substances in ashes, based on these earlier studies, indicate that the total quantities involved could be 0.07–100 g I-TEQ of dioxins, 1–7 kg of total PCBs and 20 g of hexachlorobenzene per year. In conjunction with the recent measurements performed at the three biofuel plants, ashes were also analysed for dioxins, PCBs and hexachlorobenzene. Calculated on the basis of these analyses, annual production of the substances in question in ashes would appear to total around 10 g WHO-TEQ of dioxins, 0.2 g WHO-TEQ of PCBs and 300 g of hexachlorobenzene. These new results are judged to be more representative and are therefore presented in tables 1 and 2. Since combustion ashes contain nutrients and have basic properties, recycling of them to forest land is being discussed – both to improve the soil’s resistance to acidification and to replace some of the nutrients removed when forests are harvested. The only ashes being considered for this purpose are biomass ashes, as they contain much lower levels of heavy metals and dioxins compared with ash from waste incineration, for example. At present, though, the proportion of biomass ashes recycled is very small, partly for economic reasons and because different fuel types are often mixed, which affects the quality of the ashes. The level and design of the landfill tax could influence the future scale of ash recycling.
Small-scale burning of wood

Emissions from small-scale combustion of wood have long been regarded as a potential environmental and health problem and have previously been the subject of a number of studies, though with an emphasis on other pollutants than those considered here. In addition, as part of the Swedish Energy Agency’s R&D programme *Emissions and Air Quality*, a project entitled *Biofuels Health Environment* is in progress (see Cooper *et al.* 2003), focusing on carbon monoxide, organically bound carbon, particulates, nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs) and several volatile organic compounds, including the greenhouse gas methane.

Domestic burning of wood and fuel pellets may also be one of the major sources of releases of dioxins to air in Sweden. Internationally, too, small-scale combustion is regarded as one of the more significant sources.

Previously only a couple of measurements have been made in Sweden of dioxin releases from small-scale wood burning. International emission factors have therefore been used as a basis for estimating Swedish emissions. Using these factors in combination with Statistics Sweden’s data for 2002 on small-scale combustion of wood, it can be calculated that atmospheric emissions of dioxins from this source in Sweden, assuming only clean, untreated wood was used, totalled in the range of 0.1–3.9 g I-TEQ in 2003.

As part of the present project, combustion experiments were performed by the Environmental Chemistry Section at Umeå University for the Environmental Protection Agency, to study releases of dioxins, PCBs and hexachlorobenzene to air and ash from small-scale burning of wood and pellets. The results indicate, among other things, flue-gas concentrations of dioxins from the burning of clean wood of the same order of magnitude as were suggested by earlier investigations. Four different types of equipment were studied: a pellet-fired boiler, an older dual-fuel boiler, a modern wood-fired boiler and a wood stove. Pellets, softwood and birch wood mixed with paper packaging, newspapers and plastics (a mix of plastics normally found in household waste) in various combinations were used as fuels, and combustion conditions were varied.

A comparison of the results between the older dual-fuel boiler and the modern wood-fired boiler reveals clear differences. The older boiler produced roughly ten times higher emissions of dioxins and PCBs than the modern one. Inclusion of newspapers and cardboard did not result in any increase, but including plastics increased concentrations around a hundredfold, for both dioxins and PCBs. (An earlier study performed outside Sweden pointed to greatly elevated dioxin emissions when paper/cardboard was burnt with the wood, and 200 times higher releases when PVC was included.) A number of tests involving pellets were also carried out. For dioxins, hexachlorobenzene and PCBs, flue-gas concentrations were higher than when wood was burnt. However, there were significant differ-
ences between wood and straw pellets (the straw generating higher concentrations) and between different firing conditions. A supplementary repeat measurement of releases from pellet burning (SP – Swedish National Testing and Research Institute 2005) produced lower values, but they were still somewhat higher than those obtained with wood.

Overall, it may be noted that the values recorded varied widely between the different boilers and between the different combustion experiments, and that only one sample was analysed for each experiment. The results are consequently to be seen primarily as a pointer to the kinds of concentrations that may occur. The higher emissions from pellets, compared with wood, were somewhat surprising and should be followed up, although there is scarcely any reason to assume that burning of pellets generally produces higher emissions.

An estimate of total emissions to air from small-scale burning, based on the results recorded in this study, gives figures of <4 g WHO-TEQ of dioxins, <0.3 g WHO-TEQ of PCBs and <400 g of hexachlorobenzene.

Concentrations in ashes were also analysed. They were generally low and varied in step with flue-gas concentrations, i.e. easily the highest levels were found in ashes from the burning of fuels mixed with plastics.

Further details can be found in the background report from Umeå University.

‘Backyard burning’
Uncontrolled burning of waste is a potential and as yet uncharted source of releases of unintentionally formed substances. At present, virtually no data are available on the scale of ‘backyard burning’ in Sweden, although here the principal material disposed of in this way is probably garden waste. In 2004 a Belgian report showed that the burning of such waste affects both air quality and deposition of dioxins in the surrounding area. Since legislation and hence the types of waste burnt differ between countries, it is difficult to use the few emission factors that have in fact been calculated internationally. In the United States, for example, household waste is sometimes burnt in garden fires, which is not permitted in Sweden.

In view of the dearth of information about the extent of backyard burning in Sweden and the materials burnt, a questionnaire was sent out to local authorities to assemble such information as was available. It was drawn up by the Environmental Chemistry Section at Umeå University, on behalf of the Environmental Protection Agency, and was sent to 290 local authorities, of which 119 responded. Very little is in fact known about what people burn privately, and estimates from local authorities are uncertain. Most local authorities permit burning of certain types of waste. Often only dry, non-compostable garden wastes, e.g. large branches and twigs, are allowed to be burnt. Private burning of household waste is not permitted. What waste fractions are burnt in practice is difficult to assess, but complaints have been
received about illegal burning, e.g. of plastics and other types of waste. In a few cases, authorities were aware of on-site burning of silage plastic, but they were unable to indicate the scale of this activity.

Combustion experiments have been conducted to study the formation of dioxins, PCBs and hexachlorobenzene in garden fires. Fourteen of the experiments were performed in a metal drum, and two as open bonfires. Various fuels were used, including garden waste, household refuse, paper and plastic packaging, and computer scrap.

Dioxin levels in the flue gases from these experiments were roughly 30 times higher than in the tests carried out on the old dual-fuel boiler mentioned earlier. No major differences in emissions between the different fuels could be observed, except when computer scrap was added, which resulted in a marked rise in concentrations. PCB levels, by contrast, were very low, up to 100 times lower than in the dual-fuel boiler experiments. The difference for hexachlorobenzene was just as great, but in that case, as with dioxins, emissions from the backyard fires were higher than with the dual-fuel boiler. In addition, levels of hexachlorobenzene were much higher with the open bonfires than when the metal drum was used.

It is not possible to draw very far-reaching conclusions from these results. The concentrations recorded varied considerably, and no correlations were found between the three substances analysed. This could be because only one sample was analysed in each experiment, and only one experiment performed for each fuel. Variations between the experiments may be due not only to the different fuels, but also to differences in combustion conditions which could not be monitored.

As the questionnaire survey of local authorities mentioned earlier made clear, very little information is available on the scale of backyard burning in Sweden. It is consequently very difficult to estimate total national emissions. Reliable estimates would require more detailed studies, for which insufficient time was available in the framework of the present project. However, to get some idea at least of the possible magnitude of releases from this source, it has been assumed that its scale corresponds to a tenth of one per cent of all waste incineration in Sweden today. That would imply that every individual burns an average of 0.3 kg of waste per year on open fires, including both legal burning of garden waste, for example, and illegal burning of other wastes. On this basis, annual dioxin releases to air from backyard burning can be estimated at 0.001–1.2 g WHO-TEQ (the value of 1.2 g is based on emission concentrations from the burning of computer scrap; the second highest value for dioxins was 20 times lower); PCB emissions at 0.02–4 mg WHO-TEQ in the case of dioxin-like PCBs and 0.8–60 g of PCBs; and releases of hexachlorobenzene at 0.6–200 g.
Fossil fuels
No Swedish studies have been made of releases of dioxins, PCBs and hexachlorobenzene from the combustion of fossil fuels in the energy sector. In the case of dioxins, though, international emission factors are available, which can be used in combination with Statistics Sweden’s data on consumption of coal and oil. On this basis, releases of dioxins to air from fossil fuels in Sweden, excluding the transport sector, can be estimated at 0.12–15 g I-TEQ (Umeå University 2005). However, process technology, fuel quality and advances in environmental technology can vary considerably between countries, which means that emission assessments from other countries are not always entirely applicable to Swedish conditions. Using emission factors from the UNEP Toolkit, a release of 1–2 g is obtained. The Environmental Protection Agency’s assessment is that emissions are presumably around the latter level, and can be reported to be less than 4 g.

Landfill fires
Two types of fires can arise in landfills: surface fires and subsurface, or underground, fires. Surface fires burn with a good supply of oxygen and are easy to discover and extinguish. Subsurface fires have a limited oxygen supply and can be prolonged, as they are more difficult to put out. The concept of landfill fires also includes fires at temporary waste holding sites.

Studies involving sampling from both subsurface and surface fires show that the latter probably give rise to the largest quantities of the unintentionally formed substances of interest here. Emissions of dioxins and PCBs have been calculated in a number of different investigations. Based on an estimate of the amount of waste that burns on landfill sites each year, annual releases can be estimated to be in the range of 3–65 g I-TEQ of dioxins and 0.3–1 kg of PCBs. These values are very uncertain, however, as the composition of the individual landfill is decisive and only a few samples have been analysed, but even so they suggest that appreciable releases could be occurring from these fires in Sweden. Comparing the emission factors calculated for landfill fires with those for incineration of household waste, we see that the factors for surface fires can be up to 5,000 times higher compared with controlled combustion in incinerators.

Combustion tests on household waste in landfills have been performed by SP Swedish National Testing and Research Institute for the Swedish Rescue Services Agency, with co-funding from the Environmental Protection Agency. Fire gases from simulated subsurface fires in household waste were analysed for dioxins, PCBs and hexachlorobenzene, among other substances. In some cases fire residues and extinguishing water were also analysed. Baled household waste of broadly known composition was allowed to burn in a container under different conditions. The results are set out in a background report from the Rescue Services Agency/SP. Dioxin levels in the flue gas were low compared with earlier studies, which may partly reflect the fact that these results relate to simulated subsurface fires, while the others were based on both subsurface and surface fires. PCB concent-
trations, on the other hand, were somewhat higher on average than those found in the earlier investigations.

On the basis of these analyses, total annual releases to air from landfill fires can be estimated at 0.4–10 g I-TEQ of dioxins, 0.4–4 kg of PCB; and 0.1–2.5 kg of hexachlorobenzene.

The Rescue Services Agency is seeking to reduce both the number of landfill fires and the emissions produced when fires do occur. The project mentioned above also included an evaluation of the effects of different extinguishing techniques on the formation and release of various pollutants. The policy instruments introduced in the landfill sector in recent years, i.e. the bans on landfill disposal of combustible and organic waste and the landfill tax, are expected to appreciably reduce the quantity of waste capable of burning in landfills, which should entail a lower risk of landfill fires accompanied by major emissions. However, additional analysis is needed of ways of further reducing the risk of fires at recycling centres and storage sites for waste awaiting incineration.

**Crematoria**

The first air pollution control equipment for crematoria was installed in the mid-1990s, and today 70% of all cremations are carried out with some form of flue-gas treatment. The main focus, though, is on removing mercury, rather than organic pollutants. Current emissions of dioxins to air have been estimated at 0.1–0.3 g I-TEQ per year (2003). Filter residues are sent to SAKAB for disposal and are estimated to contain an annual 0.2 g I-TEQ of dioxins. PCBs and hexachlorobenzene have not been analysed in this context.

**Building fires**

Household fittings and furnishings often contain a range of chlorinated compounds which, in the event of a fire, can give rise to organochlorine pollutants. The significance of this means of formation has been inadequately investigated, but surfaces and fire residues in homes damaged by fire have been found to contain dioxins. In the course of one year, fires in buildings of various kinds have been estimated to result in emissions to air of around 0.02–0.3 g TEQ of dioxins (WHO-TEQ, I-TEQ and Eadon have been summed and the result presented under the overall designation of TEQ).

3.1.1.2 **ASSESSMENT**

**Waste incineration**

Releases of dioxins, and probably also of hexachlorobenzene, from waste incineration have decreased significantly over the last 15–20 years. Dioxin emissions now stand at about 1 g/year and can scarcely be expected to fall very much further. The Environmental Protection Agency’s Waste Incineration Regulations (2002:28), which from the end of 2005 will also apply to existing plants, include provisions on
operating conditions, releases to air and water, and measurements for monitoring purposes. These regulations may be expected to result in somewhat lower emissions, but the decrease will be relatively marginal, as all incineration plants are already subject to permit conditions matching or close to the levels laid down in the regulations. As we have seen, emissions to air are not particularly high under normal operating conditions. The largest releases are probably attributable to process malfunctions and other problems that result in incomplete combustion or make it necessary to restart the plant. To ensure that emissions from normal operations remain at a low level or are reduced further, and above all to prevent peaks in emissions in conjunction with malfunctions, certain additions or improvements to flue-gas cleaning systems could be considered. Of particular interest are methods which destroy dioxins, thereby avoiding or reducing the accumulation of such substances in flue-gas residues. One such method is a relatively new technology using ‘carbon-impregnated’ tower packing material, which has proved very effective in trials, but which so far has only been tested on a large scale at a few waste incineration plants. Packing material of polypropylene doped with carbon particles is used in the plants’ wet scrubbing systems, instead of the usual pure polypropylene. The main advantage with this material is that dioxins bind very tightly to it and that it can subsequently be recycled into the incineration process, destroying the dioxins. The net release of dioxins is thus lower than with ordinary filters, where the dioxins end up in flue-gas cleaning residues. With traditional packing material, a ‘memory effect’ can arise, i.e. dioxins trapped in it can be released again, for example when a plant is restarted after a stoppage, giving rise to a temporary surge in emissions. According to the manufacturers, replacing standard polypropylene packing material with carbon-impregnated material reduces dioxin levels in outgoing flue gases by 50–70%. Introducing this method at plants which currently do not even use traditional packing material will presumably achieve an even greater reduction. The same technique has also been tested on a small scale in dry applications, where it has been found to have an even better abatement effect than in wet environments. The method needs to be studied more closely in full-scale operation before a full assessment of its potential can be made.

Selective catalytic reduction (SCR), which is primarily intended to remove nitrogen oxides, has also proved capable of destroying dioxins and hence reducing both releases to air and the amounts accumulating in fly ash. SCR has been installed at some of the new waste incineration plants. The addition of sulphur compounds has also been found to destroy dioxins.

The best way of curbing emissions of the substances in question here is of course to reduce their formation in the combustion process. As dioxins form within a certain temperature ‘window’, often said to be 200–400°C, the most significant formation of such substances occurs when flue gases are cooled from the higher temperature prevailing during actual combustion. By shortening the time the flue gases spend within this window, it is possible to reduce dioxin formation. The
feasibility of modifying the process in this way varies from one installation to
another, but should be borne in mind when plants are refitted, for example.

