

Contents Part II

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**A PVC substance flow analysis
for Sweden**

Part II: Mass flows and emissions by PVC
chain section

Report for:
Norsk Hydro

By:
TNO Centre for Technology and Policy Studies
and
Centre of Environmental Science Leiden

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1.3 Mass flows and emissions

1.3.1 Mass flows

Kemil report 17/94 gives a comprehensive view of the flows of chlorinated hydrocarbons in Swedish society in 1992 (Kemil, 1994). For this PVC-chain study, the Kemil report contains data for all substances traced up to the use of raw PVC. Since more recent production and market data have meanwhile been made available by Norst Hydri, we decided to use the latter. The earlier Kemil data have been used as a cross-check.

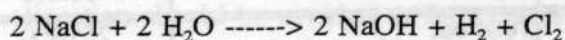
1 Production of chlorine

1.1 Introduction

In Sweden, there are three chlorine production plants. One of them is operated by Hydro Plast in Stenungsund. Virtually the whole output of this plant is used in the EDC/VCM production. Since the site is chlorine deficient, Hydro Plast uses chlorine from third parties. The two other plants in Sweden belong to the Akzo Nobel group. Until recently, the paper and pulp industry was one of the major consumers of chlorine in Sweden. The sharp decline in the use of chlorine in this market resulted in a restructuring of the chlorine production in Sweden. The number of chlorine production plants went down from five to three, and Sweden has become a net exporter of chlorine.

1.2 Production processes

Chlorine is produced by electrolysis of a salt solution. The reaction products are chlorine, caustic soda and hydrogen. The following reaction takes place:



Normally, chlorine and NaOH produced react with each other to sodium chlorate. Therefore, in the electrolysis the liquid at the anode has to be kept separated from the liquid at the cathode. Several techniques are available for this purpose. In a *mercury cell* electrolysis mercury cathodes are used which immediately dissolve the sodium metal discharged at the cathode and render it inert. The sodium amalgam is treated with water in a subsequent process to form a caustic soda solution and hydrogen. The mercury is recycled into the process. In *membrane* or *diaphragm* electrolysis the two parts of the cell are separated by a membrane or a diaphragm (usually made of asbestos). In Sweden, two production plants use mercury cells: Hydro Plast in Stenungsund and Eka Nobel in Bohus. The other (Eka Nobel in Skoghall) uses membrane electrolysis.

1.3 Mass flows and emissions

1.3.1 Mass flows

KemI report 17/94 gives a comprehensive view of the flows of chlorinated substances in Swedish society in 1992 (KemI, 1994f). For this PVC-chain study, the KemI report contains data for all substance flows up to the use of raw PVC. Since more recent production and market data have meanwhile been made available by Norsk Hydro, we decided to use the latter. The earlier KemI data have been used as a cross-check.

Besides, since the chlorine flows to production processes other than for PVC are not within the system boundaries, the exact amount to these processes is less relevant. The Norsk Hydro data have been collected for 1995. It can be assumed that the flows in 1995 will not differ too much from those of 1994, which is the base year for the rest of the study. Data for production, import, export and use of chlorine in Sweden are given in table 1.3.1. Only the chlorine flow to the EDC/VCM production is relevant for the PVC-chain and will be followed in the next sections of this report.

Table 1.3.1: Balance of elementary chlorine for Sweden in 1995 (in ton chlorine)

Inflow in section		Outflow from section	
Production	258.100	EDC-production	182.500
Import	7.800	HCl-production	26.900
		(Na-)MCA-production	21.900 ¹
		Production of FeCl ₃	2.000 ²
		Hypochlorite	2.200
		Cellulose-industry	0 ³
		Drinking water treatment	400
		Export	30.000
Total in	265.900	Total out	265.900

- 1) About 4 times higher then reported by KemI for 1992
- 2) About 2 times lower than reported by KemI for 1992
- 3) KemI reported a use of 5-8,000 tons in 1992. Possibly Norsk Hydro combined this use with the MCA production. None of these differences are important for this study, since it concentrates on the PVC-chain, and not on the other chlorine uses.

The mass balance for the production by Norsk Hydro in Stenungsund is given in table 1.3.2. It concerns data for 1995. About 114,320 ton of the chlorine produced is used in the VCM production.

Table 1.3.2 Mass balance of the chlorine production plant of Hydroplast in 1995 (in ton chlorine)

Inflow in section		Outflow from section	
Salt (as chlorine)	119,850	Chlorine	114,320
Stock mutations	-1,760	Hypochlorite	847
		HCl	1,425
		Salt losses to sea	1,000
Total in	ca.118,000	Total out	ca. 118,000

1.3.2 Emissions and resource use

Emissions have been reported by Norsk Hydro (1996b). Specifically the emissions of organochlorine micropollutants and mercury have diminished by a factor of 5 to 10 since 1992/1993. Dioxins have been detected in spent rubber and spent polyester from the Stenungsund plant (Norsk Hydro, 1996b; Allsop, 1994). A complete change to other materials has not yet been carried out, but so far the formation of HCB has been partially stopped (Norsk Hydro, 1996e).

We inventoried the emissions related to the production of chlorine within Hydro Plast, as far the chlorine is used for the production of EDC that is applied in the PVC production. Apart from this, further allocation procedures were necessary. For example, when chlorine is produced from NaCl in electrolysis not all emissions should be allocated to chlorine but a part of it should be allocated to caustic soda which is produced in the same process. Allocation of emissions is also necessary in the production of EDC/VM and PVC, described in the next chapters. This paragraph describes the basis of allocation used.

Among LCA researchers there has been a long and intensive discussion on the question which basis should be used for this allocation. There is general agreement on that allocation should be avoided as far as possible: whenever physical causalities can be used to allocate emissions this should be done. In some cases, however, physical causalities cannot be found and allocation on another basis becomes necessary. In this study a choice could be made for either physical allocation on mass base or economic allocation based on the price of the different products. One big disadvantage of physical allocation on mass base is that a rather arbitrary choice is needed to choose from the different physical units: mass, volume, etc. A disadvantage of the economic allocation is that the prices of the products will fluctuate over time.

In this study allocation was performed on an economic basis. The allocation was used for three processes:

1. the electrolysis in which NaOH, Cl_2 and H_2 are produced from brine;
2. the production of EDC/VCM from chlorine/HCl and ethene;
3. the production of p-PVC and s-PVC from VCM.

As discussed earlier, emissions were 'allocated' as far as possible to the different products via physical causality. All remaining emissions were allocated via economic allocation. As a basis for this economic allocation average market prices over the last decade were used (Table 1.3.3) together with production volumes (table 1.3.4). For chlorine the only data that could be found were for the years 1986 and 1990. For p- and s-PVC were available in a later stage but were not used since a split on mass basis seems more appropriate for these similar substances. Furthermore, since hydrogen is a minor byproduct which is mostly used internally no emissions were allocated to it.

Table 1.3.3: Market prices used for economic allocation (in DM)

Year	Chlorine spot	NaOH contract	EDC spot	EDC US spot	VCM contract
1986	216	400	438	476	978
1987		400	446	451	975
1988		478	510	547	1225
1989		506	445	467	1273
1990	116	545	218	181	943
1991		580	183	162	826
1992		600	284	262	742
1993		448	465	483	786
1994		369	438	431	949
1995		473	437	438	1189
1996		487	317	299	872
average	166	481	380	382	978

The economic allocation factors can be calculated by multiplying the marketprice with the productionvolumes of one of the outputs (to get the return for this output) and divide this by the total return of all outputs. The results of these calculation are given in table 1.3.4. Because only a part of the chlorine which is produced is used in the production of PVC a correction is necessary. The amount of chlorine needed in the production of PVC is about equal to the amount of chlorine in the produced PVC. When this amount is divided by the amount of chlorine which is produced a correction factor of 0.73 is the result. In contrast to chlorine, the amount of VCM needed is higher than the amount which is produced. Dividing the amount of chlorine in the produced VCM by the amount of chlorine in the produced PVC gives a correction factor of 1.36.

Table 1.3.4: Calculated allocation factors

	product- ion volume	market price (DM/ton)	alloca- tion factors	chlorine product- fractions ion	correction factors for amount of chlorine and VCM needed for PVC production	resulting allocation factors, corrected for amounts needed in PVC
	(ton)		(-)	(-) (ton Cl)	(-)	(-)
chlorine	114,320	166	0.23	1.00 114,320	0.73	0.17
NaOH	130,150	481	0.77			
EDC	168,796	380	0.38			
VCM	108,131	978	0.62	0.57 61,338	1.36	0.85
s-PVC	101,526	no data used	0.69	0.57 57,592		0.69
p-PVC	45,654	no data used	0.31	0.57 25,898		0.31

Table 1.3.5: Allocation in the chlorine production process. Interventions for 1995

		amount (kg)	% Cl ₂	% NaOH	Cl ₂ (kg)	NaOH (kg)	emissions from chlorine needed for PVC (73%)	remarks
air	Chlorine	0,00E+00	23	77	0,00E+00	0,00E+00	0,00E+00	
	Hg	2,20E+01	23	77	5,12E+00	1,68E+01	3,74E+00	
water	AOX	2,00E+01	23	77	4,66E+00	1,53E+01	3,41E+00	
	HCB,5CB,OCS,DCB,PCPy	2,10E-02	23	77	4,90E-03	1,61E-02	3,58E-03	
	dioxins/furans	7,00E-06	23	77	1,63E-06	5,37E-06	1,19E-06	
	chlorophenols	2,19E-01	23	77	5,11E-02	1,68E-01	3,73E-02	
	chlorobenzenes	8,00E-03	23	77	1,87E-03	6,13E-03	1,36E-03	
	hydrazine (N)	1,00E+03	23	77	2,33E+02	7,67E+02	1,70E+02	
	Hg	3,79E-01	23	77	8,84E-02	2,91E-01	6,45E-02	
	COD	2,23E+03	23	77	5,21E+02	1,71E+03	3,80E+02	
Waste	sludge	1,90E+04	23	77	4,43E+03	1,46E+04	3,24E+03	
	Hg in sludge	1,00E+00	23	77	2,33E-01	7,67E-01	1,70E-01	
	dioxins/furans in sludge	1,30E-02	23	77	3,03E-03	9,97E-03	2,21E-03	
resources	electricity (MWh)	3,86E+05	23	77	9,01E+04	2,96E+05	6,58E+04	
	oil (GJ)	2,28E+02	23	77	5,32E+01	1,75E+02	3,89E+01	
	salt	1,99E+08	23	77	4,63E+07	1,52E+08	3,38E+07	
	hydrochloric acid (30%)	2,38E+06	23	77	5,54E+05	1,82E+06	4,04E+05	
	sulphuric acid (98%)	1,62E+06	23	77	3,78E+05	1,24E+06	2,76E+05	
	CO ₂	3,31E+07	23	77	7,71E+06	2,53E+07	5,63E+06	
	nitrogen (in liter)	7,55E+07	23	77	1,76E+07	5,79E+07	1,29E+07	
	desalted water	2,31E+08	23	77	5,39E+07	1,77E+08	3,94E+07	

In table 1.3.4 the results of both the physical causality and the economic allocation are given for the chlorine production process. All emissions, waste streams, and the electricity consumption are allocated on an economic basis. One could argue that allocation on mass basis would have lead to a higher allocation of emissions to chlorine, and that this allocation favours the PVC-chain. In principle this is true. However, the most important emissions for the toxicity themes (notably dioxins) come from sources that have been allocated on the basis of physical causality totally to the PVC-chain (see next paragraph). The mercury emissions have a relative low score and even doubling or tripling the allocation factor would not result in other conclusions in part 1.

1.4 Remarks and discussion points

Chlorine production plants have been an important source of dioxins, specifically in cases when graphite electrodes were used (Svensson, 1993). Such electrodes are not used anymore in today's plants. Problems still exist with contamination of sludge, with dioxins from the water treatment, that is landfilled.

For the whole Stenungsund plant, a good insight exists into mass balances of the most important chlorinated micropollutants like dioxins chlorobenzenes and chlorphenoles. Also the total emission of individual chlorinated compounds accords reasonably with the values for sum-parameters like Absorbable Organic Halogens (AOX). Though the reported emissions of chlorinated micropollutants is rather low, sediment surveys near the Stenungsund plant show concentrations of HCB and other micropollutants. We refer to the discussion on chlorinated micropollutants in chapter 2 of part II.

Hydroplast has set itself emission reduction targets for mercury in 1997. The total mercury emission to air will have to be lowered from 22 kg in 1995 to 18 kg in 1997: a reduction of 18 %. No reduction for mercury emissions to water is foreseen, but reductions for COD and nitrogen are planned. In line with targets set in international fora like OSPARCOM and the North Sea Ministers Conference, Hydroplast has declared its intention to leave the amalgam method for the chloro-alkali production in 2010. This statement is confirmed in a letter from Hydro Plasts managing director (Norsk Hydro, 1996f). We used this zero emission for mercury as Hydro's policy target in figure 4.6.2 in the main report. In the same letter, Hydro Plast states to strive for a virtual elimination of the emission of persistent organic pollutants (POPs) by 2005. For the use in figure 4.6.2 in the main report of this project, on the basis of information of Hydro Plast staff this has been interpreted as a 90 % reduction of the emissions of dioxins to water and air compared to 1995 (Norsk Hydro, 1996e).

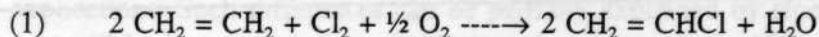
2 Production of EDC and VCM

2.1 Introduction

Hydro Plast in Stenungsund is the only producer of EDC and VCM in Sweden. The production of these two materials is very interlinked. Therefore, the production of EDC and VCM are discussed in one chapter. The main market for VCM is its captive use in the PVC production at Stenungsund. A negligible amount of VCM is used by third parties. There is no EDC used in Sweden other than for VCM production. In general there are exports of excess EDC; sometimes there are imports of VCM.

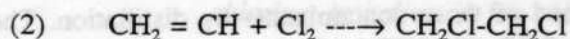
2.2 Production processes

The vinyl chloride monomer (VCM) is produced from ethylene, chlorine and oxygen in accordance with the following overall reaction (Allbright, 1976):



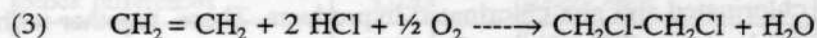
There are a number of distinct steps in this process. Figure 2.2.1 gives an illustration of a typical production plant for EDC and VCM. The intermediate product dichloroethane (EDC) plays a central role in the process. EDC is prepared by direct chlorination or oxychlorination:

- for direct chlorination, ethylene and chlorine are used:



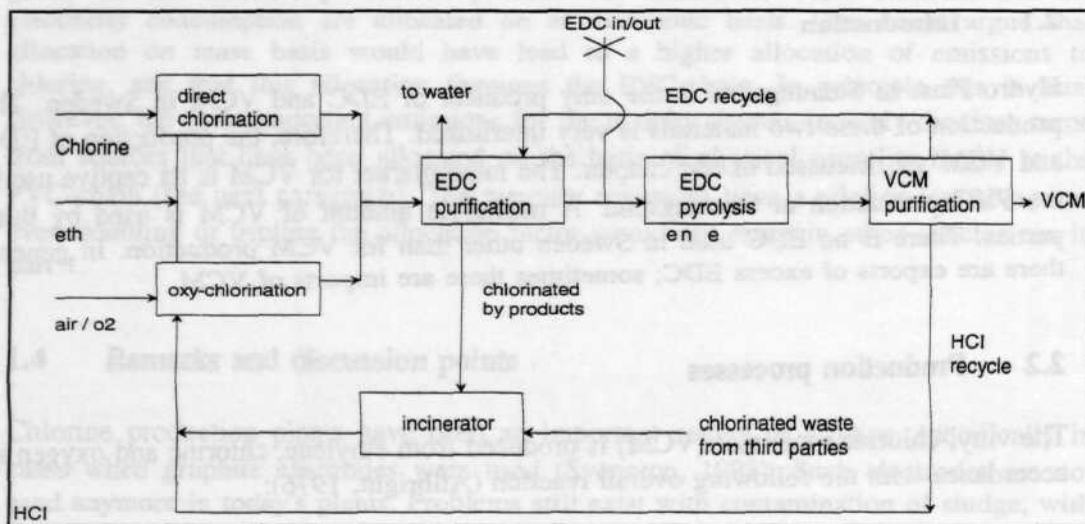
EDC acts as a solvent. The two gaseous reactants are added in practically equal measures to the solution at around 50°C. The heat of reaction is used to evaporate the EDC that is produced. Iron chloride is used as a catalyst.

- in oxychlorination, ethene, hydrogen chloride and oxygen are used.



This reaction occurs at 220-240°C and under increased pressure (4 bar). Copper chloride is used as a catalyst.

Figure 2.2.1: Diagrammatic representation of the EDC/VCM-production



The EDC that is produced is cooled and then washed with water and caustic soda to remove HCl, Cl₂ and contaminants that are soluble in water. Water is removed from the EDC by distillation.

In the above reactions, chloroethane, trichloromethane, tetrachloromethane, 1,1,2-trichloroethane and tetrachloroethane are produced as byproducts, as well as traces of chlorinated aromatics. The EDC is cleaned of these contaminants by distillation. The byproducts together account for less than 2.5% (ECOTEC 1991).

After being treated, the EDC is converted into VCM by pyrolysis at around 500°C and 10 bar.



This produces various chlorinated and non-chlorinated byproducts. These, together with non-reacted EDC, are put back into the process. The HCl that is released is in general re-used in the oxychlorination. During the process solid waste is released in the form of carbon from process filters, calcium chloride from the drying of process flows and sewage sludge.

Hydro Plast has, like some other EDC/VCM production facilities, its own incinerator for highly-chlorinated liquid and gaseous waste. Such an incinerator can convert the byproducts from the EDC production into HCl that is discharged. In order to destroy any halogenated organic compounds that are present the solid waste, like filter materials and sewage sludge, should preferably be incinerated as hazardous waste; in

Stenungsund it is landfilled. Dioxin contamination of such sludge that was landfilled, has been reported in Germany and Norway (Plinke, 1994; Allsopp, 1994). Norsk Hydro's sludge is also contaminated, still landfilled but will be incinerated in the future (Norsk Hydro, 1996b and 1996e).

2.3 Mass flows and emissions

2.3.1 Mass flows

The mass flow data have been based on Norsk Hydro data for 1995, cross-checked with data over 1992 from KemI report 17/94. We refer to section 1 for the arguments for using these data. Data for the chlorine balance of the EDC/VCM-production are given in table 2.3.1. Only the figure for VCM is relevant for the PVC-chain and will be followed in the next section of the report. The data are for 1995. The 1995 data show that there is a rather big gap between the chlorine inflow at the plant in Stenungsund and the amount of chlorine that flows out as EDC and VCM to other applications. Such differences can be partially explained by stock differences. Another part will be lost as emission of chlorinated compounds. In 1994 a part of the EDC was still sold for uses other than PVC. After pressure from environmental groups among others, all sales other than for VCM/PVC production has stopped. No waste is incinerated from third parties. So far, the HCl from the incinerator is released to sea together with sodium hypochlorite also formed in the scrubbing. Research is conducted to eliminate these flows; the goal is to terminate at least the HCl release.

Table 2.3.1 EDC/VCM production and market balance in Sweden in 1995 (in ton chlorine; in italics: in ton substance)

Inflow in section			Outflow from section		
Chlorine input from own production	114,320		VCM use 1995 (prod. plus import) ¹	83,784	<i>147,700</i>
Chlorine from third parties	74,549	<i>39,569</i>	EDC produced for export	<i>121,007.4</i>	<i>168,796</i>
VCM import	23,671	<i>41,700</i>	Ethylchloride	13.75	25
Stock differences	5,020		Heavy ends	284.75	335
			Light ends	229.77	333
			Discharges NaCl/HCl/NaOCl to sea	12,170	
Total in	217,560		Total out	217,560	

2.3.2 Emissions and resource use

Emission and resource use data for 1995 for the Hydro Plast plant in Stenungsund have been obtained from Norsk Hydro (1996b). Allocation was also necessary here. We refer to paragraph 1.3.2 for the allocation procedure. In table 2.3.2 the allocation

results are given for the EDC/VCM production. As can be seen from the remarks in the table most emissions are allocated on the basis of physical causality. The physical causality is based on information provided by Norsk Hydro. In the further calculations, chlorobenzenes and chlorophenoles have been evaluated using the (worst case) equivalency factor for hexachlorobenzene. For chloroethanol no equivalency factor was available, but it can be safely assumed that the score of chlorophenoles and -benzenes will be dominant due to their high toxicity.

2.4 Remarks and discussion points

2.4.1 Quality of the emission inventory

This paragraph discussed all the emissions from EDC/VCM production that are in general focal points of environmental concerns, including substances like dioxins, chlorobenzenes and chlorophenoles. For these substances not only have emission data been measured, but Hydro Plast in fact worked out mass balances for the whole plant. There are numerous sources that report emission data for the Hydro Plast plant and they report, within normal margins of uncertainty, data which are mutually consistent. We refer to emission data from Hydro's Environmental Survey of the Petrochemicals Division (Norsk Hydro, 1996b), additional data reported by Hydro Plast (1996e) and four studies performed by IVL (Johansson, 1994 and 1995; Fejes et al., 1994 and 1996). In fact, Hydro Plast's emission data are even in accordance with statements made by Greenpeace on the dioxin content in waste water from EDC/VCM production plants. Allsop (1994: p33) reports for a Solvay plant a discharge of 15.7 pg/l TEQ dioxins to water. Hydro Plast discharges per year 800,000 m³ waste water from the waste water treatment plant containing 0.0075 g TEQ dioxins (Norsk Hydro, 1996b and 1996e). This equals a concentration of 10 pg/l.

Greenpeace regards such data as confirmation that 'this industrial sector might be an important contributor of certain dioxin congeners' (Allsop, 1994: p32). A study of the University of Amsterdam commissioned by Greenpeace was recently published, which further analyses this aspect (Schooneboom, 1996a). The study also addresses the EDC/VCM/PVC production and we used it to cross-check our data. Relevant for this PVC-SFA was a reported dioxin contamination of EDC. A cross-check with original literature showed that a contamination of 55 ng/kg OCDF was reported by Heindl (1987). Discussion with the sponsor and the authors of that study resulted in agreement that this figure was mistakenly taken over as 55 TEQ TCDD in Schooneboom's report. A correction on this and some other errors has recently been published by the University of Amsterdam (Schooneboom, 1996b). In terms of *toxicity equivalents*, 55ng/kg OCDF means 0.055 ng/kg TEQ, which is a totally negligible amount of some mg TEQ TCDD or less in the total Swedish production of EDC (v. Zorge, 1989). Recent research reported by Carrol et al. (1996) confirmed the order of magnitude of concentrations reported by Heindl. Schooneboom (1996b) reported also contamination

Table 2.3.2: Allocation in the EDC/VCM production process. Emissions in kg. for 1995

		amount (kg)	%EDC	%VCM	allocated to EDC (kg)	allocated to VCM (kg)	remarks when allocation basis is not on the standard economic basis	amount of VCM needed for PVC (136%)
air	VCM (incl. fugitive)	14425,9	0	100	0,00E+00	1,44E+04	physical causality	1,96E+04
	EDC (Incin. stop)	10300	38	62	3,89E+03	6,41E+03		8,73E+03
	EDC (ship loading)	6300	100	0	6,30E+03	0,00E+00	physical causality	0,00E+00
	EDC (storage tanks)	0	100	0	0,00E+00	0,00E+00	physical causality	0,00E+00
	EDC (fugative)	33000	38	62	1,25E+04	2,05E+04		2,80E+04
	dioxins/furans	2,00E-04	0	100	0,00E+00	2,00E-04	physical causality	2,72E-04
	ethylchloride	3,00E+03	0	100	0,00E+00	3,00E+03	physical causality	4,08E+03
	HCl (oxy)	2,00E+02	0	100	0,00E+00	2,00E+02	physical causality	2,72E+02
	HCL (accid)	0,00E+00	0	100	0,00E+00	0,00E+00	physical causality	0,00E+00
	VCM (util.)	7,00E+02	0	100	0,00E+00	7,00E+02	physical causality	9,53E+02
	EDC (util.)	0,00E+00	0	100	0,00E+00	0,00E+00	physical causality	0,00E+00
	CFCs	42,6	25	41	1,07E+01	1,77E+01	other 33% to PVC	2,41E+01
	ethylene (incin. stop)	32600	38	62	1,23E+04	2,03E+04		2,76E+04
	CO2 (incin. +cracking)	33630000	0	100	0,00E+00	3,36E+07	physical causality	4,58E+07
	NOx (incin. +cracking)	33000	0	100	0,00E+00	3,30E+04	physical causality	4,49E+04
	solids (incin. +cracking)	2100	0	100	0,00E+00	2,10E+03	physical causality	2,86E+03
water	HCB,5CB,OCS,DCB,PCPy	4,00E-03	0	100	0,00E+00	4,00E-03	physical causality	5,44E-03
	dioxins/furans	7,00E-05	0	100	0,00E+00	7,00E-05	physical causality	9,53E-05
	NaClO	1,10E+04	0	100	0,00E+00	1,10E+04	physical causality	1,50E+04
	HCl (inc. 10%, as pure HCl)	3,57E+05	0	100	0,00E+00	3,57E+05	physical causality	4,86E+05
	HCl (accid.)	1,40E+05	0	100	0,00E+00	1,40E+05	physical causality	1,91E+05
	EDC (util. waste water; < detection limit)	9,00E+00	0	100	0,00E+00	9,00E+00	physical causality	1,23E+01
	EDC (util. daywater)	7,00E+00	38	62	2,64E+00	4,36E+00		5,93E+00
	VCM (util.; < detection limit)	1,90E+01	0	100	0,00E+00	1,90E+01	physical causality	2,59E+01
	HCB,5CB,PCPy (util.)	9,00E+01	0	100	0,00E+00	9,00E+01	physical causality	1,23E+02
	HCB (util.)	1,00E-01	0	100	0,00E+00	1,00E-01	physical causality	1,36E-01
	dioxins/furans (util.)	7,50E-06	0	100	0,00E+00	7,50E-06	physical causality	1,02E-05
	DCB (util.)	4,00E-02	0	100	0,00E+00	4,00E-02	physical causality	5,44E-02
	COD	6,70E+03	13	21	8,43E+02	1,39E+03	other 67% to PVC and Cl2	1,89E+03
	COD	1,66E+05	0	16	0,00E+00	2,66E+04	other 84% to PVC	3,62E+04
	BOD	5,80E+04	0	16	0,00E+00	9,28E+03	other 84% to PVC	1,26E+04
	N	3,11E+04	0	16	0,00E+00	4,98E+03	other 84% to PVC	6,77E+03
	P	1,99E+02	0	16	0,00E+00	3,18E+01	other 84% to PVC	4,33E+01
	AOX (util. waste wat.treat.)	4,30E+02	0	50	0,00E+00	2,15E+02	other 50% to PVC	2,93E+02
	Chloroethanol	4,73E+02	0	50	0,00E+00	2,37E+02	other 50% to PVC	3,22E+02
waste	chem sludge (util)	1,80E+05	19	31	3,40E+04	5,60E+04	other 50% to PVC	7,62E+04
	bio sludge (util.)	1,40E+05	19	31	2,64E+04	4,36E+04	other 50% to PVC	5,93E+04

of PVC with 0.86 to 8.69 ppt TEQ. This was based on a study by Swedish EPA in which two samples were taken (Allsop, 1994). Since the EDC-production by oxychlorination is in general indicated as the most suspected source of dioxins in the PVC-production, it is rather strange this reported contamination in PVC (produced from EDC) is *higher* than for EDC itself. In case the whole Swedish PVC use of about 100,000 tons (see next paragraph) were contaminated, this would represent an amount of 0.09 to 0.9 g TEQ TCDD. An extensive review by the ECVI, carried out by AEA laboratories shows that PVC is virtually free of dioxins and, taking into account the detection limits reached, certainly can not be contaminated with such levels (Wagenaar, 1996). Similar results were reported by Carrol et al. (1996); Isaksen (1996) reports similar results for PVC's precursor VCM. Wagenaar indicates it is quite difficult for laboratories to reduce background levels to sub ppt-levels, which might be an explanation of the 2 samples with higher levels. It is also suggested that high amounts of dioxins are present in unpurified waste water streams. Research of Evers (1996) shows significant amounts of TCDD in sediments and suspended particles in the Rhine and Rotterdam harbour. Akzo Nobel Botlek reported in a footnote in her annual review for 1992 an emission of 200 g TEQ TCDD before a sanitation programme. In later reports Akzo Nobel reports a dioxin emission of 6 mg TEQ per year, claiming a 99.8 % purification efficiency (Akzo Nobel, 1995). With these data it can be estimated that 3 g TEQ TCDD is present in the unpurified stream, which could also indicate the emission before the installation of the purification plant. Emissions of this order of magnitude have indeed been officially reported by the Dutch water authorities for this period (Wunderink, 1993). Most emissions reported from modern plants are 15 pg/l or less to water, in general corresponding to mass flows of less than 0.1 g/yr (a.o. Carrol, 1996; Allsop, 1994). Schooneboom further mentions the possibility that oxychlorination plants might produce up to 2.8 kg TEQ dioxins a year, which equals the amount produced in Dutch waste incinerators. This is based on dioxin concentrations reported in EDC synthesis experiments on laboratory scale (Evers, 1989)¹. These values are in contrast with mass balance studies Norsk Hydro has performed for their full-scale plants. For the plant in Rafnes and Stenungsund these mass balances show an annual production of 10 to 40 gram TEQ dioxins under practical conditions (Norsk Hydro, 1996g). An other PVC-producer states that for his plants amounts are also of this order of magnitude (EVC, 1996). A review of the Dioxin '96 conference in Amsterdam stated: "The discussion around PVC was a major subject in the 'pro' and 'con' debate. The scientific data published so far shows, using modern technology, that neither the product itself, nor the production process is a source of PCDD/PCDF. However, old technology was an argument in the debate of

¹ Based on 4.2 ng TEQ/g EDC formed in Ever's oxychlorination laboratory experiment and a Dutch production of 700,000 ton EDC (Bremmer, 1994). Schooneboom (1996b) mentions that only 1/3 of the EDC is produced by oxychlorination, but the result of 2.8 kg TEQ presented assumes that all 700,000 ton is produced this way. An estimate of about 950 grams instead of 2.8 kg TEQ should have been reported for the Dutch oxychlorination plant, leaving aside the question if Ever's concentrations are representative for operational plants.

future 'sunset' chemicals; e.g. the high PCDD/PCDF concentrations in the Rotterdam harbour are attributed to older PVC production processes" (Fiedler, 1996).