As has been mentioned, dioxins that are removed by flue-gas cleaning end up in
the residues from that process. The techniques mentioned will hopefully result in
reduced quantities in ash, but this problem probably cannot be entirely avoided. Al-
though the studies conducted show that the dioxins present in ash/sludge are stably
bound to it, it is desirable to further minimize the risk of future releases. One con-
ceivable method is thermal post-treatment of ashes to remove dioxins. However,
this method is not yet fully developed and needs to be studied more closely, for
example with respect to energy requirements. Other methods with more of a focus
on ‘locking up’ the pollutants are also being investigated, such as carbonate stabil-
ization and vitrification. Here, too, both the technology and the economic feasi-
ability require further study.

Large-scale burning of biomass fuels
The few reported measurements of dioxin emissions from combustion of biomass
fuels suggest that these emissions are relatively low, measured as concentrations in
flue gases. However, given the large number of installations, burning of such fuels
may, overall, be an important source of releases. The current low concentrations
(lower or considerably lower than the limit value for waste incineration) mean that
it is difficult to see any realistic way of further reducing emissions. Where a waste
fraction (e.g. waste timber) is burnt together with biofuels (‘co-incineration’),
higher dioxin emissions may occur. In such cases, however, the standards set for
dioxins in the Waste Incineration Regulations apply and control measures may
need to be introduced. One such measure is injection of activated carbon into fabric
filters. Where a larger waste component is involved, the situation resembles that of
‘traditional’ waste incineration, cf. the previous section. At present, no general
emission standards are in place for dioxins from biofuel-fired installations. It might
seem reasonable to apply the same standards to all forms of combustion as apply to
incineration of waste. So far, though, it would seem that emissions from biofuel
burning are already below the limits for waste incineration, and it is therefore
debatable whether anything is to be gained from formalizing such standards. If in
individual cases elevated dioxin emissions are nevertheless found to be occurring,
steps can be taken, e.g. introducing activated carbon or other measures mentioned
in the section on waste incineration.

It would be useful to have additional measurement-based data to permit a more
confident assessment of the relative role of biomass fuels in this context. Initially,
such data should be obtained by drawing attention to the need for measurements in
conjunction with official studies and research projects. It may be difficult to obtain
data of this kind purely for the purposes of knowledge advancement from com-
panies’ regular monitoring activities.
**Small-scale burning of wood**

As well as dioxins, small-scale combustion of wood gives rise to emissions of particulates that are hazardous to health, and of PAHs and volatile hydrocarbons, including the greenhouse gas methane. In earlier studies commissioned by the Government (most recently in 1998), the Environmental Protection Agency has presented various proposals to reduce emissions, primarily of volatile organic compounds (VOCs). Releases from small-scale wood-fired heating vary appreciably, depending on such factors as the type and age of the boiler, the quality of the fuel, how it is burnt etc. As more modern, ‘environmentally approved’ boilers, meeting the standards set out in the Building Regulations of the National Board of Housing, Building and Planning, have been found to generate lower levels of pollutants, there is scope to reduce releases by replacing old boilers with new ones. Correct operation may also make a major difference to both the quantity and the composition of the residues that arise. The great majority of domestic boilers used to heat individual houses in Sweden are still of older types, although they are slowly but surely being replaced with newer ones. The technical lifetime of such a boiler is around 35 years, and as only a few per cent are replaced each year, it will take a considerable time for the entire existing stock of relatively old boilers to be retired. It is therefore important to accelerate the upgrading of boilers in some way. Replacing an old, outdated boiler with a new, ‘environmentally approved’ one, or at least supplementing an older model with an accumulator tank, appreciably reduces emissions of hydrocarbons. The combustion experiments carried out as part of the present study show that releases of dioxins, too, are significantly lower in a boiler operating under good combustion conditions. Hexachlorobenzene emissions would probably also be reduced. There are thus several reasons to encourage an accelerated changeover to ‘environmentally approved’ boilers. To reduce the financial burden on households, consideration could for example be given to extending the tax relief available on the installation of new boilers to apply to all installations, not only those in new homes.

As regards new boilers, the aim should be to ensure that only ‘environmentally approved’ boilers are on the market. The amendment to the National Board of Housing, Building and Planning’s Building Regulations (BFS 1993:57) which is now envisaged, and which will mean that the environmental standards for new installations will apply outside as well as inside built-up areas, will not have very great practical significance, as most new boilers installed are replacements for existing ones, rather than completely new installations. The law should be changed to apply the environmental standards to replacements as well as new installations (inside and outside built-up areas). In 1998 the Environmental Protection Agency put forward proposals setting out how this could be done (Swedish Environmental Protection Agency 1998). The draft ordinance proposed by the Agency also incorporated a requirement to retrofit an accumulator tank to older installations. The requirements included in that proposal remain relevant.
The combustion experiments conducted as part of this project also demonstrate, like earlier studies, the significance of fuel quality and of how boilers are operated. The inclusion of plastics with the fuel (which is in fact illegal), for example, increased dioxin emissions a hundredfold. The Environmental Protection Agency has previously produced a booklet on how boilers should be operated to reduce environmental problems. Further information efforts of some kind should be considered. The same goes for ‘backyard burning’ (see below).

‘Backyard burning’
Private burning of household waste is illegal. As for garden waste, individual local authorities can issue local regulations on what private individuals are allowed to burn, and how and when. Releases from garden fires varied between the different combustion tests performed, but it is clear that the inclusion of electronic scrap in the material burnt, for example, appreciably increases dioxin emissions. Although it is already illegal to burn waste, information to households about what they can and cannot burn, and about the environmental consequences of burning waste, may be called for.

Combustion of fossil fuels
No new dioxin studies relating to the burning of fossil fuels have been carried out in the framework of this project. As was noted earlier, dioxin emissions from this source in Sweden are judged to be small. Concentrations in flue gases are low, and specific action to further reduce releases has not been proposed, in Sweden or internationally. ‘Normal’ flue-gas cleaning to control emissions of other pollutants also entails some reduction of dioxins. Additional emission data would be useful, but are not considered an urgent requirement.

Landfill fires
Landfill fires are judged to be a potentially significant source of releases of dioxins, hexachlorobenzene and PCBs. The most important preventive measure is careful management and supervision of landfill sites, to reduce the risk of fires arising. The bans on landfill disposal of combustible and organic material should result in a decreased risk of fires.

3.1.2 The metallurgical industry
3.1.2.1 BACKGROUND AND PRESENT SITUATION
Many of the dioxin data from the metallurgical industry are relatively old, and earlier data on the formation and release of PCBs and hexachlorobenzene are virtually non-existent. The many different individual processes involved in the industry make it difficult to arrive at a precise estimate. The summary below, however, shows that emissions to air could be considerable.
Table 3: Table summarizing releases of dioxins, PCBs and hexachlorobenzene from metallurgical plants of different types in Sweden. A dash in a cell means that no reliable data are available.

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th></th>
<th></th>
<th>Ash/slag</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dioxins</td>
<td>PCBs</td>
<td>Hexachlorobenzene</td>
<td>Dioxins</td>
<td>PCBs</td>
<td>Hexachlorobenzene</td>
</tr>
<tr>
<td>Pellet plants</td>
<td>1.4–3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Primary iron and steel</td>
<td>1.5–2.6</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Secondary iron and steel</td>
<td>~ 3</td>
<td>33,000</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Primary non-ferrous metal works</td>
<td>1.3–6</td>
<td>370 – 1,500</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Secondary non-ferrous metal works</td>
<td>~ 4</td>
<td>–</td>
<td>&lt;2</td>
<td>0.1</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Foundries</td>
<td>~ 0.25</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ferro-alloy, lead accumulator and graphite electrode plants</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>11–19</td>
<td>33,370 – 34,500</td>
<td>&lt;2</td>
<td>0.1</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*Pellet plants*

Pellets are a refined product manufactured from iron ore. They are sintered, marble-sized balls of ore with a high iron content and of consistent quality. Swedish pellet plants produce two types: blast furnace pellets and direct reduction pellets. At present there are a total of five plants in Sweden, at three different locations: two in Kiruna, two in Malmberget and one at Svappavaara. In Malmberget, a new plant is currently being built, to replace the smaller of the existing plants and to increase production there. An additional pellet factory is planned in Kiruna. The three different pellet production processes in existence are all represented at these Swedish plants.

Estimates by Kindbom *et al.* (2004) show emissions to have decreased in the last 20 years. During the period 1980–95, releases of dioxins to air from pellet and sinter plants are estimated to have been of the order of 6–7 g/year. With the closure of the sinter plant in Oxelösund in 1995, one major individual source was eliminated, resulting in a fall in emissions of 4–5 g.

The table below gives a summary of available information on releases to air from pellet plants that were operational in the mid-1990s.
Table 4: Data on releases to air from three pellet plants operating in the mid-1990s.

<table>
<thead>
<tr>
<th>Plant</th>
<th>µg N-TEQ/tonne iron ore</th>
<th>g N-TEQ/yr</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malmberget</td>
<td>–</td>
<td>4.4a</td>
<td>(Öberg 2003)</td>
</tr>
<tr>
<td>Kiruna</td>
<td>0.024</td>
<td>0.08</td>
<td>(de Wit &amp; Strandell 2000)</td>
</tr>
<tr>
<td>Kiruna</td>
<td>–</td>
<td>1.8b</td>
<td>(Öberg 2003)</td>
</tr>
<tr>
<td>Svappavaara</td>
<td>0.01</td>
<td>0.04c</td>
<td>(de Wit &amp; Strandell 2000)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>4.5–6.2</td>
<td></td>
</tr>
</tbody>
</table>

a 1996, b 1990, c ETEQ

Few up-to-date measurements of dioxin emissions are available at present. Such measurements as have been made suggest that emissions are between 1.4 and 3 g/year, the most recent ones indicating that they are at the lower end of that range. Emissions per tonne of pellets have fallen appreciably, and total emissions have also decreased, though not to the same extent, owing to a rise in production. Two new pellet plants are to open in the next few years, increasing the total production capacity by some 8 million tonnes per year, from a current maximum capacity of 17.5 million tonnes. This means that, unless control measures are introduced, releases of dioxins will probably also increase.

Iron and steel works
The formation and release of unintentionally produced substances at iron and steel works vary widely between plants, and are dependent on several factors. Important determinants include the proportion of scrap used and how clean it is.

Primary iron and steel works – releases
Sweden has two ore-based, integrated steelworks, located in Luleå and Oxelösund. The country’s last sinter plant was closed in 1995 and now only pellets are used in Swedish blast furnaces. This has reduced releases of dioxins and other pollutants, as pellet production generates lower atmospheric emissions than the production of sinter. At an integrated steelworks, dioxins may be emitted to air from several different component processes: from the coking plant, the blast furnace process and the LD process in the steelworks. The UNEP Toolkit gives an emission factor of 0.01 µg TEQ/tonne LS (liquid steel) for blast furnaces with particulate control. This would mean a release of the order of 0.04 g TEQ per year. Measurements made at the Luleå works in 1998 indicate an appreciably lower emission. The corresponding figures for the LD process are 0.1 µg TEQ/tonne LS, corresponding to an annual emission of the order of 0.4 g TEQ. The use of clean scrap in the LD process is an important factor in reducing releases.

Emissions of dioxins to air from the Luleå steelworks have been analysed regularly since the 1990s. These analyses indicate a specific emission of 0.3–0.6 µg per tonne of crude steel (Öberg 2003a). This is lower than for the majority of electric-arc furnaces; at a production level of 2,200 ktonnes of crude steel, it corresponds to 0.6–1.3 g/year. Total crude steel production in Sweden in 2003 was around 3,900
ktonnes (SSAB 2004), which would mean an emission of some 1.2–2.3 g/year. In the event of a process malfunction in the steelworks, floor casting is often used, i.e. casting on a bed of sand without any emission control at all. Little is known about the quantity and content of particulates released by this procedure.

There are two coking plants in Sweden, in Oxelösund and Luleå. Production at the Luleå plant was 618 ktonnes in 2003, while in 2002 the Oxelösund facility produced 438 ktonnes. Estimates based on UNEP emission factors suggest a release to air of 0.3 g TEQ/year and a release to water of 0.06 g TEQ/year. If, on the other hand, emission factors derived from Dutch measurements are used, Swedish coke production could give rise to an emission of around 0.2 g I-TEQ/year in flue gases. Measurements carried out at the Luleå plant on one occasion in 1993 indicate an appreciably lower emission.

Secondary iron and steel works – releases
There are just under 40 iron and steel producers in Sweden. Of these, around ten currently operate electric-arc furnaces. Both the composition of the scrap (degree of contamination with organic and chlorinated products) and the process employed affect the scale of dioxin formation. The scrap is charged to the furnace in batches, resulting in temperature changes and varying degrees of combustion, which in turn affect the formation of dioxins.

Studies show that annual emissions to air from secondary steelworks have fallen from around 10 g in the late 1980s to the current level of about 3 g/year for dioxins and 33 kg/year for hexachlorobenzene. The decrease is primarily attributable to process improvements (better temperature control) and improved dust removal. In addition, the number of electric-arc furnaces has declined since the 1970s, from 57 to 8. The total annual capacity, though, is largely unchanged. (Öberg 2003b.)

In many European countries, guide and limit values have been set for atmospheric emissions from metal-processing plants. Several of the plants in Sweden, however, currently find it difficult to reduce emissions below these levels. In the countries in question, levels are expressed as concentrations of dioxins in the outgoing flue-gas stream from the process, as has long been the practice for combustion installations. One reason for defining emission limits in this way, it may be assumed, is that it provides guidance on the appropriate design and capacity of flue-gas cleaning equipment. As far as environmental effects are concerned, though, the decisive factor is not the concentrations in outgoing gases, but the quantities, and in Sweden the latter factor has traditionally formed the basis for permit conditions. In conjunction with future permit applications, however, the pros and cons of these two approaches should be considered.

Waste
The slag from blast furnaces has a lower dioxin content (0.001–0.2 ng Eadon/kg, measurements made in 1992–93) than that from electric-arc furnaces (0.4–3.4 ng
Eadon/kg), which are scrap-based. The lack of data on steelworks slag makes it difficult to calculate the total quantities involved, but an estimate suggests that a few grams of dioxins per year accumulate in these waste products.

The quantities of slag formers used have decreased, and with them the amounts of slag produced. All blast furnace slag is reused or recycled; it can be used, for example, in the manufacture of cement.

Flue-gas cleaning systems collect dust in fabric filters, venturi scrubbers or electrostatic precipitators. Data from measurements performed in 1992–93 on wastes from the integrated steelworks at Öxelösund and Luleå indicate that of the order of 8 g of dioxins per year are retained in the flue dust. At both plants, this dust is recycled to the blast furnaces in briquette form. It is unclear what quantities of dioxins are landfilled. The background report from the Environmental Chemistry Section at Umeå mentions a range of 0.8–140 g per year for the primary and secondary steel industry. However, these figures are based on dioxin levels in particulate matter from secondary production of steel and, moreover, do not take into account the fact that a certain proportion of the dust removed is reprocessed and not released into the environment.

Concentrations of dioxins in particulates from electric-arc furnaces are higher than in those from blast furnaces. In measurements made at the Smedjebacken plant in 1991 and 2000, concentrations were found to be 0.2–0.7 ng Eadon/g (Öberg 2003b). Other analyses of collected flue dust indicated levels of between 0.009 and 1.5 ng/g particulates. However, the plants concerned are scrap-based, which entails a risk of higher dioxin emissions compared with primary iron and steel production. Some of the dust formed is recovered, either internally or externally. For example, flue-gas filter dust from the manufacture of stainless steel is sent to Scandust AB in Landskrona for recycling, as it contains chromium, nickel and iron. Dust with a high zinc content is recycled at the Rönnskär smelter in Skelleftehamn.