Reviewing this discussion, we feel that for the substances which are well measured by Hydro Plast, like dioxins, chlorobenzenes and chlorophenols, the mentioned reports do not give sufficient reason to question the basis of our emission inventory data. We would be surprised if it turned out that we missed significant emissions of dioxins, chlorobenzenes and chlorophenols for the Hydro Plast plant. The only potential gap might be that accidental releases (including those from flue gas incinerator stops for example) are on average higher than the accidental releases reported for 1995, which we included in the inventory. In our opinion a more important question is whether, besides these substances, other substances are emitted that show persistent, bioaccumulative and toxic properties. Table 2.3.2 shows a total AOX flow from the water purification plant of 430 kilo's. The total discharge of individual chlorinated compounds is 500-700 kg, mainly chloroethanol and chlorophenol. With 50 % or more chlorine per substance this results in 250-350 kg chlorine. Since AOX is only a very rough indication and sometimes even includes *inorganic* halogens, these values can be regarded as being in fair agreement. It is still possible that substances other than those reported are emitted, but the amounts then should be relatively low. However, experience shows that the toxicity of low amounts can not always be neglected (see: the peer review in Tukker et al., 1995b; Colborn, 1996; Johnston, 1992).

In brief, one could state there is no consensus on whether other harmful components might be emitted that have not been identified by today's measurement methods (specifically in waste water). Toxicity tests and sediment surveys give no clear cause for concern, though substances like HCB have been detected, the quantities released are measured and thus there is no uncertainty. The probability that important substances have escaped our attention thus seems low. However, existing studies can not give a 100% certainty (SFT, 1993; Tukker et al., 1995b). Further assessment of the harmfulness or otherwise of the chlorinated emissions is suggested.

2.4.2 Hydro Plast's emission targets

Hydro Plast's managing director issued a public statement on Hydro Plast's emission targets, both on short-term as on long term (Norsk Hydro, 1996f). It states to strive for a virtual elimination of the emission of persistent, bioaccumulative and toxic substances (pbt's) by 2005. For the use in figure 4.6.2 in the main report of this project, on the basis of information of Hydro Plast staff this has been interpreted as a 90 % reduction of the emissions of dioxins to water and air compared to 1995 (Norsk Hydro, 1996e). The target is a reduction of dioxin emissions to air of 90 % in 2000 and a reduction of dioxin and chlorophenol emissions to water of 90 % by 2005.

3 Production of PVC

3.1 Introduction

Hydro Plast is the sole PVC producer in Sweden. Two types of PVC are produced: paste-PVC (p-PVC) and suspension-PVC (s-PVC), making use of imported and internally produced VCM.

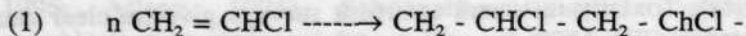
3.2 Production processes

There are three basic routes for the production of PVC from VCM, with different principles for the process of polymerisation (ECVM, 1995):

- suspension polymerisation;
- emulsion or micro-suspension polymerisation;
- mass polymerisation.

We have concentrated here on the suspension polymerisation process, which is the most commonly applied.

VCM is fed to a reactor in doses, together with a suspension stabiliser, a pH buffer, an anti-foam agent and an initiator (organic peroxides). VCM reacts to PVC as follows:



When a conversion rate of 80 to 90% is reached, the polymerisation is stopped with the aid of an inhibitor. After recovery of unconverted VCM, the suspension is filtered and temporarily stored. Residues of VCM are then stripped with open steam and transported to a gasometer. In fact, all water flows with a VCM content undergo this treatment before being pumped to a water treatment plant. Closed reactor technology has been introduced in two of Hydro Plast's PVC plants to prevent VCM emissions as much as possible.

The VCM-free suspension is processed into dry PVC powder by centrifugation and drying. The air used for this is released into the atmosphere via a bag filter. VCM is recovered from various gas flows containing VCM with the aid of a condenser. PVC is produced in batches. Before the reactor is refilled it is first rinsed with water to remove residues of PVC.

3.3 Mass flows and emissions

3.3.1 Mass flows

The mass flow data have been obtained from Norsk Hydro. A distinction is made between s-PVC and p-PVC, since these PVC types are used in different applications and also are produced in different production lines - with different emissions. Imports and exports are estimates by Norsk Hydro, based on its own market knowledge and import/export statistics. The data are given in tables 3.3.1 and 3.3.2 and are valid for 1994. In order to establish a transparent link with the segments on manufacturing of PVC products table 3.3.3 gives the Swedish application markets for raw PVC. All data have been reported by Norsk Hydro. They are reasonably in line with earlier reported market data from e.g. Norrthon (1994), KemI (1994a) and APME (1996). The specific data on paint/plastisol are data for 1992 and have been taken from Norrthon (1994). The total of this minor market segments fits in fairly well with the category 'Others' reported by Norsk Hydro. It has been assumed that the 1994 situation in these markets does not differ too much from 1992, for which Norrthon has made his estimates. The minor product group 'PVC-foam' reported by Norrthon (900 tons) is included in the Norsk Hydro statistics as part of the product categories 'flooring' and 'coated fabrics', since the material is in most cases part of these products. Since the former paragraphs gave the *production* of VCM for 1995, a correction has to be made for the *use* in 1994. The deficit/surplus can be regarded as a virtual import/export of PVC, and has been incorporated in the column 'import' in table 3.3.2.

Table 3.3.1 PVC production balance in Sweden in 1994 (in ton chlorine; in italics: in ton substance)

Inflow in section			Outflow from section (1994)		
VCM used 1995	83.784	<i>147.700</i>	Production p-PVC		<i>45.654</i>
Stock diff./other	1.073		Production s-PVC		<i>101.526</i>
Total in	84.857		Total out	84.857	<i>147.180</i>

Table 3.3.2: Market balance for PVC resin in Sweden (in ton pure PVC)

Manufacturing market	Production (1995)	Import*	Export (1994)	Domestic use (1994)
p-PVC	<i>45.654</i>	<i>19.346</i>	<i>42.400</i>	<i>22.600</i>
s-PVC	<i>101.526</i>	<i>37.974</i>	<i>60.700</i>	<i>78.800</i>
Compound		<i>5.400</i>	<i>5.300</i>	<i>100</i>
Total	<i>147.180</i>	<i>62.720</i>	<i>108.400</i>	<i>101.500</i>

* Includes correction for differences between the 1995 and 1994 production

Table 3.3.3 Raw PVC market in Sweden in 1994 (in ton substance, pure PVC)

Manufacturing market	Compound	p-PVC	s-PVC	Total
Pipes			28.800	28.800
Flooring		15.800	12.800	28.600
Cables			12.900	12.900
Profiles			10.400	10.400
Foils and films			14.400	14.400
Paint/plastisol		4.500	0	4.500
Tubes			1.300	1.300
Coated fabrics		2.300	0	2.300
Stock differences/other	100		-1.800	-1.700
Total	100	22.600	78.800	101.500

3.3.2 Emissions and resource use

Emission and resource use data for 1993 from the Hydro Plast plant in Stenungsund have been obtained from Norsk Hydro (1996b). Table 3.3.3 gives the estimated totals related to the PVC production in Sweden. For the allocation procedure used reference is made to paragraph 1.3.2. Most emissions are allocated on a economic basis but as can be seen in the remarks for a number of emissions, physical causality was provided by Norsk Hydro. CFCs were still emitted in 1995, but will be phased out in line with the Montreal protocol and the later amendments.

Norsk Hydro's emission data have been cross-checked with data from the LCA-databases from CML and TNO, and the data for Dutch chlorine plants inventoried in the Dutch chlorine chain study. No unexplainable differences were found.

3.4 Remarks and discussion points

With regard to the formation of chlorinated micro-pollutants, product contamination and the quality of the emission inventory we refer to the extensive discussion in the preceding paragraph. Some additional remarks for the PVC production are made below.

Emissions to water

After stripping the water is 'VCM free', which seems an adequate qualification in view of the high vapour pressure of VCM (3.4 bar at 20°C). There will probably be some emission into the water of the agents (organic peroxides, interfacial active substances, inhibitor, methanol, pH buffers and anti-foam agent; SPIN 1993). There are no indications that VCM emissions, other than to air, require attention from an environmental point of view (Janus, 1994).

Table 3.3.3: Allocation in the s- and p-PVC production process. Emissions in kg, for 1995

		amount (kg)	%s-PVC	%p-PVC	s-PVC (kg)	p-PVC (kg)	remarks
air	VCM (PVC drying)	5,10E+04	0,0	100,0	0,00E+00	5,10E+04	physical causality
	VCM (discontinuous)	1,90E+04	69,0	31,0	1,31E+04	5,89E+03	
	PVC-dust (< detection limit)	1,84E+04	69,0	31,0	1,27E+04	5,71E+03	detection limit taken as worst case
	CFCs	4,26E+01	16,8	16,5	7,17E+00	7,03E+00	other 67% to EDC/VCM
	VOC	6,90E+04	0,0	100,0	0,00E+00	6,90E+04	physical causality
water	PVC solid (util.)	2,50E+01	69,0	31,0	1,72E+01	7,75E+00	
	N	2,61E+04	69,0	31,0	1,80E+04	8,10E+03	
	P	1,67E+02	69,0	31,0	1,15E+02	5,19E+01	
	BOD	4,87E+04	69,0	31,0	3,36E+04	1,51E+04	
	COD	1,39E+05	69,0	31,0	9,62E+04	4,33E+04	
	AOX (util)	3,98E+02	34,5	15,5	1,37E+02	6,17E+01	other 50% to EDC/VCM
	Chloroethanol	4,73E+02	34,5	15,5	1,63E+02	7,34E+01	other 50% to EDC/VCM
	PVC	3,00E+03	69,0	31,0	2,07E+03	9,31E+02	
	chem sludge (util)	1,80E+05	34,5	15,5	6,21E+04	2,79E+04	other 50% to EDC/VCM
waste	bio sludge (util.)	1,40E+05	34,5	15,5	4,83E+04	2,17E+04	other 50% to EDC/VCM
	PVC WWT (util.)	5,00E+03	69,0	31,0	3,45E+03	1,55E+03	
	electricity (MWh)	4,26E+04	69,0	31,0	2,94E+04	1,32E+04	
Resources							

Emissions to air

The major emissions into the air are of VCM and PVC powder, mainly from diffuse sources. In the Netherlands in 1984 concentrations of VCM at 1 to 5 kilometres from production plants were already more than a factor of 10 below the Maximum Tolerable Risk level and close to the Negligible Risk level (Janus, 1994). Further reductions have been or will be realized between 1984 and 2000 (IMT, 1993). For the Dutch situation, the Dutch National Institute for Public Health and Environment therefore proposes removing VCM from the priority substance list (Janus, 1994). The production of PVC itself receives little attention in most of the literature on organic byproducts containing chlorine (Greenpeace, undated). In the extensive Dutch dioxin monitoring programme PVC production plants were not regarded as a priority for monitoring (Bremmer, 1994).

Contamination of products

Adequate stripping of the PVC suspension is necessary to minimize the concentration of VCM in the final product (Plinke, 1994). VCM which is not removed will be emitted to air during further processing and handling. After adequate stripping and drying, PVC contains less than 5 mg VCM/kg PVC, and less than 1 mg/kg for food grades and medical applications (ECVM, 1995). For the 100,000 tons of PVC used in Sweden, this means at most 0.5 tons residual VCM is present that could be released in manufacturing processes. This maximum emission is negligible compared to the emissions from the Stenungsund plant and therefore not taken further into account.

Concerning Hydro Plast emission reduction goals, the following can be remarked. It can be calculated that VCM emissions to air from PVC production in the Hydro Plast plant in Stenungsund were about 0.01 kg per ton suspension PVC and about 1.1 kg per ton emulsion (p-)PVC in 1995. In a new decision by the Franchise Board for Environmental Protection (53/96, 17 April 1996) it was stated that the emission from PVC production shall not exceed 80 ton/yr vinyl chloride and 110 ton/yr VOC (except vinyl chloride) for a production level of 180,000 ton PVC a year (FBE, 1996). The emission target for vinyl chloride from emulsion PVC production is 1.0 kg per ton PVC, from 1997, and according to measurements in 1996 this target has already been reached. Hydro Plast targets for VCM and VOC emissions to air in 1997 are 45 and 100 ton respectively.

4 Manufacturing of pipes

4.1 Introduction

The manufacture of pipes and flooring is the largest market segment for PVC in Sweden. Unlike most other PVC products, pipes are directly used as end-products. Their production and market is discussed in this segment.

4.2 Production processes

Pipe production usually takes place making use of an extrusion process. Extrusion is one of the most convenient and least expensive fabrication methods, particularly for obtaining sheet, pipes, profiles and films. The melted polymer is forced through a nozzle, the shape of which determines the shape of the object. Extrusion is also used for plasticizing the polymer before injection moulding or to develop a parison for blow moulding.

4.3 Mass balances, emissions and resource use

In 1994 about 28,800 ton of pure PVC was used in the pipe production in Sweden. In the pipe production, several additives and fillers are added to the PVC. Norsk Hydro has provided recipes for product categories, typical for the Swedish situation (Norsk Hydro, 1996a). More detailed estimates from the NPG were only available for lead, and they have been used here (NPG, 1995). The most important stabiliser is lead stearate. A typical energy use for pipe extrusion is about 3-5 MJ per kg pipe (Moller, 1995; Caesar, 1992); it is possible that the energy requirements now are even lower: 1-2 MJ/kg (PVC-Forum, 1995). Since this energy requirement is marginal compared to the energy requirement in the prior parts of the PVC-chain, we used the higher, generally accepted values here. During the manufacture of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, specifically if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He indicates that this figure can be considerably lower for non-granular additives. As an *indication* we used Eijssen's worst case emission figure for emission to air (see also TNO, 1992). During manufacturing of rigid PVC some VOC emissions are possible if the stabilisers contain solvents. However, with a typical solvent content of 10 % (TNO, 1992) and under the condition that adequate emission reduction measures are taken (with 95-99 % efficiency), VOC emissions will be about 1 ton or lower. This amount can be neglected compared to VOC emissions from e.g. the PVC production. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVM, 1995). Even with a 100 % loss these VCM emissions can be neglected

compared to those in the PVC production. For other substances no information about emissions was available, and possible emissions had to be neglected. Environmental interventions related to transport are neglected as well.

Table 4.2.1 gives a review of the emissions and resource use in the pipe production, both for 100 parts per hundred resin (phr) pure PVC and the whole Swedish production. The total estimated use of lead stabiliser fits in reasonably well with earlier estimates from KemI (1994b and 1995b).

Table 4.3.1 Emissions and resource use related to the Swedish pipe production (in ton substance)

Intervention	1 ton PVC (100 phr)	28.800 ton PVC
Material use and energy		
PVC resin	100 phr	28.800
Impact modifier (MBS)	0-6 phr	0-1.728
Processing aid	0-0.5 phr	0-144
Filler (CaCO ₃)	2-4 phr	576-1152
Stabilizer (as Pb)	0.75 phr	216
Energy	3.000-5.000 MJ	86.4-144 TJ
Emissions to air		
Pb (worst case)		(< 0,2)

4.4 Market balance

Sweden imports and exports a considerable volume of pipes. Norsk Hydro has made available data on imports and exports, partially based on its own market knowledge and partially based on data from Statistics Sweden. The data are reasonable comparable with the estimates of Norrthon (1994) for 1992. Table 4.4.1 gives the imports and exports of pipes for Sweden and the resulting domestic market. It is assumed that the imported pipes have the same composition as the pipes produced in Sweden. Virtually all pipes are used in end-use applications in the building and construction area.

Table 4.4.1: Market balance for PVC pipes in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Pipes	28.800	3.700	7.100	25.400

5 Manufacturing of flooring

5.1 Introduction

The production of flooring is the second largest market for PVC in Sweden. This market is far more important than in the rest of Europe, which reflects the important position of Sweden in the production of PVC and other flooring, like parquet. This section discusses the production of and market for PVC flooring in Sweden. The production of vinyl wall paper and roofing have been excluded from this section. They are discussed in the section on coated fabrics.

5.2 Production processes

In Sweden, two processes are used to produce PVC flooring. The first one is *calendering*, normally used for processing relatively thick films and foil (40 to 1000 μm). The foil is shaped by leading the polymer through a system of heated rollers. The thickness is determined by regulating the distance between the roller pairs. The second is *spread coating*. In this process, a glass fibre is usually applied as a substrate. Several layers, each with its own function, are applied to the glass fibre. The product is a so-called 'cushioned flooring' since it typically involves at least one foam layer.

5.3 Mass balances, emissions and resource use

In 1994 about 28,600 tons of pure PVC was used in the Swedish flooring production. In this process, several additives, plasticisers and fillers are added to the PVC. Norsk Hydro has provided recipes for product categories, typical for the Swedish situation (Norsk Hydro, 1996a). Some sources estimate the use of plasticiser in recipes given here might be somewhat lower than average (Poppe, 1996b). Because of time constraints, it was decided to work with the Norsk Hydro data in this relatively limited project and not to make a more detailed estimate of the composition of the flooring. In principle, p-PVC is used in spread coating processes and s-PVC in calendering. A typical energy use for calendering is about 6 MJ per kg PVC (Moller, 1995; Caesar, 1992). The energy use for coating is in the same order of magnitude: 8 MJ/kg (Caesar, 1992). A part of the plasticiser will be emitted. Data have been reported to Norsk Hydro by flooring producers; one producer with minor emissions is not included in these data. The breakdown given for emissions to air between calendering and spread coating is also based on these data (Norsk Hydro, 1996d). Their data accord reasonably well with the generally accepted emission factor of 0.03 % of the plasticiser use for calendering, but are a factor of 5 lower than the generally accepted emission factor of 0.25 % for coating (Sundmark, 1995c; Peijnenburg, 1991). For 1989, the reported emissions were much higher (Neste, 1991; Norsk Hydro, 1996d). The most probable explanation is that due to the abatement measures taken since 1989 the emission factor

of 0.25 % is now too high an estimate for the Swedish situation. The emissions reported by Norsk Hydro are totals for DEHP plus BBP. Estimated emission volumes of DEHP and BBP emissions have been calculated, assuming that the emission volumes are proportional to the use of the individual plasticiser.

During the manufacture of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, specifically if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He indicates that this figure may be considerably lower for non-granular additives. As an *indication* we used Eijssen's worst-case emission figure as an emission to air (see also TNO, 1992). VOC emissions for the manufacturing of products with flexible PVC are estimated at 30 g/kg PVC for a typical situation in the eighties (TNO, 1992), when in general no emission abatement measures were taken. These VOC emissions are mainly caused by solvent losses, including those present in the raw materials. In case of adequate VOC emission abatement, reductions of 95-99 % can be expected. For the current situation emission factors in the order of magnitude of 1 g/kg PVC therefore seem more adequate (Eijssen, 1993). Here we used an emission factor of 1 g VOC per kg PVC. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVI, 1995). Even with a 100 % loss these VCM emissions can be neglected compared to those in PVC production.

No process emissions to water take place. However, due to the cleaning of trucks that transport the plasticisers a worst-case emission to the sewage system of 1 kg per truck load of 20 tons (0.005 %) can be calculated (Cadogan, 1994). The actual emission might be lower due to the fact that dedicated truck systems are used: trucks that only transport phthalates, and thus need less cleaning. It is most likely that such emissions are towards a sewage system, but this was not taken into account. For other substances no information about emissions was available, and possible emissions had to be neglected.

Table 5.3.1 reviews the emissions and resource use, both for 100 parts per hundred resin pure PVC and the whole Swedish production. The total estimated plasticiser use fits in fairly well with the estimates of flooring producers and the total plasticiser use in Sweden as reported by KemI (Norsk Hydro, 1996d; KemI, 1995b). The total estimated use of Ba/Zn stabiliser corresponds reasonably well with earlier estimates from KemI (1994b and 1995b). According to KemI, about 10 tons of organotin and 35 tons of Ca/Zn are used as a stabilizer or additive for floorings. Though not reported in the recipes from Norsk Hydro, this additive use is taken into account as well.

Table 5.3.1 Emissions and resource use related to the Swedish flooring production (in ton substance)

Intervention	Calendered flooring		Coated flooring		Total market
	1 ton	Total	1 ton	Total	
Material and energy					
PVC resin	100 phr	12.800	100 phr	15.800	28.600
DEHP	30 phr	3.840	30 phr	4.740	8.580
BBP	0 phr	0	15 phr	2.370	2.370
Ba/Zn stabiliser	1.5 phr	192	2.5 phr	395	587
Ca/Zn stabiliser	0.12 phr	15.66	0.12 phr	19.33	35
Organotin	0.035 phr	4.5	0.035 phr	5.5	10
SnS stabiliser	0 phr	0	1 phr	158	158
Energy (MJ)	6.000	76.8 TJ	8.000	126 TJ	203.2 TJ
Emissions to water					
DEHP (0.005 % of use)					0.43
BBP (0.005 % of use)					0.12
Emissions to air					
Ba/Zn (worst case)		(<0.2)		(<0.4)	(<0.6)
Ca/Zn (worst case)		(<0.02)		(<0.02)	(<0.04)
Organotin (worst case)		(<0.005)		(<0.005)	(<0.01)
SnS (worst case)		0		(<0.16)	(<0.16)
VOC (0,1 % of PVC use)		12.8		15.8	28.6
DEHP		3.45		1.17	4.62
BBP		0		0.58	0.58

5.4 Market balance

Sweden imports and exports a considerable amount of flooring. Norsk Hydro has made available data on imports and exports, partially based on its own market knowledge and partially based on data from Statistics Sweden. The export estimate is somewhat higher than made by Norrthon (1994), but is in line with data from PVC Forum (1995). Apparently there has been a shift in the market. Table 5.4.1 gives the imports and exports and the resulting domestic market. It is assumed that the imported flooring has the same composition as the flooring produced in Sweden. Virtually all flooring is used in end-use applications in the building and construction area.

Table 5.4.1: Market balance for PVC flooring in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Flooring	28.600	6.300	19.900	15.000

6 Manufacturing of cables

6.1 Introduction

PVC is used as insulation for electrical cables. One of the advantages of PVC compared to other plastics is the low flammability of the material. Cables are in general used in end-use building applications. Minor markets are the automotive industry and the manufacture of electrical products, like brown and white goods.

6.2 Production processes

Cables are usually made making use of an extrusion process. Extrusion is one of the most convenient and least expensive fabrication methods. The melted polymer is forced through a nozzle, the shape of which determines the shape of the object.

6.3 Mass balances, emissions and resource use

In 1994 about 12,900 ton of pure PVC was used in the cable production in Sweden. In this production, several additives and fillers are added to the PVC. Norsk Hydro has provided recipes for product categories typical for the Swedish situation (Norsk Hydro, 1996a). Norsk Hydro used an estimate of 50 phr DIDP for 100 % of the market. Private communications with ECPI showed this might be too high, since the switch from the formerly used DEHP to DIDP is not yet complete. For this reason, it was suggested to estimate DEHP use at 33 % and DIDP use at 66 % (Cadogan, 1996). No breakdown is available for lead and Ca/Zn stabilized cable. It is assumed that the majority of the cable (70 %) is lead stabilized. Some sources give higher estimates of more than 90 %, which would lead to about 30 % more lead in use (Barfeld, 1996). However, in this level-1 project it was not possible to be more precise and a possible deviation of 30 % in the real value is seen as acceptable. With an estimated lead content of the stabilizer tri basic lead sulphate of 80 % (NPG, 1995) and a stabilizer use of 5 phr, this results in a lead use of 361 tons, which corresponds reasonably with estimates by KemI (340 tons; Kemi; 1994b).

A typical energy use for extrusion is about 3-5 MJ per kg cable (Moller, 1995; Caesar, 1992). A typical plasticiser loss to air for extrusion processes is 0.02-0.007 % (Sundmark, 1995c). The average of these values has been taken. During the manufacture of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, specifically if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He indicates this figure may be

considerably lower for non-granular additives. As an *indication* we used Eijssen's worst-case emission figure as an emission to air (see also TNO, 1992). VOC emissions for the manufacture of products with flexible PVC are estimated at 30 g/kg PVC for a typical situation in the eighties (TNO, 1992), when in general no emission abatement measures were taken. These VOC emissions are mainly caused by solvent losses, including those present in the raw materials. In case of adequate VOC emission abatement, reductions of 95-99 % can be expected. For the current situation emission factors in the order of magnitude of 1 g/kg PVC therefore seem more adequate (Eijssen, 1993). We used an emission factor of 1 g VOC per kg PVC. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVI, 1995). Even with a 100 % loss these VCM emissions can be neglected compared to those in the PVC production. For other substances no information about emissions was available and eventual emissions were neglected.

No process emissions to water take place. However, due to the cleaning of trucks that transport the plasticisers a worst-case emission to the sewage system of 1 kg per truck load of 20 tons (0,005 %) can be calculated (Cadogan, 1994). The actual emission might be lower due to the fact that dedicated truck systems are used: trucks that only transport phthalates, and thus need less cleaning. The emission is most probably to a sewage system, but as a worst-case approach this has not been taken into account.

Table 6.3.1 gives a review of the emissions and resource use both for 100 parts per hundred resin pure PVC and the whole Swedish production. KemI assumes no use of Ca/Zn stabiliser in the cable production. Since Ca/Zn is not seen as a harmful material, for the conclusions of this study the difference is not important. Due to the change from DEHP to DIDP the exact market share of each plasticiser is rather uncertain. However, the total amount of plasticiser will be fairly reliable. Also, formerly in some recipes 10 % of the plasticisers were chloroparaffins. Chloroparaffins have been phased out since early 1996, but of course can still be found in older cables that are in use in the economy.

Table 6.3.1: Market balance for PVC cables in Sweden (in ton PVC)

Production	Import	Export	Domestic use
12 900	2 000	1 000	11 900

Table 6.3.1 Emissions and resource use related to the Swedish cable production (in ton substance)

Intervention	1 ton (100 phr) PVC	For 12.900 ton PVC
Material and energy		
PVC resin	100 phr	12.900
DEHP (33 % of the market)	33 % * 50 phr	2.150
DIDP (67 % of the market)	67 % * 50 phr	4.300
Pb stabiliser (as Pb; 70 % of market)	0.8 * 5 phr	361
Ca/Zn stabiliser (30 % of market)	5 phr	193
Filler (CaCO ₃)	50 phr	6.450
Energy (MJ/ton)	3.000-5.000	38.7 - 64.5 TJ
Emissions to water		
DEHP (0.005 % of use)		0.1075
DIDP (0.005 % of use)		0.2150
Emissions to air		
Pb (worst case)		(<0,4)
Ca/Zn (worst case)		(<0,2)
VOC (0,1 % of PVC use)		12.9
DEHP (0.007-0.02% of use)		0.36 (0.15-0.43)
DIDP (0.007-0.02 % of use)		0.72(0.30-0.86)

6.4 Market balance

6.4.1 Production

Norsk Hydro has made available data on imports and exports, partially based on its own market knowledge and partially based on data from Statistics Sweden (Norsk Hydro, 1996b). The data are reasonably comparable with the earlier estimates of Norrthon (1994). Table 6.4.1 gives these data. It is assumed that the imported material has the same composition as the material produced in Sweden.

Table 6.4.1: Market balance for PVC cables in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Cables	12.900	2.000	3.000	11.900

6.4.2 Applications

According to estimates of Norsk Hydro, 92 % of the cable is directly applied in end-use applications, mainly in the building area. About 7 % is used in the production of electrical equipment. About 1 % is used in the production of cars. In Sweden, about 279,000 cars and 58,000 trucks were produced in 1994 (Eurostat, 1995). Other sources indicate that about 300 meters of cable with an average (formulated) PVC-content of 6 gram per meter are used (Poppe, 1996b). When using the recipe of table 6.3.1 this means about 3 gram per meter pure PVC, or 900 gram per car, which would mean about 300 tons in cars. The figure in table 6.4.2 for cables in cars thus might be an underestimate. The number of new licensed cars in 1994 was only 160,000 (SCB, 1996). This means the domestic use is only 58 % of the production of 279,000 cars. The net export with cars is thus 51 tons. Referring to chapter 11, we have assumed that the import of electronic applications is equal to the export.

Table 6.4.2: Market balance for PVC cables in Sweden (in ton pure PVC)

Market	Application	Import	Export	Domestic use
Cables for end use	10.950	0	0	10.950
Cables in automotive	120	0	51	69
Cables in electrical equipm.	830	p.m.	p.m.	830
Total	11.900	p.m.	p.m.	11.899

7 Manufacturing of profiles

7.1 Introduction

Profiles are another important market segment for PVC. Profiles are used in a number of applications: e.g. the building sector (including window frames and pipes for electric wire), the automotive sector and the electronics sector. The vast majority of the profiles are rigid. Flexible profiles are neglected in this study. However, this study takes into account a category 'tubes' (see section 10), which probably covers all flexible profiles.

In principle, a lot of different formulations and probably also production processes are applied, depending on the market segment. For the sake of simplicity, average emission data and average formulations are used for all profile types here.

7.2 Production processes

The dominant production process for profiles is extrusion (PVC Forum, 1995). It is one of the most convenient and least expensive fabrication methods. The melted polymer is forced through a nozzle, the shape of which determines the shape of the object.

7.3 Mass balances, emissions and resource use

In 1994 about 10,400 ton of pure PVC was used in the production of profiles in Sweden. In this production, several additives and fillers are added to the PVC. Norsk Hydro has provided recipes for product categories, typical for the Swedish situation (Norsk Hydro, 1996a). For profiles, recipes for window frames are available. No breakdown is available for lead and Ca/Zn stabilized cable. It has been assumed that 33 % is lead stabilised and 67 % is Ca/Zn stabilised. However, window profiles are only a minor share of the market. For simplicity's sake, it has been assumed that the formulation of window frames reflects the average formulation of all profiles. With an estimated lead content of the stabilizer lead stearate of 30 % (Norsk Hydro, 1996a) and a stabilizer use of 5 phr for 33 % of the market this results in a lead use of 51 tons. This estimate itself has a rather high uncertainty, maybe up to a factor of 4 or 5. This is due to the lack of 'hard' data about the market volume and the Pb content. However, the uncertainty is probably not so great, since the estimate is well in line with earlier estimates by KemI over 1992 (40 tons; KemI; 1994b). However, it must be noted that a swift transfer from lead to Ca/Zn-stabiliser is currently taking place. In 1996, more than 80 % of the profiles will be Ca/Zn-stabilised.

A typical energy use extrusion is about 3-5 MJ per kg PVC (Moller, 1995; Caesar,

1992). Plasticiser use in this segment is regarded as negligible. During the manufacturing of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, especially if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He indicates this figure may be considerably lower for non-granular additives. As an *indication* we used Eijssen's worst case emission figure as an emission to air (see also TNO, 1992). In the manufacture of rigid PVC some VOC emissions are possible if the stabilisers contain solvents. However, with a typical solvent content of 10 % (TNO, 1992) and under the condition that adequate emission reduction measures are taken (with 95-99 % efficiency), VOC emissions will be about 1 ton or lower. This amount can be neglected compared to VOC emissions from e.g. the PVC production. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVN, 1995). Even with a 100 % loss these VCM emissions are negligible compared to those in the PVC production. For other substances no information about emissions was available, and any emissions had to be neglected.