Given the paucity of measurements made, it is difficult to give an estimate of the quantities of dioxins in steelworks waste.

**Foundries**

There are currently around 200 foundries in Sweden, the majority of them non-ferrous. In numerical terms, the foundry industry is dominated by small and medium-sized companies.

As far as the different processes involved are concerned, induction furnaces generate lower emissions of dioxins than cupola furnaces. Only three plants with cupola furnaces now remain in Sweden. Measurements from the 1980s show that the majority of pollutants end up in landfill with sludge and dust, while the remainder are released into the atmosphere with flue gases. According to an estimate from the foundry industry, total releases (to air and waste) currently stand at 0.25 g N-
TEQ/year. On the basis of measurements at five foundries, however, de Wit and Strandell (2000) calculate an emission to air from foundries of 0.006–0.5 g N-TEQ/year. Foundry dust is classed as hazardous waste. Emissions to air have decreased thanks to efficient dedusting by means of fabric filters and use of recuperators.

Samples of landfilled dust and of used moulding sand and slag (dross) from one foundry point to elevated concentrations of dioxins and PCBs, but relatively low levels of hexachlorobenzene. Operations here were discontinued at the end of the 1980s, and some remediation of the site is now being undertaken. Used sand and slag from the immediate surroundings exhibited roughly 100 times lower levels of dioxins and PCBs, whereas hexachlorobenzene levels were similar to those in the dust. The sand/slag was used as a building material and as fill at several sites in the municipality in question. According to information from the industry, emissions from foundries are low, but the results show that formation and release of the substances of concern here have occurred.

*Primary non-ferrous metal works*

There are currently three plants engaged in the primary production of non-ferrous metals in Sweden: an aluminium plant (Sundsvall), a plant for the recycling of nickel/chromium dust (Landskrona) and a plant producing copper, lead and zinc (Skelleftehamn). According to the UNEP Toolkit and earlier sampling, primary production of aluminium does not give rise to any significant release of dioxins to air. However, small amounts have been found in leachate and sludge from the Sundsvall plant. The Landskrona facility mainly recycles metal dust from other steel producers, using the plasma method. Earlier measurements indicate that this operation is not responsible for any significant dioxin emissions to air either.

At the third plant (Skelleftehamn), studies show that recovery of zinc from secondary materials is one of the major sources of dioxin formation. In December 2001, equipment to reduce dioxin emissions to air was brought into operation, involving continuous injection of carbon powder upstream of the last of three electrostatic precipitators. This has reduced the release of dioxins. A provisional limit for dioxins of 1 g Eadon/year has been set for the plant. Between 2002 and 2004 the company took samples on a further 20 or so occasions, partly to fine-tune the dioxin removal system, and partly to monitor emissions of dioxins and PCBs from other significant emission sources at the site.

The results show that dioxin emissions from the zinc fuming plant have fallen by over 70% (from around 1.61 g/year to 0.45 g/year Eadon dioxins) (New Boliden 2004).

The sampling undertaken from 2002 to 2004 (New Boliden 2004) also demonstrates that dioxin emissions from the sulphur products plant and the Kaldo plant for the production of lead remain low, and that the same is true of PCB emissions...
to air. In the converter ventilation system, too, low levels of dioxins were recorded, while one of the samples indicated a larger quantity of PCBs. The throughput of air through this system is very high (800,000 Nm$^3$/hour), which means that even a low concentration will result in a relatively large total amount (in g/year). At the clinker plant, measurements point to a higher emission of dioxins than was found in earlier studies, while the release of PCBs is low (table 5).

Table 5: Dioxin and PCB releases from different emission points at the Skelleftehamn site (results for 2004 are calculated on the basis of hours of operation in 2003).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Sampling year(s)</th>
<th>Dioxins g I-TEQ/yr</th>
<th>Total PCBs g/yr</th>
<th>PCB$_7$ g/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphuric acid plant</td>
<td>2003–2004</td>
<td>0.002–0.02</td>
<td>0.35–3.3</td>
<td>0.18–1.8</td>
</tr>
<tr>
<td>Sulphur dioxide plant</td>
<td>2003</td>
<td>0.001</td>
<td>0.17</td>
<td>0.04</td>
</tr>
<tr>
<td>Kaldo plant (lead)</td>
<td>2002–2004</td>
<td>0.02–0.1</td>
<td>85</td>
<td>23</td>
</tr>
<tr>
<td>Fuming plant</td>
<td>2002–2004</td>
<td>0.24–0.76</td>
<td>0.6–120</td>
<td>0.1–0.37</td>
</tr>
<tr>
<td>Converter ventilation</td>
<td>2003–2004</td>
<td>0.09–0.17</td>
<td>260–1,200</td>
<td>47–310</td>
</tr>
<tr>
<td>Clinker plant</td>
<td>2003–2004</td>
<td>0.9–4.9</td>
<td>19–140</td>
<td>6.8–11</td>
</tr>
</tbody>
</table>

A comparison between the present study (2004) and one carried out in 1999, with regard to dioxin emissions, shows that:

- Emissions from the zinc fuming plant have decreased.
- Releases from other emission points, apart from the clinker plant, remain at roughly the same levels as in previous years.
- The quantities recorded at individual emission points vary appreciably between sampling rounds. These results illustrate the difficulties involved in dioxin sampling, for which the accuracy of an individual sample collected under optimum conditions is estimated at around ±50%.
- Dioxin emissions from the clinker plant have increased since 1999, from 0.06 to over 1 g Eadon/year.
- An overall estimate for the different plants suggests an emission of dioxins corresponding to 0.1 ng TEQ per Nm$^3$ (the level set in the EC Directive that applies to new waste incineration plants).

As regards PCB emissions, the outflow of ventilation air from copper converter aisles is high. Despite relatively low concentrations, therefore, converter ventilation is the largest individual source of PCB emissions to air. The mix of different PCB congeners indicates that probably only a small proportion of the quantity of PCBs released originates from thermal formation in the metallurgical processes at the plant. The company intends to continue to study PCBs, the first step being to collect new samples according to the latest standard (WHO-PCB-TEQ). This is expected to take around 12–18 months, up to 2006.

**Secondary non-ferrous metal works**

There are just under 20 plants in Sweden devoted to secondary production of non-ferrous metals (recovery of copper and aluminium), seven of them relatively large (‘Class A’ installations). Dioxin concentrations in flue gases depend very much on
the type of metal scrap used: for example, formation of dioxins is catalysed by an admixture of copper. On the basis of data from 1993, the total release of dioxins to air that year was around 4 g N-TEQ. The amounts of dioxins in residues are estimated to be smaller (2 g N-TEQ for dioxins and 0.1 g N-TEQ for PCBs).

**Ferro-alloy, lead accumulator and graphite electrode plants**

There are now only a small number of ferro-alloy plants (one Class A) and lead-acid accumulator plants (two sites) in Sweden, and the last graphite electrode factory was closed long ago. No data at all are available on emissions of dioxins, PCBs and hexachlorobenzene from this group of metal-processing plants.

### 3.1.2.2 ASSESSMENT

The metallurgical industry is a major sector in Sweden, and one that contributes significantly to the formation and release of dioxins. By international standards, though, its emissions are relatively low, bearing in mind the volumes produced. Even so, this is a sector that needs to play its part in ongoing efforts in this area. The question of possible dioxin releases will receive attention in connection with licensing of plants under the Environmental Code, as a basis for decisions on measures to reduce emissions of both particulates and dioxins.

**Better data**

Only limited data of use in assessing annual emissions from the metallurgical industry are available, particularly for the last few years. The Environmental Protection Agency considers it important to obtain a better set of data on which decisions can be based. This will enable better decisions to be reached as to where action will be most cost-effective.

In 2005 the Swedish Steel Producers’ Association will be embarking on a study of levels of unintentionally produced substances in various off-gas and exhaust-air streams. This will provide a sounder basis for assessing how large emissions are and where measures can most cost-effectively be deployed.

Better information is also needed regarding the pollutant content of wastes. It is important to shed light on the effects both of increased internal recycling and of the endeavour to promote greater recovery of materials in society at large.

**Particulate reduction measures**

Since dioxins bind to a large extent to dust particles, particulate control is an important technical means of reducing releases. Improvements in this area can be achieved by more efficient dedusting in flue-gas cleaning systems, appropriate dosages of adsorbents, catalytic fabric filters etc. In this context it is important to take into account the composition of the dust removed.
Process development

Process development is another important factor, representing a longer-term approach. Process changes have been of great significance in securing the emission reductions achieved so far. Measures such as preheating of scrap, for example, have had an impact. In secondary, high-temperature metal production, scrap preheating combined with post-combustion and rapid quenching is a technical solution with considerable potential to reduce releases of dioxins and mercury. It may require a significant capital investment, but this could possibly be partly offset by increased production and lower energy costs. (Öberg 2003b.) In applications in Sweden, however, scrap preheating has not been designed for this particular purpose. On the contrary, there is reason to fear that, as previously and currently practised, it has in fact increased emissions. Experience of scrap preheating in other countries too, where it is done using hot furnace gases, is not entirely favourable.

The Swedish Steel Producers’ Association has also received funding from the Swedish Foundation for Strategic Environmental Research (Mistra) for a four-year environmental research programme entitled ‘Towards a Closed Steel Ecocycle’. The aim is to reduce inputs of natural resources such as ore and coal in steel-making, together with the quantities of waste disposed of to landfill. As part of the programme, researchers will in addition be studying the effects of preheating scrap to much higher temperatures than at present, in order to burn off surface treatments and coatings of all types. Zinc is the most important material involved, but removal of mercury and organic substances will also be studied. The results of this research should provide a better basis for decisions on appropriate measures.

Pellet plants

Owing to the limited number of measurements made, there is considerable uncertainty as to the scale of emissions from these plants. As a large proportion of dioxins bind to dust particles, it is essential to minimize particulate emissions. In conjunction with applications for new and renewed permits, the question of present and future releases from plants will be examined. Emission data are needed to determine what particulate control measures, possibly supplemented with other measures directly addressing dioxin emissions, must be required to ensure that increased production does not result in higher releases.

Iron and steel works

Our assessment regarding iron and steel works is the same as for pellet plants. The iron and steel sector clearly contributes to the formation and release of dioxins, and the scale of emissions is such that it should be involved in ongoing efforts to tackle the problem. Data on the quantities released are inadequate and must be improved. Effective dust control at plants is important. The dust removed contains varying amounts of dioxins, which need to be taken into account in its subsequent treatment and disposal. To achieve a long-term solution, it is important to undertake research and process development aimed at minimizing the formation of dioxins and other similar substances.
Foundries

Foundries, too, must minimize dust emissions from operations that involve a risk of dioxin releases. Most foundries have installed fabric filters to reduce emissions to air. Exhaust capture needs to be optimized, to ensure that emissions of dust per tonne produced are as low as possible. The reference document on best available techniques (BREF) for foundries presents a number of possible techniques to cut emissions to below 0.1 ng TEQ/Nm³. It lists combustion-related measures such as temperature monitoring and control, injection of adsorbents such as activated carbon into the gas stream, and catalytic oxidation in fabric filters. Several of these measures originate in iron and steel works, but are also applicable in this sector.

3.1.3 The chemical industry, refineries and the cement industry

3.1.3.1 BACKGROUND AND PRESENT SITUATION

Sweden’s chemical industry is made up of a heterogeneous group of companies and many different ‘sub-sectors’, manufacturing a wide range of products, from basic chemicals used as raw materials for other production processes, to highly refined products. Most of the chemical industry’s output is used in other sectors of industry.

Companies manufacturing chemical compounds are usually grouped into those producing inorganic chemicals, using salt, sulphur and minerals as their raw materials, and those making organic chemicals, based largely on wood or on mineral oil and natural gas. Products of the inorganic sector include sulphuric acid, hydrochloric acid, chlorine and sodium hydroxide. The organic sector, which is larger, supplies a great many different products.

The report *Emissions of particles, metals, dioxins and PAH in Sweden* (Kindbom et al. 2004), from SMED (Swedish Methodology for Environmental Data), provides data on dioxin and other releases from various sources, including the chemical industry. It lists the sources which, in the light of the 1993 survey, are potentially of greatest importance (see also table 1). According to the present report, however, the chemical industry is not one of these. The SMED report notes that hardly any information is available on dioxin emissions from this industry, and it has not been possible to compile time-series data relating to it.

The formation of dioxins in the chlorate and chlor-alkali industry has decreased significantly since the use of graphite electrodes was abandoned at the end of the 1970s, and with the declining use of the mercury method. The titanium electrodes now employed do contribute to dioxin formation, but to an appreciably lesser extent. The most significant releases of dioxins occur from landfills and contaminated sites associated with the chlor-alkali industry, accompanying particulates released to water and sediments. The proportion emitted into the atmosphere is negligible.
In the case of hexachlorobenzene, other inorganic sectors dominate, with releases occurring primarily to air. Historically, there is also a legacy of hexachlorobenzene from the chlor-alkali and chlorate industry in soil and landfills, with a risk of leaching into water and sediments. Available data are inadequate, however, making it difficult to attempt a historical assessment of the chemical industry. According to information from other countries, this industry is not now a major dioxin source, compared with other emitters. There is much to suggest that, in historical terms, the largest source of dioxins is chlorophenol production.

Table 6: Table summarizing annual releases of dioxins from different chemical industry sectors, refineries and the cement industry in Sweden. A dash in a cell means that no reliable data are available.

<table>
<thead>
<tr>
<th></th>
<th>Air WHO-TEQ/yr</th>
<th>Water/sediment WHO-TEQ/yr</th>
<th>Landfill WHO-TEQ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil refineries</td>
<td>0.0003–0.005</td>
<td>0.0003</td>
<td>0.0034</td>
</tr>
<tr>
<td>Chlor-alkali industry</td>
<td>0(^a)</td>
<td>0.001–0.02(^a)</td>
<td>0.008–0.26(^a)</td>
</tr>
<tr>
<td>Other inorganic</td>
<td>0.007</td>
<td>0.17</td>
<td>–</td>
</tr>
<tr>
<td>PVC production</td>
<td>0.006</td>
<td>0.02–0.06(^b)</td>
<td>0.04–0.17(^b)</td>
</tr>
<tr>
<td>Cement industry</td>
<td>0.18–0.3(^c)</td>
<td>0.007(^c)</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>0.2–0.3</td>
<td>0.2</td>
<td>0.05–0.5</td>
</tr>
</tbody>
</table>

\(a\): Hydro Polymers’ contribution, based on measurements 2001–4 (data from Swedish Plastics and Chemicals Federation, 2005); \(b\): Based on measurements 2001–4 (data from Swedish Plastics and Chemicals Federation, 2005); \(c\): I-TEQ

Table 7. Table summarizing annual releases of PCBs and hexachlorobenzene from different chemical industry sectors, refineries and the cement industry in Sweden. A dash in a cell means that no reliable data are available.