Table 7.3.1 gives a review of the emissions and resource use both for 100 parts per hundred resin pure PVC and the whole Swedish production. KemI assumes no use of Ca/Zn stabiliser in the production of profiles. Since Ca/Zn is not seen as a harmful material, for the conclusions of this study the difference is not important.

Table 7.3.1 Emissions and resource use for 100 parts per hundred resin pure PVC and the whole Swedish production. KemI assumes no use of Ca/Zn stabiliser in the production of profiles. Since Ca/Zn is not seen as a harmful material, for the conclusions of this study the difference is not important.			
Resource	100 parts per hundred resin pure PVC	Whole Swedish production	Unit
Electricity	2.300	2.300	kWh
Gas	0.000	0.000	m ³
Water	0.000	0.000	m ³
CO ₂	0.000	0.000	ton
VOC	0.000	0.000	ton
Heavy metals	0.000	0.000	ton
Stabiliser	0.000	0.000	ton
Pigment	0.000	0.000	ton
Plasticiser	0.000	0.000	ton
Other additives	0.000	0.000	ton
Total	2.300	2.300	kWh

Table 7.3.1 Emissions and resource use related to the Swedish profile production (in ton substance)

Intervention	Pb stabilised		Ca/Zn stabilised		Total market
	1 ton	Total	1 ton	Total	
Material and energy					
PVC resin	100 phr	3432	100 phr	6.968	10.400
Pb stabiliser (as Pb)	1.5 phr	51	0 phr	0	51
Ca/Zn stabiliser	0 phr	0	4.5 phr	313	313
Impact modifier (MBS)	7 phr	240	8 phr	557	797
Prod. modifier	1.5 phr	51	0.7 phr	49	100
Filler and pigment (CaCO ₃ and TiO ₂)	10 phr	343	8 phr	557	900
Lubricant	0 phr	0	0.3 phr	21	15.6
Energy (MJ)	3-5.000	10-17 TJ	3-5.000	21-25 TJ	31-42 TJ
Emissions to water					
Emissions	negl.	negl.	negl.	negl.	negl.
Emissions to air					
Pb (worst case)		(<0.05)		0	(<0.05)
Ca/Zn (worst case)		0		(<0.3)	(<0.3)

7.4 Market balance

7.4.1 Production

Norsk Hydro has made available data on imports and exports, partially based on its own market knowledge and partially based on data from Statistics Sweden. Import and export data are lower than reported for 1992 by Norrthon (1994), but the production and domestic use are in reasonable agreement. Table 7.4.2 gives these data. It is assumed that the imported material has the same composition as the material produced in Sweden. However, there is no absolute guarantee of that since, for instance, cadmium-stabilised window frames or profiles are imported from other countries.

Table 7.4.2: Market balance for PVC profiles in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Profiles	10.400	900	500	10.800

7.4.2 Applications

No comprehensive insight exists into the application areas of profiles. Estimates have been made making use of various sources. Data on the production, imports and exports of window profiles are taken from estimates given by Norrthon (1994). PVC Forum (1995) has made estimates for profiles used for electrical wire. Since no good estimates for imports and exports are available it is assumed that the domestic use of these profiles is equal to the production. PVC Forum gives also a total of 3,800 ton PVC used in the building area, profiles used in manufacturing and the automotive sector. Norsk Hydro assumes that virtually no profiles are used in the Swedish automotive industry. Assuming that these 3,800 tons includes the 1,500 tons for window profiles given by Norrthon, this would leave 2,300 ton for the manufacturing sector.

For the other 4,600 tons no direct market estimates are available. Norrton (1994) indicates that cables and profiles are the main PVC applications for electronic products. According to SNV (1996), in Sweden 550,000 tons of electronic products are sold annually. Such products contain 15 - 30 % plastics, of which 4 % is PVC. This would mean 3,300 - 6,600 tons of PVC is used in electronic products in the Swedish economy each year. At this stage of the project, no data are available for the production of electronic equipment (white/brown goods) in Sweden. If the import equals the export, the use of PVC in the electronics industry would also be 3,300 - 6,600 tons. Since cables only account for 920 tons in this market, a use of at least a few thousand tons of PVC profiles could be a reasonable estimate. Apart from this, it can be assumed that window profiles will not be the only use of profiles in the building area. It is therefore estimated that of the remaining 4,600 tons PVC, about 2,300 tons is used in long-life building applications and 2,300 tons is used in the electronics industry. Table 7.4.3 gives a review of these estimates.

Table 7.4.3: Market balance for PVC profiles in Sweden (in ton pure PVC)

Market	Application	Import	Export	Domestic use
Window frames	1.500	500-1.000*	0	2.000
Profiles for electrical wire	2.400	p.m.	p.m.	2.400
Other building applications	2.300	p.m.	p.m.	2.300
Subtotal building applic.	6.200	500-1.000	p.m.	6.700
Manufacturing	2.300	p.m.	p.m.	2.300
Electrical equipment	2.300	p.m.	p.m.	2.300
Total	10.800			11.300

* The value of 500 ton has been used in the calculation

8 Manufacturing of foils, films and sheets

8.1 Introduction

Foils, films and sheets form about 14 % of the Swedish PVC market. About 60 % of the market is rigid sheet, which is among other things used for packaging in general and packaging for medical articles. Flexible films are used for all kind of purposes: furniture and leisure articles, office articles, coatings of building plate, roof covering etc. The automotive industry is also an important user of foils. Due to this very diverse range of uses, compared to the other PVC segments it is difficult to make good estimates of end-use applications. The boundary between the market segments 'flexible foil' and 'coated fabrics' (see section 10) is somewhat vague. Some reports include under 'flexible foil' PVC-applications like tarpaulins, wall paper and artificial leather. In this report these applications are included under 'coated fabrics'.

In principle, a lot of different formulations and probably also production processes are applied, depending on the market segment. For the sake of simplicity average emission data and average formulations are used here for rigid and flexible foil types.

8.2 Production processes

Calendering is the dominant production process for films and sheets (Sundmark, 1995c; Moller, 1995). The foil is shaped by leading the polymer through a system of heated rollers. The thickness is determined by regulating the distance between the roller pairs. Another process for the processing of e.g. bags is film blowing (Moller, 1995). In this process, an extruder with a ring-shaped nozzle is used. By blowing air through a nozzle the object takes the form of a large bubble which is cooled by an airstream, squeezed and rolled without contact between the two sides of the film.

8.3 Mass balances, emissions and resource use

In 1994 about 14,400 ton of pure PVC was used in the production of films and sheet. The market for rigid films is estimated at 60 % (8,640 tons) and for flexible films at 40 % (5,760 tons; Norsk Hydro, 1996c; Norrthon, 1994)). A typical energy use for calendering is 6 MJ/kg PVC (Caesar, 1992). In this production, several additives and fillers are added to the PVC. Norsk Hydro has provided recipes for product categories, typical for the Swedish situation (Norsk Hydro, 1996a). According to KemI (1994b) the bulk, 175 tons, of the organotin stabilisers used in Sweden are applied for (mainly rigid) PVC film. This was confirmed by personal communication with Norsk Hydro. It was therefore assumed that all rigid sheets are stabilised with organotin instead of Ba/Zn. The plasticiser content of flexible foil is about 25 phr.

About 0.2-0.5 % of the plasticiser used is emitted to air during calendering of foil (Sundmark, 1995c; Peijnenburg, 1991, Cadogan, 1994). The resulting emission of 2.8-7 tons fits reasonably well with estimates of the Industriforbundet in their reaction to the report of the Ecocycle commission (Industriforbundet, 1994). The value also fits fairly well with an emission inventory for calendering processes for 1995, made by Neste Oxo (1996). In the calculations an average value of 5 tons has been used. Emissions to water are negligible (Peijnenburg, 1991). However, due to the cleaning of trucks that transport the plasticisers a worst-case emission to the sewage system of 1 kg per truck load of 20 tons (0.005 %) can be calculated (Cadogan, 1994). Since in Sweden some of the suppliers of plasticisers use a dedicated truck system this might be an overestimation.

During the manufacture of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, especially if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He indicates this figure may be considerably lower for non-granular additives. As an *indication* we used Eijssen's worst-case emission figure as an emission to air (see also TNO, 1992). VOC emissions for the manufacturing of products with flexible PVC are estimated at 30 g/kg PVC for a typical situation in the eighties (TNO, 1992), when in general no emission abatement measures were taken. These VOC emissions are mainly caused by solvent losses, including those present in the raw materials. In case of adequate VOC emission abatement, reductions of 95-99 % can be expected. For the current situation emission factors in the order of magnitude of 1 g/kg PVC therefore seem more adequate (Eijssen, 1993). Here we used an emission factor of 1 g VOC per kg PVC. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVM, 1995). Even with a 100 % loss these VCM emissions can be neglected compared to those in the PVC production. For other substances no information about emissions was available, and possible emissions had to be neglected.

Table 8.3.1 gives a review of the emissions and resource use both for 100 parts per hundred resin pure PVC and the whole Swedish production.

Table 8.3.1 Emissions and resource use related to the Swedish foil and sheet production (in ton substance)

Intervention	Rigid foil		Semi-flexible foil		Total market
	1 ton	Total	1 ton	Total	
Material and energy					
PVC resin	100 phr	8.640	100 phr	5.760	10.400
DEHP	0 phr	0	25 phr	1440	1440 ^a
Ba/Zn stabiliser	0 phr	0	1.5 phr	86	86
Organotin stabiliser	2.1 phr	175	0 phr	0	175
ESO	0 phr	0	3 phr	173	173
Impact modifier (MBS)	6 phr	518	0 phr	0	518
Product modif. (PMMA)	1 phr	86	0 phr	0	86
Wax, pigment	1 phr	86	1 phr	58	104
Energy (MJ)	6.000		6.000		
Emissions to water					
DEHP (0.005 % of use)	0	0		0.07	0.07
Emissions to air					
Ba/Zn (worst case)		0		(<0.086)	(<0.086)
Organotin (worst case)		(<0.175)		0	(<0.175)
VOC (0.1 % of fl. PVC use)		0		5.8	5.8
DEHP (0.2-0.5% of use)	0	0		5	5

a: Sometimes in this market segment tarpaulins, wall paper and artificial leather are also included. In that case the plasticiser use would have been higher. In this report, these product groups are included under 'coated fabrics' (see chapter 10).

The estimated use of Ba/Zn is higher and the estimated use of Ca/Zn is lower than earlier KemI estimates (1994b). The KemI report gives no comprehensive insight as to the basis of which assumptions the Ba/Zn and Ca/Zn uses were calculated. Therefore it is impossible to properly explain the differences. Since Ba/Zn and Ca/Zn are not seen as a harmful material, for the conclusions of this study the difference is not important.

8.4 Market balance

8.4.1 Production

Norsk Hydro has made available data on imports and exports, partially based on its own market knowledge and partially based on data from Statistics Sweden. The import and export rates are very high compared to the domestic production and the earlier data given by Norrthon (1994). It is possible that the conversion factor to calculate the total amount pure PVC from the import/export statistics (which reflect PVC product) is somewhat overestimated. On the other hand, Norsk Hydro's estimates are fairly well in accordance with estimates of PVC Forum (1995). No breakdown is available for the

import and export of rigid and flexible foil. It is therefore assumed that the breakdown is equal to the breakdown for the production (60 % rigid, 40 % flexible).

Table 8.4.1: Market balance for PVC foil in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Rigid foil	8.640	9.840	8.400	10.080
Flexible foil	5.760	6.560	5.600	6.720
Total foil	14.400	16.400	14.000	16.800

8.4.2 Applications

No comprehensive insight exists into the application areas of foils. Estimates have been made making use of various sources. Data on the production, imports and exports of packaging and medical packaging have been taken from estimates given by Norrthon (1994) and have been allocated to rigid applications. According to Norrthon, foils and coated fabrics are the main intermediate products for applications in offices, like tape, maps etc. Here his total estimate for the production of such articles is allocated to foil. PVC Forum (1995) estimates the total production of building plate coated with PVC at 115 kton, making use of 3,800 ton PVC. About 11 % of this amount is coated with foil, resulting in the use of 400 ton PVC. The remainder is treated with plastisol and is discussed in section 8. About 80 % of this material is exported, the domestic use is 20 % and there are no imports. According to Norrthon (1994), no production of roof covering takes place in Sweden. According to Norsk Hydro, the net imports are about 1,500 tons PVC. There are also imports of about 1,000 tons of flexible PVC for food-packaging in grocery stores (KemI, 1996). In Sweden, there is no production of flexible PVC for this purpose.

For the other 9,400 ton foil no clear indication of the application market can be given. It can be expected that a part of it will be used in the automotive industry and the electronics industry. In section 6, the total PVC consumption in the automotive industry was estimated at 6,000 tons including additives and plasticisers, of which 120 tons are covered by cables and 2,000 tons by artificial leather. A use of several thousands of tons of foil seems not unreasonable; here an assumption of 2,000 tons is used, totally allocated as flexible film. In chapter 6 it was indicated that the Swedish sales of new cars was about 58 % of the national production in 1994. With this value, the net export was calculated. The remaining application of 7,400 tons is allocated to a product group 'other rigid' or 'other flexible', for which net imports are assumed to be zero. According to PVC Forum, 80 % of the foil has a life-time of 10 years or more. Since the packaging shown in table 8.4.2 accounts for about 30 %, it is assumed that this product group miscellaneous is used in medium-life applications. Table 8.4.2

reviews these estimates.

Table 8.4.2: Market balance for PVC foils in Sweden (in ton pure PVC)

Market	Application	Import	Export	Domestic use
Rigid				
Packaging	4.500	1-1.500*	4.000	1.500
Medical packaging	1.000		500-900**	300
Other rigid	4.580	p.m.	p.m.	4.580
Subtotal rigid	10.080	1.000	4.700	6.380
Flexible				
Automotive	2.000	p.m.	853	1.147
Office equipment	1.500	0	0	1.500
Coated building plate	400		320	80
Roof covering	0	1.500	0	1.500
Grocery packaging	0	1.000	0	1.000
Other flexible	2.820	p.m.	p.m.	2.820
Subtotal flexible	6.720	2.500	1.173	8.047
Total	16.800	3.500	5.873	13.927

* Calculated with 1.000 tons

** Calculated with an average of 700 tons

9 Manufacturing of paint and plastisol applications

9.1 Introduction

A minor PVC application in Sweden is the production of paint/plastisol. This paint is mainly applied in the production of coated building plate in Sweden. This section covers both the paint production and the application of building plate.

9.2 Production processes

No clear data on the plastisol production are available. Normally, paint production involves mixing and blending the ingredients of the paint. Environmental interventions most probably will be related to the energy use for mixing, the use of raw materials, and some VOC emissions.

9.3 Emissions and resource use

The plastisol recipes have been taken from PVC Forum (1995). KemI (1994b) reports the use of Ba/Zn and organotin stabilisers for these applications. Industriforbundet (1994) reports a use of 5,700 ton material a year consisting of 3,500 ton PVC and 1,425 tons plasticiser (25 %) for coil coating only. This means an amount of plasticiser of about 40 phr. Here we used exactly 40 phr for the sake of simplicity. Norsk Hydro estimates that outside the building market about 1,000 tons are used in other applications. This means a total plastisol market of 4,500 tons. Extrapolating, this would mean a plasticiser use of 1,800 tons. It is assumed that emissions to air during the production of plastisol are negligible. This assumption is reasonable if adequate vent treatment takes place. The assumption is confirmed by a recent inventory on plasticiser emissions made by Neste Oxo (1996). We therefore also assumed close to zero VOC emissions. Some losses of stabilisers and pigments might occur, but it seems inappropriate to apply the worst-case emission factor of 0.1 % used in the preceding paragraphs for this specialised industry, particularly in working with pigments. Due to the cleaning of trucks that transport the plasticisers a worst-case emission to the sewage system of 1 kg per truck load of 20 tons (0,005 %) can be calculated (Cadogan, 1994). The actual emission might be lower due to the fact that dedicated truck systems are used: trucks that only transport phthalates, and thus need less cleaning. Table 9.3.1 reviews these data.

Table 9.3.1 Emissions and resource use related to the production of plastisol (in ton substance)

Intervention	per hundred resin PVC	For 4.500 ton PVC
Material and energy		
PVC resin	100 phr	4.500
DEHP	40 phr	1.800
Organotin stabiliser	phr	50
Ca/Zn stabiliser	phr	70
Pigments	ca. 1-50 phr	45-4.500
Antimonytrioxide	ca. 5-10 phr	225-450
Energy (MJ)	p.m.	p.m.
Emissions to water		
DEHP (0.005 % of use)		0.09
Emissions to air		
Pigments, stabilisers		neglected
VOC (0%)		0
DEHP (0 % of use)		0

9.4 Market balance

Table 9.4.1 gives a market balance for plastisol for 1994, based on production data from the previous paragraph and import/export data for 1992 from Norrthon (1994). It is assumed that the 1994 data will be similar. He estimated that a majority of about 3,000 ton plastisol is used domestically for the covering of building plate. Industriforbundet (1994) mentions a domestic use of 3,500 tons in 1992, and PVC Forum (1995) mentions a domestic use of 3,800 tons for building plate, including foil covered plate which has 11 % of the market. A use of 3,000 tons of plastisol for building plate seems a reasonable estimate; this leaves about 1,000 tons for other applications.

Table 9.4.1: Market balance for PVC plastisol in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Plastisol	4.500	500	1.000	4.000

9.5 Applications of paint and plastisol

9.5.1 Production processes, emissions and resource use

Coating is a process whereby liquid PVC (like plastisol or organosol) is sprayed, dipped or painted onto an other material. In the coating process, the processing temperature is 150-200 °C. This results in a relatively high loss to air of phthalates, up to 0.25-1 % of the plasticiser consumption (Sundmark, 1995c). However, if adequate emission abatement measures are taken this figure seems an overestimation and, depending on the measure, could even be close to zero (Cadogan, 1994; Peijnenburg, 1991). The recent investigation by Neste Oxo into the industrial phthalate emissions showed that the emissions from paint and plastisol indeed were about zero (Neste Oxo, 1996). Therefore, a zero emission value has been used. We assumed that these effective emission abatement measures also resulted in a close to zero emission of VOC. The energy use in this process is not directly available from literature. A general energy use of 5 to 10 MJ/kg, which is the range for most PVC processing, is used.

Table 9.5.1: Emissions and resource use related to the production of coated building plate and other applications (in ton substance)

Intervention	1 ton (100 phr) PVC	For 4.000 ton PVC
Material and energy		
PVC plastisol ^a	100	4.000
Energy (MJ)	5.000-10.000	20-40 TJ
Emissions to water		
p.m.	p.m.	p.m.
Emissions to air		
VOC (0 %)	0	0
DEHP (0%)	0	0

a: Includes 25 phr DEHP; in total 4000 tons PVC and 1600 ton DEHP are used

9.5.2 Market balance

PVC Forum (1995) estimates that 50 % of the production of building plate is exported and that 25 % of the production is imported, resulting in a domestic use of PVC coated building plate of about 2250 ton. For the other applications no data are available; it is assumed that the production is equal to the domestic use.

Table 9.5.2: Market balance for plastisol applications in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Plastisol-covered building plate	3.000	750	1.500	2.250
Other applications	1.000	p.m.	p.m.	1.000

10 Other applications

10.1 Introduction

There are two other product groups in which the remaining amount of PVC is used. Those markets account for about 4 % of the PVC used in Sweden and are:

- the production of tubes;
- the production of coated fabrics.

The production processes and markets are discussed in this section.

10.2 Tubes

10.2.1 Introduction

Norrthon (1994) describes in his material flow study on PVC a category 'tubes'. Such pipes include flexible hoses, flexible pipe for compressed air etc. It is possible that these pipes are partially covered by the category 'Profiles'.

10.2.2 Production

The dominating production process is extrusion. For a description of the process, see the preceding paragraphs.

10.2.3 Emissions and resource use

According to Norsk Hydro, the amount of PVC used for the production of flexible pipes is about 1,300 tons. This fits in reasonably well with data for 1992 from Norrthon (1994). About 600 tons were used for the production of medical applications. No specific recipe is available. We assumed that the recipe for cables is a reasonable approximation. It is known that for medical applications DEHP is the dominant plasticiser. In contrast to cables, we have assumed that other tubes are plasticised with DEHP as well. This will possibly give an underestimation for the use of DIDP, which is an alternative. The energy use for extrusion is about 3-5 MJ/kg PVC. The only relevant emissions to air will be most likely from phthalates: for extrusion this is normally 0.02 % - 0.007 % of the use (Sundmark, 1995c). We used the average to calculate the emission. Due to the cleaning of trucks that transport the plasticisers a worst-case emission to the sewage system of 1 kg per truck load of 20 tons (0.005 %) can be calculated (Cadogan, 1994). The actual emission might be lower due to the fact that dedicated truck systems are used: trucks that only transport phthalates, and thus need

less cleaning. During the manufacture of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, especially if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He indicates this figure may be considerably lower for non-granular additives. As an *indication* we used Eijssen's worst-case emission figure as an emission to air (see also TNO, 1992). VOC emissions for the manufacture of products with flexible PVC are estimated at 30 g/kg PVC for a typical situation in the eighties (TNO, 1992), when in general no emission abatement measures were taken. These VOC emissions are mainly caused by solvent losses, including those present in the raw materials. In case of adequate VOC emission abatement, reductions of 95-99 % can be expected. For the current situation emission factors in the order of magnitude of 1 g/kg PVC therefore seem more adequate (Eijssen, 1993). Here we used an emission factor of 1 g VOC per kg PVC. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVN, 1995). Even with a 100 % loss these VCM emissions are negligible compared to those in the PVC production. For other substances no information about emissions was available, and eventual emissions had to be neglected.

On the basis of these assumptions, table 10.2.1 gives a review of emissions and resource uses related to the production of flexible profiles/tubes.

Table 10.2.1 Emissions and resource use related to the Swedish production of flexible profiles/tubes (in ton substance)

Intervention	per hundred resin PVC	For 1.300 ton PVC
Material and energy		
PVC resin	100 phr	1.300
DEHP (46 % of the market)	50 phr	650
Pb stabiliser (as Pb; 70 % of market)	0.8 *5 phr	36.4
Ca/Zn stabiliser (30 % of market)	5 phr	19.5
Filler (CaCO ₃)	50 phr	650
Energy (MJ)	3.000-5.000	3.9-6.5 TJ
Emissions to water		
DEHP (0.005 % of use)		0.032
Emissions to air		
Pb (worst case)		(<0.04)
Ca/Zn (worst case)		(<0.02)
VOC (0.1% of PVC use)		1.3
DEHP (0.007-0.02 % of use)		0.09 (0.05-0.13)

10.2.4 Market balance

Norrthon (1994) has given estimates of the amount of tubes used on the Swedish market (2,000 tons). This seems somewhat high compared to estimates for 1994 from Norsk Hydro. Here the Norsk Hydro production data are combined with the Norrthon import and export data. The resulting domestic use is given in table 10.2.2.

Table 10.2.2: Market balance for PVC tubes/hoses in Sweden (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Tubes/hoses	1.300	500	0	1.800

Medical applications with a market volume of about 600 tons are the most important application (Norsk Hydro, 1996c), which is in accordance with the Norrthon data if the use of medical articles is equal to the Swedish production. It is assumed that medical products have a life-time of 1 to 2 years. No breakdown is given for other applications, but it can be assumed that such articles are mainly medium to long life applications. The applications are given in table 10.2.3.

Table 10.2.3: Market balance for PVC tubes (in ton pure PVC)

Market	Application	Import	Export	Domestic use
Medical applications	600	p.m.	p.m.	600
Other applications	1.200	p.m.	p.m.	1.200
Total	1.800	p.m.	p.m.	1.800

10.3 Coated fabrics

10.3.1 Introduction

About 2,300 tons of PVC a year are used for the production of coated fabrics. These textiles include artificial leather (a.o. for cars), rain coats and 1,500 tons of camouflage fabrics (defence products). For a lot of other uses Sweden imports coated fabrics.

10.3.2 Production

Coating is - not surprisingly - the dominant process for the production of coated fabrics. All coated fabrics are produced with paste-PVC. A typical energy use for such a process is 8 MJ/kg PVC (Caesar, 1992), including the energy necessary for incinerating volatile substances. PVC Forum mentions an electrical energy use of 668 kWh/ton (2,5 MJ/kg) plus 74 m³ gas per ton, which corresponds reasonably with the 8 MJ/kg.

10.3.3 Emissions and resource use

Norsk Hydro has provided recipes for product categories, typical for the Swedish situation (Norsk Hydro, 1996a). It is clear that recipes can vary quite a lot with the application; for simplicity's sake here average recipes are used. Depending on the application, the plasticiser use is 55 to 75 phr. DEHP is generally used, but some producers prefer DIDP. Here an average of 55 phr DEHP and 10 phr DIDP is assumed. About 1.5 to 3 phr Ba/Zn stabiliser is used; in some cases Ca/Zn is preferred. Here only Ba/Zn is taken into account, partly because in that case the calculated stabiliser use is in close agreement with the estimates from KemI (1994b). Pigments and ESO are only used in 2 of the 4 recipes. We assumed these substances are only applied in 50 % of the products. Bonding agent was only used in one recipe; for this reason we assumed it is used in only 25 % of the applications. Concentrations have been taken from Norsk Hydro's recipes. Emissions to air will be dominated by the plasticisers. The air from the coating process can contain up to 500 mg/m³ plasticiser; this can be 25 mg/m³ when efficient abatement measures are taken (Sundmark, 1995c; Peijnenburg, 1991) or close to zero when the air is treated thermically (Poppe, 1996b). With an average flow of 20 m³ air per kg plasticiser the emission factors of 0.04-1 % to air given in the table can be calculated (Sundmark, 1995c; Cadogan, 1994). We used an emission value of 0.1%. With this value, the emissions from coating processes in this study are more or less equal to the total emission from coating processes in Sweden given in a study by Neste Oxo (1996). No process emissions to water take place. However, due to the cleaning of trucks that transport the plasticisers a worst-case emission to the sewage system of 1 kg per truck load of 20 tons (0,005 %) can be calculated (Cadogan, 1994). The actual emission might be lower due to the fact that dedicated truck systems are used: trucks that only transport phthalates, and thus need less cleaning. As a worst-case assumption, it has not been taken into account that the emission is possible to a sewage system.

During the manufacturing of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. They are not mentioned in most LCA-databases or studies (e.g. v.d. Berg, 1996; Frischknecht, 1994), but this seems a simplification. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, specifically if granular material is used. Eijssen (1993) mentions a worst-case loss of 0.1 % for granular additives. He

indicates this figure can be considerably lower for non-granular additives. As an indication we used Eijssen's worst-case emission figure as an emission to air (see also TNO, 1992). VOC emissions for the manufacturing of products with flexible PVC are estimated on 30 g/kg PVC for a typical situation in the eighties (TNO, 1992), when in general no emission abatement measures were taken. These VOC emissions are mainly caused by solvent losses, including those present in the raw materials. In case of adequate VOC emission abatement, reductions of 95-99 % can be expected. For the current situation emission factors in the order of magnitude of 1 g/kg PVC therefore seem more adequate (Eijssen, 1993). Here we used an emission factor of 1 g VOC per kg PVC. The amount of residual VCM in PVC is less than 1 ppm (TNO, 1992; ECVN, 1995). Even with a 100 % loss these VCM emissions are negligible compared to those in the PVC production. For other substances no information about emissions was available, and possible emissions had to be neglected.

Table 10.3.1 gives a review of the emissions and resource use both for 100 parts per hundred resin pure PVC and the whole Swedish production.

Table 10.3.1 Emissions and resource use related to the Swedish production of coated fabrics (in ton substance)

Intervention	1 ton (100 phr) PVC	2.300 ton PVC
Material and energy		
PVC resin	100 phr	2.300
DEHP	55 phr	1.265
DIDP	10 phr	230
Ba/Zn stabiliser	2 phr	46
ESO (50 % of the market)	3 phr	69
Pigments (50 % of the market)	0.5 * 4 phr	46
Bonding agent (25 % of the market)	0.25 * 4 phr	23
Energy (MJ)	8.000	18.4
Emissions to water		
DEHP (0.005 % of use)		0.06
DIDP (0.005 % of use)		0.01
Emissions to air		
Ba/Zn (worst case)		(<0.05)
VOC (0.1 % of PVC use)		2.3
DEHP (0.1% of use)		1.2
DIDP (0.1% of use)		0.2

10.3.4 Market balance

The production and import/export balance for coated fabrics is given in table 10.3.2. It is based on data from Norsk Hydro, unless corrections are indicated below. It is assumed that camouflage fabrics and artificial leather are directly used as end-products.

The products made with coated fabrics are used in other products that are imported and exported as well, like artificial leather for automotive applications. There are also some kinds of coated fabrics for end-use applications, that are not produced in Sweden. These flows are indicated in table 10.3.2. The net Swedish export of automotive products is about 43 % of the national production. This way, the amount of artificial leather with cars exported was calculated. Tarpaulins are used for big trucks and nearly all imported. In 1994, 2,100 new trucks were sold in Sweden (SCB, 1996). With an estimated amount of PVC of 100 kg per truck (Norsk Hydro, 1996c) the import of tarpaulins is estimated at 210 tons. Data about wall paper have been taken from Norsk Hydro (1996c).

Table 10.3.2: Market balance for the production of coated fabrics (in ton pure PVC)

Manufacturing market	Production	Import	Export	Domestic use
Camouflage fabrics	1.500	p.m.	p.m.	1.500
Artificial leather (autom.)	550	1.450	p.m.	2.000
Artif. leather (other)	250	1.750	p.m.	2.000
Total	2.300	3.200	p.m.	5.500

Table 10.3.3: Market balance for the application of coated fabrics (in ton pure PVC)

Application market	Production	Import	Export	Domestic use
Artificial leather (autom.)	2.000	p.m.	860	1140
Tarpaulins (automotive)	0	210	0	210
Wall paper	0	300	0	300
Total	2.300	510	860	1.650

11 End use of PVC products

11.1 Introduction

As described in the former sections, PVC is applied in several end-use applications. Since PVC is an inert material, the emissions related to its use in general can be regarded as negligible. Migration of stabilisers like lead and organotin is in general regarded as unimportant, certainly in the short term (Plinke, 1994; Sundmark, 1995a and 1995b; Sloof, 1993; Kapteijns, 1996). About the long-term behaviour of PVC little is known. This is important for the evaluation of the use of PVC as such, but not for this SFA. An SFA, notably, concentrates on the emissions that take place in one year. Unlike e.g. in LCAs, emissions that might take place in the distant future are not taken into account. An important exception with regard to this migration are the plasticisers that are used in the PVC products. Depending on the application, phthalates can leach out to water or be emitted to the air. It is important to take into account that these emissions do not only occur for the amount of PVC products *produced* in a certain year, but for *all the products accumulated in the society*. Since a considerable amount of PVC is applied in long life applications, this can have an important effect that is not always taken into account. Estimates for this accumulation can be made in two ways:

1. taking the current annual use as a basis, and multiplying this by the expected life-time. In a steady-state situation this gives a reasonable approximation of the amount accumulated;
2. using data on yearly new production and waste generation over the period that covers the life-time of the product under consideration.