<table>
<thead>
<tr>
<th></th>
<th>Air PCBs TEQ/yr</th>
<th>HCB g/yr</th>
<th>Water/sediment PCBs TEQ/yr</th>
<th>HCB g/yr</th>
<th>Landfill PCBs TEQ/yr</th>
<th>HCB g/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil refineries</td>
<td>0.001</td>
<td>–</td>
<td>0.1</td>
<td>–</td>
<td>0.024</td>
<td>–</td>
</tr>
<tr>
<td>Chlor-alkali industry</td>
<td>–</td>
<td>12,400</td>
<td>0.1–0.65(^a)</td>
<td>1.5–15.5(^a)</td>
<td>0.4–1.2(^a)</td>
<td>7–29(^a)</td>
</tr>
<tr>
<td>Other inorganic</td>
<td>–</td>
<td>12,400</td>
<td>–</td>
<td>40</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>PVC production</td>
<td>–</td>
<td>–</td>
<td>0.9–14.9(^b)</td>
<td>10.8–13.8(^b)</td>
<td>0.4–1.2(^b)</td>
<td>7.6–17.9(^b)</td>
</tr>
<tr>
<td>Cement industry</td>
<td>0.4(^c)</td>
<td>&lt;3.9(^d)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>0.001</td>
<td>12,400</td>
<td>1.1–16</td>
<td>50–70</td>
<td>1–2.6</td>
<td>14–47</td>
</tr>
</tbody>
</table>

\(a\): Hydro Polymers’ contribution, based on measurements 2001–4 (data from Swedish Plastics and Chemicals Federation, 2005); \(b\): Based on measurements 2001–4 (data from Swedish Plastics and Chemicals Federation, 2005); \(c\): WHO-TEQ; \(d\): Data from one plant

Refineries
Of the five refineries in Sweden, three produce petrol, among other products. Petrol production involves a process, known as platforming, that has been found to have the potential to release substances of concern here. It is in conjunction with regeneration of the catalyst that these emissions can occur. In some cases (e.g. Scanraff) the catalyst is regenerated continuously, in others (e.g. the Preem and Shell refineries) intermittently. At the last two plants, regeneration is performed two or three
times in a four-year period. When the problem was discovered a number of years ago, measurement programmes were mounted, and all three refineries have now monitored their emissions. Remedial action has also been taken, and further measurements have been carried out.

The action taken has been of different types, depending on whether regeneration is continuous or intermittent. Where it is continuous, a change has been made to the platforming process, while at the refineries with intermittent regeneration, scrubbers and activated carbon filters are being used to reduce emissions. The action taken has been largely successful. Further minor adjustments may prove appropriate. In addition, monitoring of emissions should continue.

Inorganic chemicals

The chlor-alkali industry

Chlor-alkali plants produce chlorine and caustic soda. In mercury cell-based chlor-alkali production using graphite electrodes, dioxins are to be found in the graphite sludge that arises as waste. Most of the sludge produced was disposed of to landfill or discharged to water and sediments. Graphite electrodes were used in the Swedish chlor-alkali industry until 1980. The total quantity of dioxin equivalents produced at ten chlor-alkali plants in the country up to 1980 has been estimated to be in the range of 315–1,843 g, of which 229–1,338 g was discharged to water. The quantity landfilled has been estimated at 78–460 g. Replacing graphite with titanium electrodes dramatically reduces levels of dioxins, although they can still be detected. This change has already been effected in Sweden. In 1993, the annual quantity of dioxin equivalents from the remaining three chlor-alkali plants was estimated at 0.25 g. The accumulated amount disposed of to landfill from plants with titanium electrodes was estimated the same year at 3.35 g. All the figures given are uncertain, as they are based on only a small number of analyses.

Further reductions can be achieved if the mercury-based process is abandoned in favour of one using membrane technology. There are now two mercury-based plants still operating in the country, but they will probably be decommissioned by 2010, since the use of mercury is to be phased out. The difference between the mercury process and membrane technology in terms of the amounts of dioxins generated can be illustrated by comparing the estimated quantity produced annually at Akzo Nobel’s Bohus plant, 0.18 g, with the figure for Skoghall, 0.013 g. Earlier sampling has shown that dioxins can find their way into groundwater, though at relatively low concentrations.

Releases of hexachlorobenzene have also occurred from chlor-alkali and chlorate plants, and have been detected in earlier samples of graphite sludge (2–7 mg/kg) and recent soil samples (0.5–0.9 µg/kg). No historical data on PCBs are available. Sampling has shown that leaching occurs from land and landfill sites used to store graphite sludge, but the scale of these losses is difficult to estimate.
Hydrochloric acid production

The manufacture of hydrochloric acid involves the liberation of chlorine, which can form organochlorine compounds. At Kemira Kemi’s plant in Helsingborg, annual emissions of hexachlorobenzene to air have been reported to total 5–10 kg. However, this figure is expected to be reduced to less than 0.1 kg following fine-tuning of a carbon filter. The annual discharge to water is of the order of 35 g. Annual releases of dioxin equivalents from the same plant are reported as 7 mg to air and 170 mg to water. Hydrochloric acid is also produced as a by-product at the vinyl chloride plant at Stenungsund. Treatment of flue gases using an activated carbon filter reduces emissions to air.

New samples have been taken at an industrial landfill, at which sludge from hydrochloric acid production was among the wastes deposited. No elevated concentrations of dioxins, PCBs or hexachlorobenzene could be detected either in the water entering the sedimentation basin or in the receiving water. Thus, no evidence was found of leaching from landfilled waste from the production of hydrochloric acid.

Chlorate plants

The number of chlorate plants in Sweden (which produce sodium chlorate, a chemical used at pulp mills to manufacture chlorine dioxide, which is in turn used to bleach the pulp) has decreased from six to two. Releases have mainly occurred as discharges to water, and the majority of the pollutants released are to be found in sediments. Overall, formation of dioxins in the chlorate and chlor-alkali industry has decreased appreciably since the switch away from graphite electrodes, although it has not been entirely eliminated. However, there are several sites, including former industrial sites, with contaminated soils and landfills containing dioxin-contaminated sludge, from which considerable leaching may be occurring. Releases from the different sites vary, though, being dependent on hydrogeological and other factors. No data are available on current emissions from chlorate plants, and it is therefore not possible to estimate their contribution. As the processes involved are similar in many ways to those used at chlor-alkali plants, however, dioxin concentrations in the sludge from chlorate factories may be assumed to be comparable to those found in chlor-alkali sludge.

Organic chemicals

Dioxins can form during the manufacture of pesticides, since several of the intermediate products involved contain chlorine. This is the case with pentachlorophenol, for example. Releases may occur during production, but probably they are chiefly associated with the application of the agents concerned. No pesticides are produced in Sweden. Pesticides can only be used with the approval of the National Chemicals Inspectorate, and in accordance with regulations issued by the Environmental Protection Agency (SNFS 1997:2).

There is currently one plant manufacturing polyvinyl chloride (PVC) in Sweden. Annual measurements from 2000 onwards point to a downward trend in emissions
of dioxins, PCBs and hexachlorobenzene. This has been achieved, above all, by process improvements such as filtration, more advanced wastewater treatment, treatment using activated carbon, and a changeover to more inert materials in processing equipment. There are several stages in the manufacture of PVC, and dioxins form during the production of chlorine gas, in the vinyl chloride plant and in the combustion of process gases and by-products. At the vinyl chloride stage, the quantities of dioxins formed can be appreciably reduced by using pure oxygen instead of 80% oxygen in the oxychlorination process. Virtually no particulates are formed during the process, and emissions to air are very low. According to the plant’s environmental report for 2003, total dioxin releases from all the component processes were 6 mg to air, 9–67 mg to water and 20–25 mg to sludge. The majority of these releases originate in the production of vinyl chloride. Dioxins pass with water to the internal wastewater treatment plant, and most of them end up in the sludge. Sludge from the treatment plant is disposed of in the company’s own landfill, while sludge from the chlorine plant is sent to SAKAB for incineration.

The cement industry
Three plants in Sweden produce cement using rotary kilns and what is known as the ‘dry process’. Internationally, a great many measurements of dioxin emissions have been made. The conclusion drawn from them is that emissions are typically below 0.1 ng TEQ/Nm³, a figure which tallies with Swedish measurements. They are also well below the emission limit for cement kilns which co-incinerate waste (limit value 0.1 ng/m³, NFS 2002:28). The aggregate annual emission from the Swedish cement industry can be estimated at around 0.3 g TEQ.

Some of the dioxins released are bound to particles, and emissions could therefore be reduced by more efficient particulate control. The equipment currently used meets BAT (best available techniques) standards at two of the three plants, but from a purely technical point of view emission abatement could be further enhanced. This will presumably happen too, since, with effect from 2008, the Environmental Protection Agency’s co-incineration regulations will set a limit value for particulates below the limits currently laid down in permits for such plants. Additional reductions are not judged to be possible without incurring major costs. Emissions are not of such an order of magnitude that such costs would be environmentally justified.

3.1.3.2 ASSESSMENT
Figures for the industries described are very uncertain, and there are major differences in formation and release between the individual plants concerned. Leaching is occurring from land and landfill sites where sludge from different operations has been stored or disposed of, although the scale of this problem is difficult to estimate.

In the chlor-alkali industry, a changeover from the mercury-based process to membrane technology would reduce dioxin emissions. There are currently two plants
still using the mercury method, and one of them is to be closed in 2005, which means that releases of dioxins from this site will eventually be eliminated. As for the other plant, a decision in principle has been taken to convert to the membrane method no later than 2010.

At the former chlor-alkali plant at Bengtsfors, there are plans for remediation of the site which will reduce loadings to a nearby lake by over 50%.

One hydrochloric acid plant is to be closed in 2005. At another, there are plans to add small quantities of sulphur dioxide to reduce chlorine levels, and to install an activated carbon filter to curb formation of dioxins.

In the vinyl chloride process, most of the dioxins formed are destroyed in the process’s treatment stage; a small proportion of them are released with the wastewater stream, but these are largely removed with the sludge in the wastewater treatment facility for the site as a whole, or by filters. In addition, the wastewater stream from the chlorine plant is treated by means of activated carbon. The hydrochloric acid formed as a by-product is purified in a corresponding manner. In all, around 0.02 g of dioxins are released from each treatment plant to the receiving water, and a hundred times less is emitted to air from the furnace. A similar amount is retained in the sludge, and this fraction can be reduced by also using a carbon filter in the wastewater stream from the site as a whole.

Two of the three cement works currently use BAT for particulate control. Abatement requirements will probably be tightened up. The Environmental Protection Agency’s regulations on co-incineration will apply from 2008, introducing a limit value for particulates below that stipulated in existing operating permits. This will reduce releases of particulates and hence of unintentionally formed substances.

Emissions from these industries are small and are expected to decrease still further with the phase-out of older process technology, especially in the chlor-alkali industry. Releases from organic chemicals production are substantially lower than those from inorganic chemicals, partly following abatement measures introduced at Sweden’s one PVC production plant.

### 3.1.4 The forest products industry

Table 8: Table summarizing annual releases of dioxins from the pulp and paper industry in Sweden.

<table>
<thead>
<tr>
<th>Dioxins from the pulp and paper industry, g TEQ^a/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air</strong></td>
</tr>
<tr>
<td>1.2</td>
</tr>
</tbody>
</table>

---

a: Equivalency scheme not defined
b: Calculated on the basis of non-forest industries
3.1.4.1 BACKGROUND AND PRESENT SITUATION

Most dioxin data from the Swedish forest products industry are relatively old, and specific data on the formation and release of PCBs and hexachlorobenzene are not available. In the 1980s, this industry and waste incineration were the main focus of the dioxins debate in Sweden. At that time, pulp bleaching based on elemental chlorine was identified as the most significant source of dioxins in the forest products sector, and discharges to water were the principal concern. The measures subsequently introduced in the industry were chiefly designed to reduce the formation of dioxins and their release to water and in products. They included far-reaching process changes which, combined, served to reduce dioxin emissions in the course of the 1990s.

Using the standardized values employed in the industry, releases of dioxins to air have been estimated to be roughly comparable to those from the incineration of household waste. In relation to the amount of energy produced, they can be estimated at 0.007 ng/MJ (1.2 g/170,200 TJ), which can be compared with waste incineration emissions of 0.03 ng/MJ. Very great uncertainty attaches to the quantities of dioxins that may be incorporated in residual products. There is also considerable uncertainty about the extent to which dioxins previously discharged to water, and now to be found in contaminated sediments, are leaching into the surrounding environment.

No data are available on the formation of PCBs and hexachlorobenzene in the pulp and paper industry. However, measurements performed in the 1980s showed PCBs to be present in sediments close to paper recycling plants. They originated from carbonless copy paper, in which they were used up to 1971. When pulp was produced from recycled paper, PCBs ended up in the de-inking sludge. These PCBs were not formed during the process, but were present in the paper or possibly in the printer’s ink, and can therefore hardly be classed as unintentionally produced.

Pulp and paper mills

For many years, chemical pulp was bleached using elemental chlorine (chlorine gas), a process that could result in the formation of organochlorine pollutants, including dioxins. To address this problem, elemental chlorine has gradually been replaced with chlorine dioxide or other agents, and releases of highly chlorinated organic pollutants to water have been markedly reduced. Since February 1994, elemental chlorine has not been used for bleaching at any pulp mill in Sweden. Today, pulp is bleached using techniques referred to as ECF (elemental chlorine-free) or TCF (totally chlorine-free). ECF methods use chlorine dioxide, whereas TCF techniques use neither chlorine gas nor chlorine dioxide. Total annual dioxin emissions to water are now estimated at less than 0.1 g. This can be compared with a figure of 16 g per year presented by the Swedish Forest Industries Association in 1987. As a result of the high discharges of dioxins to water from many mills in the 1980s and earlier, there are now considerable quantities of these substances in
sediments and fibre beds in the vicinity of the plants concerned. The total emission to water between 1960 and 2003 is estimated at 100–800 g N-TEQ.

Dioxins and PCBs that are formed during or introduced into a process can accompany the product resulting from it, in this case the paper pulp. In this way, tens of grams of dioxins may have entered into circulation in society each year prior to 1993. The corresponding figure today is estimated at less than one gram per year. In the case of PCBs, too few data are available on levels in pulp to permit a confident assessment. However, it seems clear that most of the PCBs that were to be found in pulp originated from recycled paper (see above).

The forest products industry is very energy intensive. To a large extent, it meets its energy needs by burning various residual products, such as bark, pitch oil and spent pulping liquors. It is assumed that, like other combustion processes, these processes generate dioxins, PCBs and hexachlorobenzene. No data are available on the formation and atmospheric emission of the last two of these at Swedish mills. It is reasonable to assume, though, that they are formed and occur in flue gases in similar proportions to those associated with the burning of biomass fuels in other sectors. Releases of dioxins to air have been estimated at 1.2 g per year.

The industry’s bark-fired boilers generate large quantities of ash, the annual total being estimated at 200,000 tonnes. No measurements of dioxins, PCBs or hexachlorobenzene in this ash have been reported. If, in the same manner as above, ash from this source is considered to be comparable to that from other processes involving combustion of biofuels, it could contain <5 g of dioxins, 500–4,000 g of PCBs and 14 g of hexachlorobenzene. These estimates are extremely uncertain, however, as there are significant differences between the processes used in the pulp and paper industry, on the one hand, and large-scale burning of biomass fuels, on the other.

Another residual product that has previously been found to contain dioxins is deinking sludge (see above). Concentrations in this sludge are probably lower now than they used to be. However, old sludge has been landfilled at various sites, and there is a risk of the dioxins and other substances it contains contaminating the immediate surroundings and, in the long term, an increasingly wide area. See 3.2.1 for further discussion.

**Sawmills**

At many sawmills, timber used to be treated by dipping it in pentachlorophenol (PCP) and other chlorophenol products. The agents used were found to contain dioxins, resulting in a release of dioxins via chlorophenol-based products. A ban on the use of pesticides containing chlorophenols took effect at the beginning of 1978. In several cases, pressure treatment and immersion of timber resulted in direct spillage on the ground. So far, over 370 sites contaminated with chlorophenols have been identified (see the section on contaminated land for further discussion).
The scenarios presented in the background report from the Environmental Chemistry Section at Umeå University also give some idea of the quantities of dioxins that may have entered into circulation in society primarily as a result of the early use of chlorophenols. They show that as much as 200 kg of dioxins may have been incorporated in the timber treated. On the basis of that figure, up to 30 kg of dioxins could still be present in timber in use in Swedish society.

3.1.4.2 ASSESSMENT
The action taken in the forest products industry to reduce the formation and release of dioxins has been effective, particularly as far as releases to water and in products are concerned. It is reasonable to assume that the formation and release of PCBs and hexachlorobenzene have also been reduced by the measures introduced.

Today, the largest quantities of unintentionally formed substances with POP characteristics are associated with the industry’s energy production processes (combustion of various residual products). Here, as with biomass burning in other sectors, there is cause to monitor both the formation and the release of such substances, especially dioxins. Monitoring should cover dioxins in both ashes and atmospheric emissions.

The forest products industry’s contribution to the formation and release of PCBs and hexachlorobenzene is probably very small, compared with the quantities of these substances that have been manufactured and are now present in the environment and in buildings and equipment. Nevertheless, a systematic study of how significant that contribution in fact is today would be useful.

The reports suggesting that large amounts of dioxins could still be present in society should be followed up, and if it emerges that appreciable quantities may remain in pressure-treated timber which is still in use, the feasibility of identifying and removing such material should be investigated. Such a study could initially focus on assessing the feasibility of identifying where in society contaminated timber might occur and how it could be recovered and disposed of. In addition, an assessment should presumably be made of the consequences of refraining from taking action (the ‘zero option’).

3.1.5 Shipping

3.1.5.1 BACKGROUND AND PRESENT SITUATION
Existing emission factors for dioxins, PCBs and hexachlorobenzene from ships are based on relatively few studies and relatively old data. Shipping consumes large quantities of fuel every year, and the figure is rising. How dioxins can form in the oil burnt is not known. Crude oil contains only trace amounts of organic chlorine, but contamination may occur through degreasing agents, solvents or other additives involved in the process. Metal chlorides bound to ash particles may be one source. Fuel with a higher chlorine content probably gives rise to higher emissions of
Table 9: Table summarizing annual releases of dioxins, PCBs and hexachlorobenzene to air from shipping in Sweden.

<table>
<thead>
<tr>
<th></th>
<th>Dioxins g WHO-TEQ/yr</th>
<th>Total PCBs g/yr</th>
<th>Hexachlorobenzene g/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipping using fuels sold in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swedena</td>
<td>0.37–0.85</td>
<td>480–1,100</td>
<td>120–280</td>
</tr>
<tr>
<td>Shipping in Swedish waters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>calling at Swedish portsb</td>
<td>0.2–0.5</td>
<td>280–660</td>
<td>70–160</td>
</tr>
<tr>
<td>North Sea and Baltic Sea</td>
<td>2.7–6.0</td>
<td>3,600–8,300</td>
<td>880–2,040</td>
</tr>
</tbody>
</table>

a: Based on fuel figures for 2002; b: Corresponds to half the distance travelled by shipping in the Baltic Sea calling at Swedish ports

dioxins, PCBs and hexachlorobenzene. To improve the basic data available and obtain more reliable emission figures, the Environmental Protection Agency commissioned the Swedish Environmental Research Institute (IVL) to carry out a new programme of measurements on board ships of three different types in 2003–4. Exhaust gases, fuels and lubricating oils were all analysed. Samples were collected under varying operating conditions, from both main and auxiliary engines. The three types of vessel chosen were representative of the ships sailing in Swedish waters, and represented a selection of different marine diesel engines, fuel types and operating conditions. The highest emissions were recorded when the main engines were started, and from engines run on heavy oils – both situations in which combustion conditions are typically poor. In addition to measurements of dioxins, PCBs and hexachlorobenzene, carbon dioxide and oxygen sampling was performed. A point to be noted is that an analysis of the lubricating oils employed showed the clean, unused oil to have a higher content of dioxins, PCBs and hexachlorobenzene than the dirty, used oil.

3.1.5.2 ASSESSMENT

This was only an initial study, and it has not revealed any alarming figures for the shipping industry. It should be borne in mind, though, that the samples were collected to reflect different operating cycles, and under controlled conditions. There is a risk that emissions could be higher under non-normal operating conditions, for which we have no data. Longer-term studies, involving more extreme variations, need to be conducted in the future. On the basis of existing knowledge, shipping is not judged to be a significant source of releases of unintentionally produced substances. Dioxin emissions are low: for shipping using fuels sold in Sweden, 0.37–0.85 g WHO-TEQ. The emissions recorded agree quite closely with earlier measurements, but new emission factors are proposed in the light of the new measurements. For dioxins, lower factors are proposed, and for hexachlorobenzene, a higher one. On the other hand, it is not considered necessary to use different emission factors for different engine types or engine speeds.

In WHO-TEQ terms, dioxin releases from shipping are low compared with total national emissions. Emission data for Swedish shipping are calculated on the basis of fuel sold in Sweden, combined with the emission factors. It is important to be aware, though, that a decrease in fuel sales could perhaps be due to fuel being
cheaper in another country, and emissions may not necessarily be falling at the same rate. Reduced use of diesel engines and greater use of land-based energy supplies in ports would probably result in a further decrease in releases of unintentionally formed substances.

### 3.1.6 Land-based transport

Emissions from land-based diesel-engined vehicles (road vehicles, non-road mobile machinery, military vehicles and locomotives) are reported to contribute 0.3 g WHO-TEQ. The combined emission of dioxins from all road transport in 2001 has been estimated at 0.57 g TEQ. This figure reflects a significant decrease since the introduction of unleaded petrol. In the 1980s, it was over 6 g (Kindbom et al.).

### 3.2 Secondary sources

‘Secondary sources’ refers here to sites, accumulations and processes in which unintentionally produced substances, after they have formed, may occur in elevated concentrations or quantities. Contaminated sites (soils and sediments) are one example. The concept also implies that a secondary source is not necessarily the ‘final resting place’ of a substance. With such an approach, digested sewage sludge can also be regarded as a secondary source and, in addition, as a transport pathway. Long-range atmospheric transport from both primary and secondary sources, resulting in continuous deposition over large areas, can be regarded both as an extremely dynamic secondary source and as a transport pathway.

As the total quantities of dioxins, PCBs and hexachlorobenzene currently to be found in and around different contaminated sites may be substantial, such sources could be of appreciable significance for the release of these substances, now and/or in the future. Similarly, we can see that atmospheric transport, especially long-range, can result in a level of deposition, at least of dioxins, that seems to be higher than can be explained solely by national emissions from primary sources.

### 3.2.1 Landfills

At some landfills, leachate is collected and treated, and the pollutants it contains may then form part of the loading from the treatment plant; in other cases, the leachate escapes into streams, wetlands or directly into groundwater. These diverse dispersion pathways make it difficult to gain an overall picture of releases to water, soil and air from landfill sites. Many sources of pollutants may be involved, including atmospheric deposition.

Landfills sometimes contain renovation and demolition wastes or other PCB-contaminated wastes from the manufacture of products containing PCBs. A few landfills may contain very large quantities, up to tens of tonnes.

In a study of leachate sampled from sedimentation basins at a municipal landfill, elevated concentrations of both dioxins (0.35 pg WHO-TEQ/l) and PCBs (0.6 pg WHO-TEQ/l) were detected. Levels of hexachlorobenzene, on the other hand, were
low. At another landfill for household waste, potential losses to air and in biogas from the site were studied. No evaporation of dioxins, PCBs or hexachlorobenzene was found, but elevated levels of total PCBs and hexachlorobenzene were detected in the biogas from the landfill. Judging from these values, the total PCB content of gas from Swedish landfill sites could be in the range of 150–1,500 g per year. This gas is burnt in various ways, and depending on the combustion process dioxins could be formed.

At a landfill for sludge from a hydrochloric acid plant, samples were taken of leachates entering a sedimentation basin and of the receiving stream. None were collected from the actual landfill, as a wide range of other wastes were also deposited there, i.e. it was a very heterogeneous site. It was assumed that the landfill contained large quantities of hexachlorobenzene, as high levels had been recorded in the nearby harbour, but no leaching could be observed during the sampling period, of either hexachlorobenzene or the other substances of interest.

A landfill for de-inking sludge from the paper industry was found to contain high levels of total PCBs. Large quantities of dioxins and WHO-PCBs were also found. There was no clear evidence of leaching into nearby streams. Samples from older parts of the landfill contained higher levels of dioxins, PCBs and hexachlorobenzene than those collected from the newer part. Concentrations probably vary between landfills, but the sampling performed at this site reveals one source of these unintentionally (and intentionally) produced substances.

3.2.2 Sewage treatment plants
Existing data on dioxins, PCBs and hexachlorobenzene in water at sewage treatment plants are limited. Pollutant discharges from such plants vary widely, depending on the activities and industries they serve (households, factories and waste sites). At treatment plants receiving waste water from textile factories, for example, concentrations of dioxins tend to be higher, probably owing to dioxin contaminants from impregnation of the textiles. As dioxins have low solubility in water, they tend to bind to organic particles and accompany the sludge fraction from the sewage works, resulting in lower levels in the effluent from the works. Large volumes of air are supplied to the plants’ aeration tanks, and from here PCBs especially are emitted, along with small quantities of dioxins and hexachlorobenzene. On the basis of samples collected in 2004, it has been estimated that 150–200 g of total PCBs/year are released to air in Sweden. The PCBs emitted to the atmosphere are primarily low-chlorinated congeners. It is estimated that 0.1–0.2 mg WHO-TEQ of dioxins, 1–2 mg WHO-TEQ of PCBs and 1–2 g of hexachlorobenzene are released in this way from Sweden’s sewage treatment plants every year. PCBs occur at higher concentrations than dioxins in sludge, but represent a lower TEQ value.

Sludge
PCB concentrations in sewage sludge showed a clear downward trend throughout the 1990s. The few data available on hexachlorobenzene indicate that levels of this
compound are lower than those of PCBs. Dioxin concentrations, too, appear to have fallen somewhat over time, judging both from studies at sewage works between 1990 and 2002 and analyses performed in conjunction with sludge-spreading experiments in Skåne in 1989–97. This trend is consistent with those recorded outside Sweden. It should also be noted that regular sampling reveals varying levels of PCBs in sludge: old PCB contaminants can give rise to temporary surges in leaching, affecting concentrations in sludge. Sludge is a heterogeneous material, which also affects the results of analyses. Although concentrations are low, substantial amounts of dioxins, PCBs and hexachlorobenzene accumulate in sewage sludge, owing to the large quantities produced. For 2002, the total release of dioxins in sludge has been estimated at 0.2–14 g N-TEQ. In the case of PCBs, the quantity is estimated at 6–20 kg, of which dioxin-like PCBs account for around 2–4 g N-TEQ/year. In the case of hexachlorobenzene, an annual accumulation of 2–20 kg is estimated. The Stockholm County Administrative Board has produced a report on sludge from municipal sewage treatment plants in the county of Stockholm (in prep.). It includes data on quantities of sludge and PCB\textsubscript{7} levels in the sludge from permit-holding plants in the county between 1992 and 2003. The results indicate that the total quantity of PCB\textsubscript{7} in sludge in the county in 2003 was around 2.2 kg, and that the mean concentration, weighted for sludge production, shows a slight downward trend.

The Institute of Environmental Medicine (IMM) has performed a risk evaluation of dioxins and PCBs in sludge and concluded that, at the concentrations currently occurring, these pollutants do not represent an increased risk of endocrine-disrupting effects in humans due to consumption of food grown on land fertilized with sludge.

### 3.2.3 Contaminated land

The Environmental Protection Agency has asked Sweden’s county administrative boards to submit a regional programme each year for the remediation of contaminated land. These programmes include a list of the ‘Top 30’ sites in each county most urgently in need of remediation.

In earlier sections of this report dealing with primary sources, it was noted that, at some installations such as chlor-alkali plants and sawmills, past production methods resulted in the formation of dioxins and their release to soils and sediments. In the case of chlor-alkali plants, soils and sediments are often contaminated with both dioxins and mercury, and if remediation is carried out both pollutants can be dealt with at the same time. Studies of the potential for dispersion, and the associated risk of damage to the environment, have only been undertaken at a few sites. Inventories and other studies are in progress in many counties to develop a better understanding of the significance of these pollutants. At present, though, there is no basis for assessing the possible quantitative significance of current and future leaching for the exposure of humans and the environment to the substances concerned.
Pressure treatment of timber with chlorophenol-based products took place for a number of years in the 1960s and 1970s, but was prohibited in 1978. One of the commonest products used, KY-5, primarily contained tri- and tetrachlorophenols. Pentachlorophenol (PCP) was also employed at many sawmills. Sites formerly used for pressure treatment and dipping of timber are often now classed as contaminated. So far, over 370 sites affected by chlorophenols have been identified, and the total figure is estimated at around 500. Some 30 of the 370 have been studied with regard to dioxins in soil, water and/or sediments. Total concentrations of dioxins have only been estimated at two sites. As the data available on the scale of dipping operations are limited, considerable uncertainty exists, but the total quantity of dioxins in soil from pressure treatment and dipping at sawmills is estimated at 5–50 kg WHO-TEQ. Both PCBs and hexachlorobenzene can form during the manufacture of PCP, but the amounts involved probably depend very much on the method of production. No data have been found on possible occurrences of PCBs and hexachlorobenzene resulting from sawmill and pressure treatment operations in Sweden.

At one site where chlorophenols were once used, high dioxin concentrations (4–19 ng WHO-TEQ/kg dry matter (DM)) were found in the soil. Total PCB levels were also elevated (17–68 µg/kg DM), though not to the same extent as concentrations of dioxins. For hexachlorobenzene, no major differences were found. One of the samples showed consistently lower values, demonstrating that, given the uneven distribution of these pollutants, the choice of sampling location is important.

At a site where remediation was under way – the former location of a chlor-alkali plant that had produced chlorine using the mercury method – air sampling revealed elevated concentrations of both dioxins and hexachlorobenzene. Emissions to air from waste sites are thus possible, especially in the case of hexachlorobenzene, which showed high evaporation rates. Evaporation can thus contribute to long-range atmospheric transport of the substances in question. In soil samples, dioxin concentrations were elevated in one case. In both soil and evaporation samples, the highest levels were recorded in the case where the ground had been stripped of vegetation as part of the clean-up operation.

From a site where copper cables had previously been burnt, samples of soil, groundwater, stream water and sediments in the receiving lake were collected. Substantially increased levels of dioxins (2–5 ng WHO-TEQ/g DM) could be detected in the soil samples, along with elevated concentrations of PCBs, including dioxin-like PCBs, and hexachlorobenzene. A similar pattern to that found in the soil samples from the landfill could be identified both in groundwater and in the stream draining the site. Elevated concentrations were also observed in lake sediments a kilometre downstream, again correlating with the soil samples. At this site, in other words, it could be established that leaching was occurring.
3.2.4 Remediation of contaminated sites currently in progress

The Swedish Parliament has adopted an environmental target stipulating that, by 2005, contaminated sites are to be identified and remediation is to have begun at a minimum of 100 of the sites given highest priority with regard to the risks to human health and the environment. In addition, remediation is to have been completed at a minimum of 50 of the sites at which such work has begun. At the request of the Government, the Environmental Protection Agency has proposed new interim targets for the period 2005–2010, with the aim of remediating the highest-priority sites within 45 years.