Where possible, the second method has been applied since it gives the best estimates. However, this was not always possible. In such cases, the first method was used.

This section discusses the most important end-use applications of PVC. Estimates of the total amounts of accumulated PVC will be made, and also estimates of the amounts of PVC that are transferred to the waste stage. Chalmers (1994) has performed a study for the Ecocycle Commission that forms a good basis for such estimates. They calculated for the period since the introduction of PVC in Sweden, in about 1965, what amounts have been applied in which market. Taking into account a normal, average life-time for the application, it was possible to estimate the yearly accumulation for each application, plus the amount of PVC that would appear after its useful life in the waste stage. The plasticiser emissions are calculated on the basis of estimated totals in use in the economy and generally accepted emission factors (see e.g. Sundmark, 1995c; Cadogan, 1994; Peijnenburg, 1991). An important restriction in this study is that the estimated total stocks in the economy are calculated on the basis of *current PVC recipes*. In some cases this can cause differences of up to a factor of 2-3 compared with calculations on the basis of recipes actually applied in the past. Also, with this approach we miss additives and plasticisers which were only used in the past, like chloroparaffins and possibly cadmium in imported products. Another important

assumption made already in the earlier paragraphs is that the formulation of the imported and exported materials is the same as the materials produced in Sweden.

11.2 Pipes

In section 4 it is estimated that the total use of new pipes is about 25,400 tons per year. Chalmers (1994) estimates the total amount of pipes accumulated in Sweden since the sixties at 895,000 tons. Since pipes can have a life-time of 100 years and more, at this moment the amount of pipes in the waste stage is low. There will be some PVC waste as a result of demolition of buildings where PVC has been applied in the last decades. Rough estimates indicate a volume of less than 1,000 tons, most probably as building waste. Table 11.2.1 gives a review of this flow. Emissions of stabilisers are negligible and occur only in the initial period, up to a maximum of 1 kg of lead a year. The lead flow with water used for human consumption is 0.96 grams per year (NPG, 1995). An analysis by Hjertberg and Gevert (1995a) did not show any concentration gradient of lead in a pressurised waste pipe installed in 1972. They conclude that, *if* any lead loss takes place at all, it must be by an initial loss from a possible, very thin layer of lead stabiliser on the surface of the virgin pipe. Björklund (1995) calculated on the basis of flush tests with drinking water pipe this initial loss of lead per m² inner surface of the pipe. Extrapolating this to *all* Swedish pipes, and assuming losses from both the inner surface and the outer surface, he calculated a maximum worst-case loss of about 83 kg to water/soil in 1993, when 225 tons of lead stabiliser in pipes were used (in 1994: 217 tons lead).

Table 11.2.1: Use stage for pipes (in ton pure PVC)

Product	In use 1994	New 1994	To waste	In use 1995
Pipes	895.000	25.400	1.000	919.400

11.3 Flooring

11.3.1 Mass flows

In section 4 it is estimated that the total use of new flooring is about 15,000 tons per year. Chalmers (1994) estimates the total accumulated amount in Sweden since the sixties at 394,400 tons, assuming an average life-time of 20 years. This means that the amount of flooring sold in 1974 on the Swedish market will be disposed of as waste in 1994. Chalmers estimates this amount at 11,700 tons. It must be noted that other literature uses shorter life-times, e.g. 10 or 15 years (Cadogan, 1994; Sundmark, 1995c). We have assumed that a majority, 11,200 tons, is disposed of as building waste, and a minor amount of 500 tons is disposed of as domestic waste. Under these assumptions, the total amount of PVC (from flooring and other PVC products) in

domestic waste is reasonably in accordance with the observed values in waste surveys. Table 11.3.1 gives a review of this flow. With the amount of flooring, plasticisers are also accumulated in Swedish society. Assuming the accumulated flooring has the same formulation as given in table 5.3.1 for the flooring produced in 1994, the table gives the accumulated amount of plasticiser as well. BBP is only used in coated flooring of which 55 % of the production is in Sweden; it is assumed that coated flooring also accounts for 55 % of the accumulated amount. The related emissions are calculated in the following paragraph.

Table 11.3.1: Use stage for flooring (in ton pure PVC)

Product: Flooring	In use 1994	New 1994	To waste	In use 1995
Amount PVC	394.400	15.000	11.700*	397.700
DEHP (30 phr)	118.320	4.500	3.510	119.310
BBP (15 phr; market 55 %)	32.538	1.240	614	20.879

* Assumption: 500 tons domestic waste, 11.200 tons building waste.

11.3.2 Emissions

From flooring, plasticiser emissions are possible by two processes: diffuse emission to the air and emissions to water during washing. Most authors refer to one source that indicates that the emissions for indoor applications are about 2.3×10^{-4} ug/sec/m² of plasticised PVC (Peijnenburg, 1991; Cadogan, 1994; Sundmark, 1995c). On average, about 0.4-0.5 kg plasticiser per m² flooring is used (Sundmark, 1995c; Cadogan, 1994). Per year, this gives an emission factor to air (E_a) per ton plasticiser of:

$$E_a = 2.3 \times 10^{-4} \text{ ug/sec/m}^2 * 3600 \text{ sec/hr} * 24 \text{ hr} * 365 \text{ days} * 1/0.45 \text{ m}^2/\text{kg} = 16 \cdot 10^{-6}$$

During the first period of the use of flooring VOC emissions will occur. The most important substances are e.g. methylpyrrolidone, butoxyethanol and ethylhexanoic acid. The emitted amount diminishes over time. Regular tests show an emission of about 10 to 30 ug/m²*hr after 26 weeks of use (Tarkett, 1996). Using a somewhat pessimistic average of 20 ug/m²*hr over a whole year, an emission of 0.17 g/m² per year can be estimated. With roughly 1 kg PVC per m² this results in an emission factor of 0.17 g/kg PVC. It is assumed that emissions after the first year are negligible, so this emission factor is only applied on the amount of *new use* of PVC in flooring.

Emissions to water are mainly caused by (wet) cleaning of the flooring. Phthalates are the most important substances emitted. Several estimates of emission factors are available. Sundmark (1995c) gives an emission factor to water of 0.015 % per treatment, which would mean 0.78 % a year with cleaning once a week (52 treatments).

Since a time-lag in extraction has been shown a reduction factor of 0.1 to 0.01 seems reasonable (Sundmark, 1995c). PVC Forum (1995) uses an emission of 23 mg/m³, which is 0.005 % per year, which is in accordance with the data of Sundmark combined with the reduction factor of 0.01. Since the 0.005 % has been based on specific research done in Denmark (Vikelse, 1995), this number will be used. Using these emission factors, table 11.3.2 gives the emissions to air and water.

Table 11.3.2: Emissions from the use stage for flooring (in ton)

Substance	Basis for emission factor		To water		To air	
	Basis	Amount (ton)	Emission factor	Emission	Emission factor	Emission
DEHP	DEHP in use	118.320	0.005 %	6	$16 \cdot 10^{-6}$	1.9
BBP	BBP in use	32.538	0.005 %	1.5	$16 \cdot 10^{-6}$	0.5
VOC	New use PVC	15.000	0	0	$1.7 \cdot 10^{-4}$	2.6

11.4 Cables in building applications

11.4.1 Mass flows

In section 6 it is estimated that the total use of new cables in end-use applications is 10,950 tons. Chalmers (1994) estimates the total accumulated amount in Sweden since the sixties at 387,000 tons. However, they assumed that *all* cables would be used in building applications, where in fact 8 % is used in cars and electrical equipment. This figure for accumulation was therefore corrected by this percentage. In Chalmers' figure it was also assumed that the life-time of cables is so high that in the previous years *no* cable has been disposed of as waste: it assumes that all cable produced is still in use. According to Norsk Hydro, a reasonable amount of PVC in cables is entering the waste stage now: about 6,000 tons, which is half of the new use in 1994. This figure was estimated in a (still confidential) project on recycling of cable waste; however, the order of magnitude seemed reasonable to the authors of that study (Mueller, 1996). This number is not in agreement with the life-time of 40 years for cables assumed by Chalmers when calculating his accumulated amount. Renovation and demolition of houses result in the fact that every year a number of cables enter the waste stage, before the end of their technical life-time. Annex 2 to this study corrected Chalmers' calculation for this effect. The calculation showed that if it is assumed that every year 2.5 % of the cables in use enter into the waste stage due to renovation etc., the current accumulated amount is about 250 ktons PVC. The calculated amount of waste of 6,250 tons then corresponds fairly well with the amount inventoried in the recycling project. On the basis of the same calculation, it can be shown that with a low market penetration of DIDP as plasticiser in the last 6 years the amount of DEHP in the stock will be about 90 %. Only 10 % is DIDP. It is assumed that this breakdown is also valid for the amount that enters the waste stage. These data will certainly be

simplifications, since in former times besides DEHP chloroparaffins were also used as plasticiser. Table 11.4.1 gives a review of this flow. The related emissions are calculated in the following paragraph.

Table 11.4.1: Use stage for cables (in ton)

	In use 1994	New 1994	To waste	In use 1995
Amount PVC	250.000	10.950	6.000	254.950
DEHP (50 phr)	112.500	1.825	2.700	113.375
DIDP	12.500	3.650	300	15.850

11.4.2 Emissions

The currently available data for phthalate emissions from cables are quite controversial. Some authors assume that they are negligible, including the Swedish EPA (Sundmark, 1995c). Other authors do not mention them at all (Peijnenburg, 1991). The factors for diffusion-controlled emissions to air of Cadogan (1994) would lead to a Swedish emission of several tons a year. Emissions in this order of magnitude figure in most other reports on emissions of phthalates from cables.

However, one study suggests emissions that are very high compared to all earlier estimates, up to about 0.5 % a year (Hjertberg, 1995a). Hjertberg analysed the composition of a cable that had been 20 years in the ground. He compared the result with an (estimated) recipe. The amount of phthalates, di-iso-octylphthalate, was determined to be about 20 %, with a tendency towards lower concentration levels in the outer layer of the insulation. For this type of cable, Hjertberg estimated that the original plasticiser content can be expected to be 25-28 %. Additional analysis showed that apart from the 20 % phthalates, the cable also contained about 2 % of highly aromatic oils. In former times, this material was used as a cheap secondary plasticiser. He concluded therefore that the analysed material consisted for about 22 % of the plasticiser, compared with a presumed 25 to 28 % in new material. According to him, the difference of at least 3 % (which is more than 10 % of the original 25 %) could be caused by phthalate losses. This 10 % in 20 years would mean 0.5 % a year.

It has to be underlined that Hjertberg's calculations have one very basic weak point that makes it impossible to draw any conclusion in favour or against the hypothesis of phthalate loss: the original recipe is not known. Apart from this, it seems that not all additives in the cable have been analysed, and it would be no surprise if the cable contained another plasticising component that would explain the gap of 3 % (Poppe, 1996a). Poppe also indicated that, depending on the formulation, the plasticiser contents of cables can be between 20 and 27 %. Some examples are given in table 11.4.2. A measured plasticiser content of 22 % is thus no proof of plasticiser loss.

Table 11.4.2: Possible recipes of PVC cables

	Recipe 1		Recipe 2		Recipe 3	
	phr	weight%	phr	weight%	phr	weight%
PVC	100	54.1	100	43.5	100	44.5
Plasticiser	50	27	50	21.7	45	20
CaCO ₃ -filler	30	16.2	75	32.6	75	33.3
Pb-stab.	5	2.7	5	2.2	5	2.2
Compound	185	100	230	100	225	100

In brief, the conclusions in the work of Hjertberg could be both a message of a possible environmental problem or just a completely wrong analysis, due to the failure to take into account the uncertainty that is introduced due to the lack of data on the original recipe of the cable.

However, at this stage it would in our opinion be imprudent to totally exclude the possibility of a relatively high plasticiser loss from cables in advance. The amount of plasticiser accumulated in cables in society is quite high. The concentration gradient in the cables indicates that losses, though their quantification is impossible now, cannot totally be neglected. It should be certain that any unexpected high emissions are absent. The proof can be rather easily obtained by analyzing old cables, for which the producer and the recipe can be obtained. Even a rather weak interpretation of the precautionary principle demands that such research is performed on short notice, and quickly gives unambiguous results.

We therefore present two values here. The first value is based on diffusion-controlled losses to air, and can be regarded as a certain, but possibly minimal estimate of the real emission. We simply used the emission factor derived for flooring in this calculation (see paragraph 11.3). The second value is only used as a theoretical indication. It gives a theoretical 'worst case' estimate, that indicates the emission if all Hjertberg's assumptions turn out to be right. The value can only be used if additional research has shown that all uncertainties about these rather questionable assumptions can be ruled out. In that case, a plasticiser loss of 0.5 % a year would occur. Apart from this, a distinction has to be made between cable that is used in a non aggressive environment (e.g. compare flooring) and a more aggressive environment for which the high emission factor is valid. Virtually no data on different applications are available. We just assumed 50 % for the high emission factor. In brief, this would mean an average emission factor of 0.25 % in the theoretical, worst-case situation. The value can only be used if additional research has shown that all uncertainties about the very questionable assumptions that led to this value can be ruled out. Once again it has to be stated that at this moment there are as many arguments to opt for a 0 % emission as for a high value. Table 11.4.3 gives the calculated values.

It is unclear whether, as with flooring, some initial VOC emissions can be expected in the first year of use. Application of the same emission factor (0.17 g/kg PVC*yr) and other assumptions used for flooring (only emissions in the first year) leads to a VOC emission of 2 tons in 1994.

Table 11.4.3: Emissions from the use stage for cables (in ton)

Substance	Basis for emission factor		To water/soil		To air	
	Basis	Amount (ton)	Emission factor	Emission	Emission factor	Emission
DEHP	DEHP in use	112.500	*	*	$16 \cdot 10^{-6}$	1.8
DIDP	DIDP in use	12.500	*	*	$16 \cdot 10^{-6}$	0.18
VOC	New use PVC	10.950	0	0	$1.7 \cdot 10^{-4}$	2

* On the basis of very questionable assumptions an average emission of 0.025 % under unfavorable conditions can be calculated. This would lead to relatively very high additional emission of DEHP and DIDP. The uncertainty, however, is so high, that a zero additional emission is also very defensible.

11.5 Other applications in the building area

11.5.1 Mass flows

In section 4 to 10, several other PVC applications in the building area are given. They include:

- a: rigid profiles (window frames, pipes for electrical wire and other; see section 7);
- b: film (foil-coated building plate and roof covering; see section 8);
- c: plastisol-covered building plate (see section 9);
- d: wall paper (see section 10).