As of the end of 2004, the country’s county administrative boards had identified just over 41,000 contaminated sites, of which around 1,500 are in the highest risk category and have thus been given the highest priority. Where responsible operators or landowners can be identified, the supervisory authorities are seeking to enforce the necessary action, since grants are not available in such cases. Grant funding of some SEK 50 million a year is being provided for studies of individual sites. This work will also yield data on the contaminants linked to different activities, on dispersion risks, and other information. Such information can be used even in cases where grants are not available.

Around the end of 2004, county administrative boards attempted to identify the primary and secondary contaminants occurring on sites placed on their ‘Top 30’ lists. For 36 sites (6% of the total number), dioxins were given as the primary contaminant, compared with nine (1%) which were mainly contaminated with PCBs. In addition, dioxins were said to be the second most serious contaminant at 30 sites, compared with two sites in the case of PCBs. Dioxins most commonly occur at sawmill sites where timber used to be pressure treated with or dipped in timber preservatives. In this context, contamination with dioxins and arsenic or creosote may be found in the same place. When a site is remediated, all the contaminants found there are dealt with. A survey of the quantities and distribution of dioxins at a sawmill may cost SEK 1–2 million. The cost of remediation depends on the degree of contamination of the site. Rehabilitation of a pressure treatment site where CCA or creosote was used can cost SEK 10–70 million.

3.2.5 Contaminated sediments

Sediments represent important sinks for persistent compounds with low solubility in water, as such compounds often bind to particles, which sooner or later settle to the bottom. The groups of substances of interest here are considered to have very long half-lives in sediments. Sediments contaminated with dioxins, hexachlorobenzene or PCBs are primarily to be found in the vicinity of chlor-alkali plants and certain paper mills. Two major remediation projects that have been undertaken have involved the clean-up of Lake Järnsjön and Örserumsviken in the county of Kalmar. Sediment remediation projects are normally very costly. Before they are embarked on, it has to be established that they can be carried out in a way that does not in itself cause disturbance of the environment. If studies show that pollutants
are not being released from the sediments, remediation measures are not considered a priority. As in the case of contaminated land, existing knowledge is insufficient to determine precisely what significance contaminated sediments may have, now and in the future, for the large-scale dispersion of dioxins and other pollutants.

Studies of levels of unintentionally produced substances in various sediments can be of very great value in identifying and sometimes also quantifying the impacts of primary and secondary sources on a body of water.

3.2.6 Future remediation efforts

The background report from Umeå University provides a summary of current knowledge and will be used in subsequent efforts to identify, prioritize and study potential contaminated sites. New findings from studies and inventories which may be of general interest are disseminated continuously through a network linking the relevant authorities. Intensified efforts on the part of the supervisory authorities are resulting in a growing number of studies and remedial measures being undertaken in cases where a responsible owner or operator can be identified.

There are several networks today with a focus on remediation issues, both at the Nordic and EU levels and for all countries interested. Participation in the more important of these networks forms a good basis for benefiting from the results of investigations conducted by others.

3.2.7 Treated timber

As noted elsewhere in this report (in the section on sawmills under 3.1.4), there are indications that large amounts of dioxins may be present in society in construction timber which, prior to the banning of the substance, had been treated with the preservative pentachlorophenol. The extent of this problem, the potential for leaching and possible remedial action should be studied more closely.

3.2.8 Long-range transport

The significance of long-range transport for current environmental loadings is poorly understood, although there are signs that it could be very appreciable. At the same time as Sweden receives deposition originating from primary and secondary sources in its vicinity, the country also ‘exports’ some of the pollutants released from primary and secondary sources within its borders.

Very few measurements have been made over the years with the aim of quantifying the importance of long-range atmospheric transport for the concentrations in air of the substances of concern here, and for the deposition to soils, vegetation and water arising from this transport pathway. As part of the EU’s POPCYCLING-BALTIC project, the half-life of dioxins in air over the Baltic Sea was estimated at between 200 and 9,600 hours. Data on dioxin concentrations in air above the Baltic, however, are not available.
Denmark’s National Environmental Research Institute has measured atmospheric concentrations and also calculated deposition of dioxins to land areas. At the Risø station, a concentration of 4 pg WHO-TEQ/m³ was found in summer, while the winter average was ten times higher. Danish estimates of daily deposition have produced values of around 2.4 pg WHO-TEQ/m² in winter and 0.9 pg WHO-TEQ/m² in summer. Measurements made in November 2001 yielded a figure as high as 67 pg WHO-TEQ/m², which on an annual basis would mean a deposition of 24 mg WHO-TEQ/km². Total deposition in Denmark has been estimated at 35–635 g WHO-TEQ/year (Hansen & Hansen 2003). In Germany, dioxin levels of 40–120 pg I-TEQ/m³ have been recorded in urban air. In Hamburg, daily deposition fell from 10 to 2 pg I-TEQ/m² over the period 1991–99. In southern Germany, deposition was 5–10 times higher, but here too a downward trend could be observed.

Attempting to estimate Swedish deposition levels on the basis of these data is of course fraught with difficulty. There seems to be a north–south gradient in atmospheric concentrations and deposition. It is therefore likely that deposition in Sweden will not be ten times higher than the level calculated for Denmark. It could accordingly be of the order of 100–1,000 g WHO-TEQ/year, or at any rate well in excess of the total released annually from known primary sources within the country’s borders.

### 3.2.9 Assessment

Sewage treatment plants, landfills and contaminated sites are all heterogeneous secondary sources which do not lend themselves to an overall assessment; account has to be taken of the operations currently or formerly associated with them. The sampling of contaminated areas that has been carried out confirms the existence of a number of problem sites. In several locations, moreover, leaching has been shown to be occurring. An aggravating factor is that the history of earlier operations is not always known, which can result in considerable variation between samples collected within a single site, and which can also make it difficult to determine the extent of a site. However, the problem has received a good deal of attention, and extensive clean-up and other measures are planned. As yet, experience of remediation of dioxin-contaminated sites is limited. Research is still under way, and only a couple of sites have been cleaned up. The results indicate that it is more important to look at the total quantities of environmentally hazardous substances leaching from a landfill or contaminated area than the concentrations in leachates. The number of kilograms and grams that are being, or could be, leached out and released into the wider environment, i.e. the site’s significance as a secondary source, is more important than the concentrations of different pollutants within the site.

The fact that very large amounts of dioxins have entered into circulation in society in pentachlorophenol-treated timber, and that a proportion of this timber may still be in use, underscores the need to gain a better understanding of the scale of this
problem and, on that basis, to establish what measures are appropriate to reduce the further dispersion of these substances into the environment.

3.3 Summary and conclusions

This chapter has provided a survey of primary and secondary sources responsible for releases of unintentionally produced substances to the environment, with an emphasis on dioxins. The results are summarized in tables at the beginning of each section.

3.3.1 Releases to water from primary sources

Our survey shows that releases to water from primary sources can be said to be low, owing in particular to the far-reaching emission reduction measures introduced in the forest products industry. Although few measurements are available for other sources, there is no reason at present to question this assessment. Operators who release unintentionally formed substances to water, however small those emissions may be, have a responsibility to produce data showing how and to what extent the environment is affected by them.

3.3.2 Releases to water from secondary sources

As far as releases to water are concerned, the focus needs to be on secondary sources. How large their waterborne emissions are at present, in total, we are not in a position to assess, but in the long term they could result in large-scale dispersion of unintentionally produced substances. Contaminated sites and sediments already constitute significant local sources in a number of places, and some even have regional impacts. Landfills containing PCBs and dioxins are not judged to be significant sources at present. However, particularly when they contain wastes from operations involving intentional use of PCBs, they do represent a future threat, especially if they are unsuitably sited, poorly designed or inadequately managed. Given that the dioxins removed from flue gases from primary sources mostly end up in waste, a large proportion of which is landfilled, a more careful study and risk assessment of the future threat which such sources represent is important. We need a better understanding and risk assessment of the long-term significance of secondary sources for human exposure to unintentionally produced substances, and this is very much a responsibility of society as a whole.

3.3.3 Releases to air from primary sources

Primary sources used to be responsible for appreciable emissions to air of unintentionally produced substances, particularly dioxins. These emissions occurred on such a scale that they no doubt contributed significantly to the existence of an unacceptable health risk. Over the last 10–15 years, though, they have largely been reduced, and no new, previously unknown types of primary sources have emerged.

In view of this, it is the Environmental Protection Agency’s assessment that the total loading of unintentionally formed substances to air from primary sources is now so limited that it can scarcely explain why human exposure to dioxins and
dioxin-like PCBs is only marginally below the level set by the EU as the highest tolerable daily intake. The Agency takes the view that, on the basis of present data, it would not be appropriate to issue general recommendations on the measures to be adopted by the different sources to reduce the formation and release of unintentionally produced substances.

3.3.3.1 BETTER DATA
However, with an environmental loading which, overall, is too high, it is important to take a closer look at the significance of current releases for human exposure to the pollutants in question. This presupposes, for one thing, access to measurement-based data which show more reliably how large emissions of unintentionally produced substances from these sources are under varying conditions. Such data therefore need to be collected, and should in fact already have been available. The operators concerned, who have been fully aware for some time that their operations involve the formation and release of unintentionally produced substances, are required under the Environmental Code to investigate how and to what extent their activities affect the environment. This should be done regardless of the conditions set for them, and without pressure having to be applied by the authorities. The survey carried out by the Environmental Protection Agency as part of the present project has unfortunately revealed that, with few exceptions, operator self-monitoring in this respect has been inadequate. At the same time it has to be said that, even if the data had been available and had shown more clearly that the Agency’s estimates of overall emissions were in the vicinity of the ‘true’ figures, it is not known at present to what extent those emissions contribute to human exposure to the unintentionally produced substances concerned.

3.3.3.2 MEASURES TO REDUCE FORMATION AND RELEASE
Regardless of these gaps in current knowledge, it is also the case that, under the Environmental Code, the operators in question are required to use the best available techniques, if these are environmentally justified and do not entail excessive cost. Given existing loadings, the environmental justification is clear, and therefore ways of eliminating or reducing the formation of unintentionally produced substances and their release to air, water and waste should be regularly considered in conjunction with licensing and supervision of relevant activities. Attention should also be paid to the question of to what extent such substances are present in the products manufactured. The aim should be to further reduce emissions from individual plants and to ensure that there is at any rate no increase in the total environmental loading from each sector concerned. On the basis of the survey in this chapter, the Environmental Protection Agency concludes that, in the metallurgical sector especially, there is still reasonable scope to reduce releases to air, in particular of dioxins. Particularly for newly established operations, or where major changes are made to existing ones, this should, in the Agency’s opinion, be a mandatory requirement.
One factor touched on earlier is that unintentionally produced substances that are removed from flue gases largely end up in some form of waste instead, which means that flue-gas treatment does not represent a final solution to the problem. The greater the quantity of substances formed is, the more there will be in the waste. There is thus every reason, especially for the sectors with the highest levels of formation of such substances, to study more closely how their formation can be reduced, and also how their transfer to waste or the quantities ending up in waste can be minimized. Furthermore, companies generating waste containing significant amounts of unintentionally produced chemicals have a responsibility to investigate how these substances will behave in the waste, what the short- and long-term risks of releases to air or water are, and how they may ultimately affect the environment and contribute to human exposure to the substances concerned. Here, too, metallurgy is the main industry of interest, although the waste incineration sector also has a part to play. The goal should be to develop new technologies that will avoid unintentionally produced substances being formed or transferred to waste streams, and to introduce such technologies, especially at new plants or in connection with major changes to existing ones.

The Environmental Protection Agency also considers that it makes sense to look more closely at unintentionally formed substances in conjunction with the burning of biomass fuels. Although the concentrations in emissions seem low, and are well below the limits normally set for such operations when biofuels are burnt together with certain wastes, the large volumes involved and the growth of the sector mean that total emissions may rise to relatively high levels. In the Agency’s view, the environmental policy goal of greater reliance on biomass fuels should not be allowed to result in excessive releases of unintentionally formed substances to the environment. Those managing operations of this kind, which also include the combustion undertaken within the forest products industry, therefore have a responsibility to establish more clearly what loadings they give rise to, partly as a function of the choice of fuel, and how they can be reduced, and to take reasonable steps to curb emissions.

Mention should also be made in this context of small-scale burning of wood. This is dealt with in some detail in section 3.1.1 and is above all of significance when all the separate sources are added together. The fact that the contribution of each individual boiler is a very small piece in the overall picture affects the strategic approach needed to reduce the aggregate loading from wood burning in a reasonable manner. The Environmental Protection Agency has previously proposed changes to the law in this area. Its assessment is that these changes remain relevant in terms of the standards to be met, but that the legal framework for their implementation may need to be reappraised. Alongside general regulations and their enforcement, key instruments are information and guidance. Above all, it is necessary to create an awareness of the fact that what people burn, and how they go about it, makes a major difference to emissions from individual boilers and their contribution to environmental pollution. It is also important to take individual cir-
cumstances into account, so that people feel motivated to play their part in reducing pressures on the environment – in the same way as is often the case when it comes to separating waste at source. These two issues are in fact related, in that a waste separation system which individuals do not feel takes account of their circumstances can result in them burning their plastic and paper packaging, for example, in their own boiler. This is probably very much the case when it comes to ‘backyard burning’, too.

### 3.3.4 Releases to air from secondary sources

Finally, the survey in this chapter shows that, in certain cases, significant releases to air can occur from secondary sources. Secondary sources which mainly give rise to emissions to water may also have impacts on the atmosphere. Perhaps the most extreme example of this is landfill fires. That such fires can be significant sources of unintentionally formed substances is quite clear. What is difficult to assess, though, is the total loading for which they are responsible. Action has been and is being taken which is very greatly reducing the risk of landfill fires arising. The risk of fires breaking out at temporary holding facilities for combustible waste is probably greater, but the consequences of such fires are not normally as far-reaching. Evaporation of unintentionally formed substances from landfills and contaminated sites is a source that is often neglected. Once again, quantification is difficult, but this is a problem that should receive more attention than it does at present, particularly in risk assessments of contaminated sites.

A potential secondary source whose significance is difficult to estimate is timber previously treated with pentachlorophenol (PCP) and similar dioxin-contaminated compounds. The assessments made suggest that up to 30 kg of dioxins could still be present in treated wood in Swedish society, of the estimated total of 200 kg incorporated in timber before this method of treatment was outlawed. These are extremely large amounts, whose past and future effects are very unclear. So significant is the magnitude of this source that further studies should be undertaken.
4 Management of waste containing unintentionally produced substances

4.1 Legislation

Questions relating to waste are regulated in chapter 15 of the Swedish Environmental Code, on ‘Waste and producer responsibility’. That chapter sets out the legal definition of waste: ‘any object, matter or substance belonging to a specific waste category which the holder disposes of or intends or is required to dispose of’. The principal subsidiary legislation in this area is the Waste Ordinance, but other ordinances contain additional provisions on specific issues and substances. Chapter 9 of the Environmental Code and the Ordinance on Environmentally Hazardous Activities and Health Protection form the basis for licensing of environmentally hazardous undertakings, while the Landfill and Waste Incineration Ordinances regulate their respective fields. Other legislation is also of interest in relation to persistent organic pollutants: two ordinances on PCBs, one dealing with waste oil, and a Swedish ordinance and an EC Regulation on the control of shipments of waste between countries. For certain individual categories of waste, additional legislation exists. The Regulation of the European Parliament and of the Council on persistent organic pollutants (the POPs Regulation) forms the principal basis for the incorporation into Swedish law of the undertakings made by Sweden and the European Union as parties to the Stockholm Convention. A review of other Swedish legislation affected is still in progress.

4.1.1 Substances covered by the POPs Regulation

Work is currently under way in the relevant international bodies to define what wastes are covered by the rules on persistent organic pollutants. First, the substances listed in the POPs Regulation: Annex I, Part A, lists eight pesticides subject to prohibitions: aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex and toxaphene. Annex IV lists the substances that are directly subject to the waste management provisions of the Regulation. They include all the prohibited pesticides mentioned in Annex I, together with chlordecone and hexachlorocyclohexane (HCH), including lindane. Also listed there are a number of industrial chemicals and unintentionally produced POPs: PCBs, hexabromobiphenyl and dioxins. Annex III lists substances, releases of which are to be reduced in accordance with the Protocol to the Convention on Long-Range Transboundary Pollution (CLRTAP) on Persistent Organic Pollutants: dioxins, hexachlorobenzene, PCBs and PAHs.
4.1.2 Wastes covered by the POPs Regulation
The secretariats of the Stockholm and Basel Conventions are working together to
define concentration limits for persistent organic pollutants. The last meeting of the
Conference of the Parties to the Basel Convention agreed to propose limits in waste
of 15 ng/g for dioxins and 50 µg/g for PCBs and the regulated pesticides. A deci-
sion under the Stockholm Convention will be reached, at the earliest, at the first
meeting of the Conference of the Parties in Uruguay on 2–6 May 2005. Under
Article 7(5) of the Regulation, moreover, the European Commission is to establish
concentration limits for the implementation of Annex V no later than 31 December
2005.

4.1.3 Wastes in Sweden specifically affected by the rules
None of the pesticides listed in Annex I to the EC Regulation are permitted to be
used in Sweden – in some cases earlier registrations have long since been with-
drawn, while in others the products have never been registered. This means that
unused stocks of such agents may be found in conjunction with cleaning of
premises, or they may be discovered in the course of inventories of contaminated
sites, resulting in a need for appropriate measures, with the costs which they entail.
The assessment made is that the greatest risk exists in conjunction with remediation
work. To deal with leftover pesticides, and also concentrates from soil washing and
other remediation measures, treatment facilities based on best available techniques
are available at SAKAB’s incineration plant.

The basic rule in the POPs Regulation is that the substances covered by its provi-
sions are to be destroyed (Article 7(2)). This could mean that the waste from a
waste incinerator has to be incinerated a second time, which could give rise to
further releases of the hazardous substances in question, as well as involving
significant consumption of energy. This dilemma could arise with all predomin-
antly inorganic wastes containing POPs below a certain concentration. The relevant
concentration limits are to be specified by the Commission by 31 December 2005
and entered in the table in Annex IV. Another exception allows wastes of certain
types containing POPs up to a certain level, and listed in Annex V, Part 2, of the
POPs Regulation, to be dealt with in other described ways, provided that certain
conditions are met – see Article 7(4)(b) (i)–(iii). Briefly, the requirements are that
it is not feasible to decontaminate the waste, that destruction does not represent the
environmentally preferable option, and that the competent authority has authorized
the method in question. The method must be in accordance with Community legis-
lation, and the Commission and the other member states must have been informed
of the authorization and the justification for it.

The annex covers wastes arising from thermal processes in industry and from waste
incineration, together with a number of other, mainly inorganic wastes which may
be suspected to contain the regulated substances. Some of the types of waste are
described as ‘containing dangerous substances’, and there are thus corresponding
categories that are free from such substances, i.e. concentrations of them are below
a certain level. This level can, as far as hazards to health are concerned, be determined from the risk phrases of the Dangerous Preparations Directive. On the basis of the risk phrase, the concentration limit can be derived from the comments in Annex 3 to the Waste Ordinance. One consequence of this approach is that a certain waste of a type listed in Annex V may constitute a hazardous waste and yet not be covered by the POPs Regulation – in practice, not contain a concentration of dioxins exceeding the limit in Annex IV. The waste may for example contain such a concentration of hazardous heavy metals that it is classed as a hazardous waste on that account.

To enable the quantities of POP-contaminated wastes arising to be reported, considerably more detailed waste statistics are needed, broken down into waste categories defined by six-digit codes as in Annex V to the POPs Regulation. In addition, there is a need for far more data on the true concentrations of POPs in waste than are presented in official statistics or the data Umeå University has managed to gather through its data searches and questionnaires.

Regulation of existing waste incineration plants is currently based on the conditions laid down in permit decisions. Under the transitional provisions of the new Waste Incineration Ordinance, these plants are also covered by the Environmental Protection Agency’s Regulations on Incineration Plants for Household Waste. ‘New plants’ are defined in the transitional provisions, which are complex; for the purposes of this report, it is sufficient to note that the number of plants involved is small. After 28 December 2005, the Waste Incineration Ordinance will also come into effect with respect to existing plants. This Ordinance is far wider in its application than the current Agency regulations, dealing not only with household waste, but also with many commercial and industrial categories of waste. There are exceptions, however, of which, in quantitative terms, untreated wood and certain fibre sludges from the forest products industry are particularly important.

Section 12 of the Waste Incineration Ordinance regulates management of the waste arising from incineration. Operators are required to perform analyses to determine the properties of this waste, in order to assess the pollution risks associated with its recovery or disposal. This requirement is couched in fairly general terms, but may be expected to be defined more precisely in conjunction with permit applications or supervision. Such analyses could provide a better picture of levels of dioxins and other substances in the waste. There is no corresponding requirement to analyse waste from other relevant industrial plants, such as copper and aluminium smelters, solid fuel installations etc., beyond what follows from the self-monitoring requirement, any permit conditions set, and undertakings entered into in agreed monitoring programmes. Improved monitoring of flows of persistent organic pollutants will only be possible if relevant data are generated and collated.

As has been noted, existing waste statistics are not sufficiently detailed to compile quantitative data on the types of waste listed in Annex V to the POPs Regulation,
or to meet future reporting requirements. The quantity data set out in the background report from Umeå University are the most complete currently available. The existing database of environmental reports on releases does not contain data on quantities of waste in a form that can readily be processed. The Eurostat Regulation aggregates the waste categories given in the list of wastes. Unfortunately it does not do so in a way that is of use in the POPs context, and therefore it does not seem at present as if annual reporting under the Eurostat Regulation will be of any help. Nor does current reporting at three-yearly intervals under the Waste Framework Directive and the Hazardous Waste Directive include detailed figures on different waste categories, and still less on wastes grouped according to the concentrations of POPs they contain.

The Environmental Protection Agency’s Regulations on Criteria for the Acceptance of Waste at Landfills very closely reflect the European Commission’s decision on such criteria, and POPs are only dealt with in relation to inert waste. The regulations come into force in their entirety on 16 July 2005. The required characterization of wastes has already begun, since without it it will not be permissible to accept waste at landfills. For landfill disposal of inert waste, limit values have been set for the following POPs: PCBs (1 mg/kg), seven carcinogenic PAHs (10 mg/kg DM) and nine other PAHs (40 mg/kg DM). The various EC regulatory frameworks need to be coordinated, and the first steps in this direction are now being taken, with the revision of certain directives in the area of waste. When concentration limits for POPs have been established, additional persistent organic pollutants should be included within the scope of the landfill legislation.

The Waste Oil Ordinance requires anyone draining off insulating oil as waste to investigate whether PCBs are present and to handle the waste oil as PCB waste if PCBs are detected in the analysis.

The Ordinances on PCBs and the Disposal of PCBs are concerned with the handling of deliberately produced PCBs and include, among other things, a ban both on all new uses of these compounds, and on continued use of them in transformers and power capacitors.

The Council Regulation on the supervision and control of shipments of waste includes wastes containing dioxins and PCBs on its red list. This entails the tightest restrictions in this field, which is subject to very careful and detailed regulation.

As regards waste categories containing POPs which may turn out to be generated in annual quantities of thousands of tonnes, depending to some extent on whether the proposed limit values are adopted, one relevant category is fly ash from waste incinerators. For this fly ash, post-treatment may be an alternative in cases where improved design or operation of the plant is not enough to achieve a sufficient reduction of POP formation.
5 Environmental monitoring of dioxins, PCBs and hexachlorobenzene

5.1 Background, possibilities and requirements

The substances with which we are concerned here are produced unintentionally during combustion. It is reasonable to assume that they enter the environment through emissions to air, by leaching from landfills or via sewage treatment plants. On the basis of environmental monitoring data alone, however, it will not be possible to trace them to particular types of sources. If some alarming development is discovered, we need to be able to undertake more extensive studies to establish, for example, the sources responsible for the effects observed or the reasons why concentrations in the environment are rising (or not falling).

None of the environmental monitoring currently being undertaken is directly relevant to characterizing and determining the scale of emissions from different sources. If an initial detailed survey of sources is carried out and the measurements made as part of the Environmental Monitoring Programme are put into context, it is possible that they may also be of future use in determining, for example, the magnitude of sources. However, this will only be possible if and when a wide-ranging characterization of releases from different types of sources has been undertaken.

What a monitoring programme can do is track the effects of future measures in the somewhat longer term and provide a means of quality control of the progress made.

Under the Stockholm Convention, the parties are required, within their national capabilities, to monitor persistent organic pollutants with regard to their presence, levels and trends in humans and the environment. That means that monitoring programmes need to be in place which include measurements of dioxins, hexachlorobenzene and PCBs, both in humans and in the environment.

An environmental monitoring programme for dioxins, hexachlorobenzene and PCBs can never be all-encompassing, but must focus on certain critical matrices at selected strategic sites around the country. It is important to monitor

• releases into the environment,
• the extent to which long-range transport is occurring,
• the extent to which the compounds concerned are accumulating in the environment, and
• human exposure.
5.2 The existing environmental monitoring programme

5.2.1 Releases via sewage treatment plants
As part of the National Environmental Monitoring Programme, annual measurements of dioxins, PCBs and hexachlorobenzene in sewage sludge are made at seven wastewater treatment plants, scattered across the country. In addition, other sewage plants monitor a large number of chemicals at different times on their own initiative. This makes it possible to attempt at least a rough estimate of the quantities of dioxins entering the environment via such plants, and provides relatively rapid confirmation of whether measures implemented are having an effect.

5.2.2 Atmospheric transport
A monitoring programme should include some kind of estimation of atmospheric transport. The national air monitoring programme currently includes measurements of PCBs and hexachlorobenzene, which take place annually at three sites: Råö, Aspvreten and Pallas. An extension of this programme is proposed, to include annual measurements of dioxins in air and precipitation. This would provide some idea of the diffuse background loading of this group of substances, too.

Concentrations in air and deposition are partly dependent on long-range transport and thus have less information value as far as national sources are concerned. It can take much longer to detect any effect in the form of a decline in these concentrations.

5.2.3 Concentrations in sediments and biological materials
Concentrations of persistent pollutants should preferably be measured in matrices in which such substances accumulate, such as sediments and biological materials, to determine whether loadings are rising or falling. Some regular measurements of this type are already being made in the framework of the Environmental Monitoring Programme. Further sampling sites may need to be added to provide better geographical coverage.

Sediment measurements were performed at 17 stations in marine environments in 2003–4 as part of the Environmental Monitoring Programme. These are intended to be repeated at certain intervals, probably every five years. PCBs and hexachlorobenzene were among the substances covered. Dioxins were not included, but should be among the substances monitored regularly in future surveys. No corresponding survey of freshwater sediments has been undertaken, but it is suggested that an overall picture of accumulation in sediments can be obtained from measurements in marine environments only.

Levels of PCBs and hexachlorobenzene are measured annually in
• fish from Harufjärden, Holmöarna, Ängskärsklubb, Syd Landsort, Kvädöfjärden, SE Gotland, Utlängan, Fladen/Nidingen and Väderöarna;
• guillemot (Uria aalge) eggs from Stora Karlsö.
• common mussels (Mytilus edulis) from Fladen/Nidingen and Kvädöfjärden.

Dioxins are monitored every year in herring at three marine sites, off the west coast of Sweden, in the Baltic Sea and in the Bothnian Bay. During 2004 a retrospective study was undertaken at Ängskärsklubb to obtain another time series. These measurements need to continue. However, it is also important to study how they should be designed so as to provide the best possible information about both environmental loadings and human exposure to dioxins in fish. At present, only the first of these requirements is met, i.e. an estimation of loadings to the environment.

Yet another regular series of dioxin measurements is included in the Environmental Monitoring Programme, focusing on guillemot eggs from Stora Karlsö. The guillemot is a top predator which reflects the environmental situation in part of the Baltic Sea. It is important that this monitoring also continues, since it provides another type of description of the state of the environment.

Other top predators that could conceivably be monitored include seals. At present, though, recurring measurements in seals are not being proposed. However, material from the Environmental Specimen Bank at the Museum of Natural History, Stockholm, has been analysed for PCBs and hexachlorobenzene.

5.2.4 Human exposure

Another important question is to what extent human beings are exposed to persistent pollutants, and whether concentrations are rising or falling. Monitoring of levels in humans is also one of the requirements of the Stockholm Convention. The most important source of dioxins as far as the general population is concerned is fish.

Monitoring should therefore focus on concentrations in foodstuffs, and in particular in fish. The environmental measurements made consequently need to be designed in such a way as to meet this requirement as well.

It is suggested that concentrations in humans, resulting from exposure, should be measured in breast milk and in blood. Analyses of human milk are carried out as part of the Environmental Monitoring Programme, currently in the Uppsala area at two-yearly intervals. PCBs, hexachlorobenzene and dioxins are among the substances investigated.

To get an idea of to what extent the population at large is exposed to PCBs and dioxins, measurements should be made of levels in blood from individuals who eat large amounts of fish. If concentrations are low in these cases, it can be concluded
that they will not be any higher in the rest of the population. Measurements of this kind are planned roughly every three years as part of the Environmental Monitoring Programme, covering PCBs and hexachlorobenzene, among other substances. Dioxin levels in blood could also very well be determined in the framework of such studies, although they are not included at present.

### 5.2.5 Current measurements

Table 10: Summary of dioxin measurements included in the existing environmental monitoring programme.

<table>
<thead>
<tr>
<th>Measurement/matrix</th>
<th>Frequency</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrations in sludge</td>
<td>Annually at 7 sewage works</td>
<td>Data available from 2004 on</td>
</tr>
<tr>
<td>Concentrations in fish</td>
<td>Annually at 3 sites</td>
<td>Data available from about 1990 on</td>
</tr>
<tr>
<td>Concentrations in top predators (guillemot eggs)</td>
<td>Annually at 1 site</td>
<td>Data available from about 1970 on</td>
</tr>
<tr>
<td>Concentrations in human milk</td>
<td>Every 2 years at 1 location</td>
<td>Data available from 1996 on. Dioxin measurements included in programme from 2004 on</td>
</tr>
</tbody>
</table>

Table 11: Summary of measurements of PCBs and hexachlorobenzene included in the existing environmental monitoring programme.

<table>
<thead>
<tr>
<th>Measurement/matrix</th>
<th>Frequency</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-range transport</td>
<td>PCBs measured annually at 3 sites</td>
<td>Data available from about 1995 on</td>
</tr>
<tr>
<td>Concentrations in sludge</td>
<td>PCBs and hexachlorobenzene measured annually at 7 sewage works</td>
<td>Data available from 2004 on</td>
</tr>
<tr>
<td>Concentrations in fish</td>
<td>PCBs and hexachlorobenzene measured annually at 9 sites</td>
<td>Data available from about 1990 on</td>
</tr>
<tr>
<td>Concentrations in common mussels</td>
<td>PCBs and hexachlorobenzene measured annually at 2 sites</td>
<td>Data available from about 1980 on</td>
</tr>
<tr>
<td>Concentrations in top predators (guillemot eggs)</td>
<td>PCBs and hexachlorobenzene measured annually at 1 site</td>
<td>Data available from about 1970 on</td>
</tr>
<tr>
<td>Sediment survey</td>
<td>Every 5–10 years (frequency not determined): PCBs, hexachlorobenzene, dioxins</td>
<td>First undertaken in 2004</td>
</tr>
<tr>
<td>Concentrations in human milk</td>
<td>PCBs and hexachlorobenzene measured every 2 years at 1 location</td>
<td>Data available from 1996 on</td>
</tr>
</tbody>
</table>

Apart from the measurements in human milk currently being carried out in the framework of the Environmental Monitoring Programme, there are earlier time series of such data from breast milk banks, begun in 1972 (dioxins) and 1967 (PCBs).

Freshwater fish are not analysed for PCBs and hexachlorobenzene on an annual basis at present, but only at less frequent intervals. However, biological material is
collected every year from 18 lakes and placed in a specimen bank. This material
can if necessary be used to measure and perform retrospective analyses of dioxin
levels, and to continue the annual measurements of PCBs and hexachlorobenzene
in fish previously performed at certain sites.

In addition to the National Environmental Monitoring Programme, various regional
programmes are being undertaken, on varying scales. Extensive monitoring is for
example being conducted in Lakes Vättern, Vänern and Mälaren.

5.2.6 Possible measurements under other auspices
More diffuse releases and releases from minor sources such as ‘backyard burning’
are very difficult to monitor. To track diffuse loadings in urban areas, current local
authority monitoring would have to be extended to include measurements in air,
precipitation and soils, and analyses of sewage sludge would have to be performed
as a matter of routine. It will scarcely be possible to require such programmes.

Where emissions of unintentionally produced substances occur from a major plant,
the plant itself must be expected to meet the cost of measuring them. This could be
achieved by including the parameters in question as a mandatory element of the
operator’s monitoring programme. It should also be possible to include measure-
ments in soil in the vicinity of the plant. Data from operators’ monitoring pro-
grammes and environmental reports are submitted to the relevant county adminis-
trative board.

5.2.7 Proposed additions to the monitoring programme
An expanded programme of environmental monitoring would provide a better basis
for monitoring the effects of measures to achieve the goals of the Stockholm Con-
vention. The most important additions are listed in table 12.

<table>
<thead>
<tr>
<th>Proposed measurement/matrix</th>
<th>Frequency</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-range transport</td>
<td>Annually at 3 sites</td>
<td>Programme needs to be extended to include hexachlorobenzene and dioxins</td>
</tr>
<tr>
<td>(deposition)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrations in marine sediments</td>
<td>Every 5–10 years</td>
<td>Programme needs to be undertaken regularly</td>
</tr>
<tr>
<td>Concentrations in fish</td>
<td>Extend to include annual dioxin measurements at an additional site</td>
<td>Currently 3 sites. At one site a retrospective study is now being made in order to provide an additional time series on dioxins</td>
</tr>
<tr>
<td>(herring)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrations in human blood</td>
<td>Every 3 years</td>
<td>Programme needs to be extended to include dioxins</td>
</tr>
</tbody>
</table>
6 Conclusions and proposals for further action

The Environmental Protection Agency considers the most important aim for subsequent work in this area to be to obtain better data, as a basis for determining the scale of the problems and their component elements.

**Better data**
To permit more accurate quantification of the formation, release, dispersion and cycling of the groups of substances concerned, taking into account both primary and secondary sources, there is a need both to obtain better measurement-based data and to develop models that will furnish more reliable information about emissions, transport, retention, degradation etc.

Particular responsibility for ensuring that such data are produced rests with the sectors concerned. In addition, operator self-monitoring with regard to unintentionally produced substances needs to be improved across the board, and the need for measurement data should always be emphasized in conjunction with operational changes (whether or not they are subject to a permit requirement), particularly when such changes involve the use of new raw materials, (waste-derived) fuels etc.

**International action**
Ultimately, efforts to manage unintentionally produced substances cannot be confined to Swedish sources alone. The relative significance of long-range transport for the loadings that can currently be observed is probably considerable. The scale of this process should be studied more closely, to provide a basis for assessing its importance in relation to the quantities of substances now formed at and released from primary sources within Sweden’s borders. The Environmental Protection Agency should therefore pursue these issues, above all in the framework of international conventions and the EU, but also in other international contexts, e.g. in the elaboration of BAT reference documents (BREFs) under the IPPC Directive.

The inclusion of additional components in the Environmental Monitoring Programme would provide a better basis for monitoring the effects of measures introduced under the Stockholm Convention. This proposal requires an increase in the allocation made to the Environmental Protection Agency for environmental monitoring.

**National action**
On the basis of the data currently available, the Environmental Protection Agency sees no reason to issue general recommendations on the measures to be adopted by
different sectors/operators. However, the message should be that no individual plants, and no sectors overall, should increase their emissions, even in the event of increased production. Great weight should be attached to unintentionally produced substances in the context of licensing, especially licensing of the primary sources concerned.

As well as better measurement data, technical solutions to avoid the formation or reduce the release of unintentionally produced substances need to be developed and given careful consideration in conjunction with licensing, particularly in the iron and steel and non-ferrous metals sectors, but also at plants for the incineration of waste and the combustion of biomass fuels. A specific assessment of the dioxin problem should be submitted when changes are to be made which could involve a risk of increased formation of dioxins, e.g. if waste-derived fuels are to be burnt in installations other than waste incinerators, if certain scrap materials are to be used etc. Improved processes and new technologies to avoid unintentionally produced substances forming or being transferred to waste streams, together with measures to destroy such substances in ashes and residual products, should if possible be introduced or tested, particularly at new plants or when major changes are made to existing ones.

As dioxins bind to a large extent to dust particles, improved particulate control is a key factor in many cases, although combustion-related measures, such as temperature monitoring and control, are also important. A higher degree of internal recycling and increased recovery of materials in society at large could also help to reduce releases into the environment.

The fact that very large amounts of dioxins have entered into circulation in society in pentachlorophenol-treated timber, and that a proportion of this timber is probably still in use, underscores the importance of gaining a better understanding of the scale of this problem. A study of pentachlorophenol should initially focus on assessing the feasibility of identifying where in society such timber is to be found and how it could be recovered and disposed of. In addition, an assessment should be made of the consequences of refraining from taking action (the ‘zero option’).

Greater resources should be devoted to supervisory and advisory initiatives in certain areas. For example, efforts to avoid fires in landfills and on waste holding sites should continue and be stepped up. In addition, measures should be introduced to encourage the replacement of small wood-fired boilers with environmentally approved ones, as previously pointed out by the Environmental Protection Agency. The law should be changed to apply the environmental standards of the National Board of Housing, Building and Planning’s Building Regulations to replacements as well as new installations (within and outside built-up areas). In 1998 the Agency set out how this could be done in proposals for a new ordinance. The requirements proposed in that context remain relevant. The aim should be to ensure that only ‘environmentally approved’ boilers are on the market. Tax relief or other
means of reducing the financial cost to households of installing new boilers should also be considered. There is a need for further efforts to disseminate information on what should and should not be burnt in small boilers and in the open air. This information should include advice on environmentally beneficial operating techniques, but also on the consequences of inappropriate fuel choices and procedures.

We need a better understanding of the long-term risks of environmentally excessive leaching of unintentionally produced substances from landfills and contaminated sites, and of the relative significance of different exposure pathways, both now and in the future. It is particularly important to understand to what extent such substances and other POPs, present in landfills, contaminated sites or society at large, may contribute, now and in the future, to the exposure of humans and the environment. Funding for research and survey work with such a focus should be able to be made available from the Environmental Protection Agency’s environmental research allocation, and by Formas, Mistra and other funding bodies, but also from the allocation for remediation of contaminated sites. In the framework of the Agency’s environmental research allocation, a programme of future research and survey work is currently being developed with reference, inter alia, to the environmental quality objective ‘A Non-Toxic Environment’, concerning the causes of and risks associated with large-scale changes in loadings of different toxic pollutants to the environment.
# Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAT</td>
<td>Best available techniques</td>
</tr>
<tr>
<td>BREF</td>
<td>Best available techniques reference document: EU document setting out the best available techniques in a given sector</td>
</tr>
<tr>
<td>Chlorinated dibenzofurans</td>
<td>Chlorine-substituted aromatic compounds consisting of two benzene rings joined by a single carbon bond and an oxygen bridge</td>
</tr>
<tr>
<td>Chlorinated dibenzo-p-dioxins</td>
<td>Chlorine-substituted aromatic compounds consisting of two benzene rings joined by two oxygen bridges</td>
</tr>
<tr>
<td>Class A installation</td>
<td>Large-scale environmentally hazardous activity requiring a permit as provided in the annex to the Ordinance on Environmentally Hazardous Activities and Health Protection. Permit decisions are taken by an environmental court</td>
</tr>
<tr>
<td>Eadon-TEQ</td>
<td>Eadon Toxic Equivalents: weighting system to measure the relative toxic activity of different dioxins in comparison to the most toxic dioxin, TCDD</td>
</tr>
<tr>
<td>ECF</td>
<td>Elemental chlorine-free: bleaching of paper pulp that does not involve the use of chlorine gas</td>
</tr>
<tr>
<td>Formas</td>
<td>Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning</td>
</tr>
<tr>
<td>HCB</td>
<td>Hexachlorobenzene: benzene fully substituted with chlorine</td>
</tr>
<tr>
<td>Hexachlorobenzene</td>
<td>See HCB</td>
</tr>
<tr>
<td>IARC</td>
<td>International Agency for Research on Cancer: agency of the World Health Organization devoted to the prevention of cancer</td>
</tr>
<tr>
<td>IPPC</td>
<td>Integrated Pollution Prevention and Control: EC directive on the licensing of large-scale environmentally hazardous operations</td>
</tr>
<tr>
<td>I-TEQ</td>
<td>International Toxic Equivalents: weighting system to measure the relative toxic activity of different dioxins in comparison to the most toxic dioxin, TCDD</td>
</tr>
<tr>
<td><strong>LRTAP-POP</strong></td>
<td>Protocol to the Convention on Long-Range Transboundary Air Pollution on Persistent Organic Pollutants, adopted by the UN ECE (Economic Commission for Europe)</td>
</tr>
<tr>
<td><strong>Mistra</strong></td>
<td>Swedish Foundation for Strategic Environmental Research: a research organization seeking to promote sustainable development</td>
</tr>
<tr>
<td><strong>N-TEQ</strong></td>
<td>Nordic Toxic Equivalents: weighting system to measure the relative toxic activity of different dioxins in comparison to the most toxic dioxin, TCDD</td>
</tr>
<tr>
<td><strong>PCB(s)</strong></td>
<td>Polychlorinated biphenyl(s): chlorinated compound(s) consisting of two chlorine-substituted benzene rings joined by a single carbon bond; can contain between one and ten chlorine atoms</td>
</tr>
<tr>
<td><strong>PCB$_7$</strong></td>
<td>Summed quantity or concentration of seven chosen polychlorinated biphenyls</td>
</tr>
<tr>
<td><strong>PCB$_{tot}$</strong></td>
<td>Total quantity or concentration of polychlorinated biphenyls in a sample. Often measured by determining and adding certain congeners and multiplying the sum by a factor determined by the degree of chlorination of the commercial PCB mixture which the sample resembles</td>
</tr>
<tr>
<td><strong>PCDD/F</strong></td>
<td>Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, ‘dioxins’</td>
</tr>
<tr>
<td><strong>PCP</strong></td>
<td>Pentachlorophenol: chlorine-substituted phenol, a now prohibited pesticide previously used to protect timber, e.g. from sapstain fungi and wood-boring insects.</td>
</tr>
<tr>
<td><strong>POP(s)</strong></td>
<td>Persistent organic pollutant(s): stable organic compounds which are also toxic and bio-accumulate in the environment</td>
</tr>
<tr>
<td><strong>recuperator</strong></td>
<td>Heat exchanger used to heat combustion air by means of flue gases</td>
</tr>
<tr>
<td><strong>SAKAB</strong></td>
<td>Swedish company specializing in the treatment of hazardous waste</td>
</tr>
<tr>
<td><strong>Stockholm Convention</strong></td>
<td>Stockholm Convention on Persistent Organic Pollutants: global UN convention to protect the environment from persistent organic pollutants, often referred to as POPs</td>
</tr>
<tr>
<td><strong>TCDD</strong></td>
<td>2,3,7,8-tetrachlorodibenzo-p-dioxin: the ‘Seveso dioxin’</td>
</tr>
<tr>
<td>Acronym</td>
<td>Definition</td>
</tr>
<tr>
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<tr>
<td>TCF</td>
<td>Totally chlorine-free: bleaching of paper pulp not involving the use of either chlorine gas or chlorine dioxide</td>
</tr>
<tr>
<td>TDI</td>
<td>Tolerable daily intake</td>
</tr>
<tr>
<td>TEF</td>
<td>Toxic equivalency factor: the relative weight, between 1.00 and 0.0001, given to a substance that binds to the Ah receptor. Provides an overall measure of the toxic activity of dioxins and dioxin-like compounds such as certain PCBs</td>
</tr>
<tr>
<td>Total PCBs</td>
<td>See PCB&lt;sub&gt;tot&lt;/sub&gt;</td>
</tr>
<tr>
<td>UNEP Toolkit</td>
<td>Collection of emission factors etc. for dioxins, published by the United Nations Environment Programme</td>
</tr>
<tr>
<td>VOCs</td>
<td>Volatile organic compounds. Methane is often excluded: NMVOCs, non-methane volatile organic compounds</td>
</tr>
<tr>
<td>WHO-PCBs</td>
<td>World Health Organization: PCBs that are dioxin-like in their biological effects</td>
</tr>
<tr>
<td>WHO-PCB-TEQ</td>
<td>Toxic equivalents for dioxin-like PCBs</td>
</tr>
<tr>
<td>WHO-TEQ</td>
<td>WHO toxic equivalents: weighting system to measure the relative toxic activity of dioxins in comparison to the most toxic dioxin, TCDD; also applied to dioxin-like PCBs</td>
</tr>
</tbody>
</table>
References

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www.boliden.com, 22 December 2004
Survey of sources of unintentionally produced substances

A report to the Swedish Government, 31 March 2005

The Swedish Environmental Protection Agency has undertaken a survey of current sources of persistent organic pollutants, primarily dioxins, but also PCBs and hexachlorobenzene. The survey covers releases of such substances from the metallurgical, cement, forest products and chemical industries, as well as from a range of combustion processes. Most of the dioxin sources known to us in the 1980s appear to have reduced their emissions, although in many cases recent data are not available. Levels in the environment have also fallen, but this decrease is slowing down. More than 10% of Sweden’s population are still exposed to levels of dioxins in their diet which exceed the highest tolerable daily intake defined by the EU.

The Agency considers the most important aim for subsequent work in this area to be to obtain better data generally concerning the formation, release, dispersion and cycling of the groups of substances in question, so as to be better able to determine the scale of the problems.