Categories b) and c) are the most important for this section, since they contain plasticisers that can be emitted to air and/or water. No good estimates are available for the amount of PVC that is already accumulated in society in the other applications. Estimates therefore have been made on the basis of the expected life-time of the applications. Profiles are assumed to have a life-time of more than 30 years. In theory, the accumulated amount can be estimated by multiplying the use in 1994 by 30 in case of a constant consumption. The actual accumulated amount is estimated to be somewhat lower due to lower consumption in the sixties (compare e.g. Chalmers, 1994). We therefore introduced an additional correction factor of 80 %, and thus estimated the stock in 1994 with the following formula: use in 1994 * 30 * 80 %. Due

to the long life-time, the amount of waste at this moment is assumed to be low (around 66 tons for each category profiles). It is assumed that plastisol-covered building plate and foil-coated building plate have a life-time of minimal 20 years (Sundmark, 1995c). For roof covering sometimes assumptions of a life time of 10 years are made. However, since roof covering after its useful life is covered a few times with a new layer, it is assumed that the roofing will stay 20 years in the economical system. Assuming a constant use during the past 20 years, a steady state situation has been reached. In that case the accumulated amount is 20 times the annual use and the annual amount of PVC waste is equal to the annual use. For wall covering a useful life of 10 years has been estimated and the calculations have been made with a factor 10. Table 11.5.1 gives a review of these flows. Assuming the recipes of the flexible PVC applications have always been equal to those given in section 4 to 10 also the total amount of accumulated plasticisers is calculated. The emissions are discussed in the next paragraph.

Table 11.5.1: Use stage for other building applications (in ton)

Other building applications	In use 1994	New 1994	To waste	In use 1995
Window frames	48.000	2.000	66	49.934
Pipes for electrical wire	57.600	2.400	66	59.934
Other building applications	55.200	2.300	66	57.434
Foil coated building plate				
- PVC	1.600	80	80	1.600
- DEHP (25 phr)	400	20	32	400
Roof covering				
- PVC	30.000	1.500	1.500	30.000
- DEHP (25 phr)	7.500	375	375	7.500
Plastisol building plate				
- PVC	45.000	2.250	2.250	45.000
- DEHP (40 phr)	18.000	900	900	18.000
Wall paper				
- PVC	3.000	300	300	3.000
- DEHP (55 phr)	1.650	165	165	1.650
- DIDP (10 phr)	300	30	30	300
Total (PVC)	240.400	10.830	4.330	246.900

11.5.2 Emissions

When flexible PVC is in direct contact with water, plasticisers can leach out. Such losses can be expected when flexible PVC is used in outdoor applications: it is subjected to attack by many forces including heat, UV radiation, microbiological attacks, frost, humidity, etc. According to Sundmark (1995c) it has not been possible to estimate a theoretical rate of plasticiser loss outdoors. However, all authors seem to

agree on the use of an emission factor of 0.5-1.0 % a year (Sundmark, 1995c; Cadogan, 1994; Peijnenburg, 1991). It is assumed that building plate and roofing is subject to such exposure and thus has such emission factors. It is very difficult to assess whether this has to be regarded as an emission to water or soil. In urban areas, one can expect that the phthalates are for a large part transported with the water run-off and therefore can be regarded as an emission to water. In rural areas the water will end up in the soil, and thus the emission has to be regarded as to soil. About 80 % of the Swedish population lives in rural areas (SCB, 1996). But since we don't think that even in rural areas all phthalates will be transported by run-off, we simply assumed an average of 50 % emission to water and 50 % emission to soil.

For emissions of phthalates to air, quite diverging emission factors are available. Peijnenburg (1991) uses an emission factor of 0.1 % to air, which can be 0.01 % for products with small surface contact. Cadogan (1994) and Sundmark (1995c) do not mention any emission to air for outdoor applications. Their emission factor for flooring is much lower than the values of Peijnenburg ($16 \cdot 10^{-6}$; see section 11.3). This might be an underestimate since flooring is thicker than foil or plastisol, and thus more surface is exposed to air. A factor of 5 higher might be a better estimate, since foil and coating is about 5 times as thin as flooring for which the emission factor has been derived. This would mean a value of 0.009 %, which is comparable with the low value of Peijnenburg. Since no better estimates seem available, for the diffuse losses to air the 0.01 % of Peijnenburg is used. Table 11.5.2 reviews the calculated emissions to air, soil and water, making use of the estimated accumulated amount of plasticiser given in table 11.5.1. For wallpaper only the diffuse losses into the air are taken into account.

The emission to water and soil for building plate is lower than the 300 tons estimated earlier by SNV, but exceeds the 36 tons estimated by a.o. Industriforbundet (1994) in the reaction to the report of the Ecocycle commission. The difference is mainly caused due to differences in estimates about the amount PVC accumulated. Industriforbundet uses an accumulated amount of $120 \cdot 10^6 \text{ m}^2$ plate, coated with 0,2 mm PVC of 1 kg/l consisting of 30 % plasticiser. This would mean an accumulated amount of 7,200 tons of plasticiser. With 0.5 % loss a year the 36 tons can be calculated. The difference with our data is that we tried to estimate an accumulated amount of building plate in society on the basis of the present use and an estimated life time. Even if the figure of Industriforbundet for the accumulated amount was more accurate than the estimate of TNO/CML, this would merely mean that at this moment the steady-state situation has not yet been reached. If the current production levels of plastisol plate do change, with an average life-time of 20 years at some point in the future the accumulated amount of plasticiser will reach the steady-state amount of 18,000 tons. At that moment, the total emission will also be 90 tons.

Eventual VOC-emissions in the use phase from flexible PVC are neglected for these applications. The amounts of PVC are relatively low. Application of the emission factors for the use of flooring would lead to negligible VOC emissions compared to other sources in the PCV-chain.

Table 11.5.2: Emissions from the use of other building applications (in ton)

	In use 1994	To water	To soil	To air
Emission factor		0.5 % * 50 %	0.5 % * 50 %	0.01 %
Coated building plate: DEHP	400	1	1	0.04
Roof covering: DEHP	7.500	18.7	18.7	0.75
Plastisol building plate: DEHP	18.000	45	45	1.8
Wall paper - DEHP	1.650	not relevant	not relevant	0.17
- DIDP	300	not relevant	not relevant	0.03
Total	27.850	65	65	2.79

11.6 Cars

11.6.1 Material flows

In the former paragraphs, several PVC flows have been allocated to the production of cars. In fact this gives an estimate of the breakdown of the PVC types used in Swedish car production. The total number of cars and trucks in Sweden is 3,619,000 and 845,000 (Eurostat, 1995). Of these, about 1/3 have been produced in Sweden, 1/3 in Europe and 1/3 in the Far East (SNV, 1996). The number of newly registered cars 1994 is estimated at 160,000 (SCB, 1996). In both imported and domestically produced cars PVC-containing foil, cables and coated fabrics are applied. It is assumed that the total PVC-stock for these applications in 1994 can be calculated on the basis of the ratio of the total number of cars (3,619,000) and newly licensed cars (160,000).

Apart from the PVC in the above-mentioned materials, additional PVC enters Sweden with imported cars. In 1994, 2,100 new trucks were licensed (KemI, 1996). On average, about 100 kg PVC in tarpaulins is used for a truck (Norsk Hydro, 1996): a total new use of 210 tons. This material is not produced in Sweden but all imported. The formulation is assumed to be similar to coated fabrics. The total amount of licensed big trucks in Sweden is about 58,000 (SCB, 1996). With 100 kg per truck this gives 5,800 tons tarpaulins. Further, about 2/3 of the 160,000 newly licensed cars in 1994 are imported. A considerable number of them has PVC undercoating. We have estimated this at a conservative 60 %, resulting in the assumption that 40 % of the Swedish cars have PVC undercoating. In general such undercoatings have a weight of 12 kg/car (Norrthon, 1994). This consists of 4 kg PVC, 4 kg plasticiser (assumed: DEHP) and 4 kg of other material (Poppe, 1996b). For 1994 an import of 256 tons pure PVC with undercoating can be calculated. The total stock is calculated on the basis of new cars in 1994 and the total number registered.

APME (1996) assumes that a car and a truck have a life time of about 12 years. This means the cars and trucks sold in 1982 will become available in the waste stage. Counting with 218,000 cars and 18,000 trucks licensed in 1982, and a plastic content in that production year of 70.2 and 107 kg, APME estimates the amount of automotive plastics waste at 17,000 tons. This is in fair agreement with SNV (1996). PVC counts for 20 % of the plastics used in the European automotive industry; this would mean an amount of PVC in the waste stage of 3,400 tons including additives and plasticisers. The amount of pure PVC is calculated on the basis of the average fraction of PVC in the total new use in 1994. Table 11.6.1 gives a review of these material flows.

Table 11.6.1: Use stage for PVC in the automotive sector (in ton)

	In use 1994	New 1994*	To waste	In use 1995
Cables				
- PVC	1557	69	55	1571
- DEHP (50 phr)	259	11	9	262
- DIDP (50 phr)	519	23	18	524
Foils				
- PVC	25943	1147	910	26179
- DEHP	6486	287	228	6545
Coated fabrics				
- PVC cont	25943	1147	910	26179
- DEHP (55 phr)	14268	631	501	14399
- DIDP (10 phr)	2594	115	91	2618
Undercoating				
- PVC	5039	256	202	5809
- DEHP	5754	256	202	5809
Tarpaulins				
- PVC	5800	210	167	5843
- DEHP (55 phr)	3190	116	92	3214
- DIDP (10 phr)	580	21	17	584
Total (PVC+phthalates)	98647	4289	3.400	99536
Total PVC content	64996	2829	2.243	65582

* Of which: undercoating 100 % import (no export), the rest 66 % import (equal to export). For cables, for the sake of simplicity the current recipe has been used to calculate the DIDP and DEHP stock. Since DIDP has only recently penetrated the market, this will give an underestimation of the DEHP stock.

11.6.2 Emissions

The car undercoatings are exposed to the influence of the weather. With respect to phthalates, only for this part the emission factor of 0.5 % to weathering for outdoor use is applied. As with building applications, here also it is difficult to identify the compartment to which it is emitted: soil or water. The best assumption could be made

by estimating the amount of car-kilometres on roads with a sewage system and roads without such a system. Such data are not available to us. As a best guess, we estimated the emissions to soil and water at 50 % of the total emission each. For emissions to air, the emission factor of 0.01 % of Peijnenburg has been used (see the former paragraph). Table 11.6.2 reviews the calculated emissions to air, water and soil, making use of the estimated accumulated amount of plasticiser given in table 11.6.1. The dominant emission is from the car undercover. For a better estimate, more precise data on the number of cars with PVC coatings have to be available, as well as more reliable emission factors. The same applies for the emissions to air.

For cars, eventual VOC-emissions in the use phase from flexible PVC are neglected. The amounts of PVC are relatively low. Application of the emission factors for the use of flooring would lead to negligible VOC-emissions compared to other sources in the PCV-chain.

Table 11.6.2: Emissions from the use of PVC in cars (in ton)

	In use 1994	To water	To soil	To air
Emission factor		0.5 %*50%	0.5%*50%	0.01 %
Cables		not relevant	not relevant	
- DEHP	259			0.03
- DIDP	519			0.05
Foils: DEHP	6.486	not relevant	not relevant	0.65
Coated fabrics				
- DEHP	14268	not relevant	not relevant	1.4
- DIDP	2594	not relevant	not relevant	0.26
Tarpaulins				
- DEHP	3190	8	8	0.32
- DIDP	580	1.45	1.45	0.06
Undercoating: DEHP	5754	14.3	14.3	0.6
Total	33651	23.7	23.7	3.5

11.7 Electronic applications

11.7.1 Mass flows

Sections 4 to 10 allocate a certain use of several intermediate products to the construction of electronic and similar equipment. It concerns profiles and cables. The import of such articles is assumed equal to the export. Table 11.7.1 reviews these data. The new use of plastics is in the lower range of the estimates that can be calculated with data from SNV (1996): a yearly consumption of 550,000 tons electrical products consisting for 15-30 % of plastic. Since PVC accounts for 4 % of the plastics in the electronics industry, a total of 3,300-6,600 tons can be calculated. However, compared

with calculations made with data of APME the figure is maybe too high. APME (1996) estimates the use of plastics in the Swedish electronics industry at 30,000 tons. With 4 % PVC this would mean 1,200 tons of PVC. Even if cables are not taken into account as PVC input in the electronics industry, the total use in table 11.7.1 is too high. An explanation could be that Sweden is a net importer of electronic goods, whereas the assumption is that the import is equal to the export.

According to SNV, the accumulated amount of electronical products is 6.5 times the consumption in the nineties. We assumed that the accumulated amount had the same recipes as the new use. The yearly amount of electronic waste is 200,000 ton, which is 36 % of the consumption. This means electronic equipment is still accumulating in society (SNV, 1996). Most of it will be disposed of as domestic or non-specific industrial waste. With the factors 6.5 and 0.36 the stock and the amount of waste is calculated.

Table 11.7.1: Use stage for electronical equipment (in ton)

	In use 1994	New 1994	To waste	In use 1995
Cables *				
- PVC	5.395	830	299	5.926
- DEHP	899	138	50	988
- DIDP	1.798	277	100	1975
Profiles: PVC	14.950	2.300	828	16.423
Total (PVC)	20.345	3.130	1.127	22.348

* As for cables in cars, here also the current recipe was used to calculate DIDP and DEHP stocks. This might have given an overestimation of the amount of DIDP in stock.

11.7.2 Emissions

It is assumed that no outdoor use of electronic equipment takes place. For emissions of phthalates to air, the emission factor of 0.01 % of Peijnenburg has been used. Possible VOC-emissions from flexible PVC are neglected. The amounts of PVC are relatively low. Application of the emission factors for the use of flooring would lead to negligible VOC-emissions compared to other sources in the PCV-chain. Table 11.7.2 reviews the calculated, minimal emissions to air, making use of the estimated accumulated amount of plasticiser given in table 11.7.1.

Table 11.7.2: Emissions from the use of electrical equipment(in ton)

	In use 1994	To water/soil	To air
Emission factor		0.5 %	0.01 %
Cables			
- DEHP	899	not relevant	0.1
- DIDP	1789	not relevant	0.2

11.8 Coated fabrics

11.8.1 Mass flows

It is estimated that every year about 2,000 tons PVC is used for artificial leather and similar textiles, containing 55 phr DEHP and 10 phr DIDP (see section 8.4). About 1,500 tons is used in camouflage fabrics. A reasonable life-time for these materials is 10 years (PVC Forum, 1995). With this data, the total accumulated amount is estimated at 35,000 tons PVC. Assuming a steady state situation the yearly volume of waste will be about 3,500 tons. About 1,500 is camouflage fabrics, which will be non-sector specific waste. The coated fabrics will be partially used by households and partially in industry or similar organisations. Here it is assumed that of the 2,000 tons waste about 1,000 tons is domestic waste and 1,000 tons is non-sector specific waste. Table 11.8.1 reviews these data.

Table 11.8.1: Use stage for coated fabrics (in ton)

	In use 1994	New 1994	To waste	In use 1995
Artificial leather				
- PVC	20.000	2.000	2.000	20.000
- DEHP (55 phr)	11.000	1.100	1.100	11.000
- DIDP (10 phr)	2.000	200	200	200
Camouflage fabrics				
- PVC	15.000	1.500	1.500	15.000
- DEHP (55 phr)	8.250	825	825	8.250
- DIDP (10 phr)	1.500	150	150	1.500

11.8.2 Emissions

With respect to phthalates, it is assumed that for rain clothes and similar material the emission factor of 0.5 % due to weathering can be used (Sundmark, 1995c; Peijnenburg, 1991). It is estimated that these fabrics are only used for 5 % of the time outdoor; this results in an emission factor of 0.025 %. For camouflage fabrics it is

assumed they are mainly used in rural areas: they then cause an emission to soil. For coated fabrics, the estimate is uncertain. It is assumed that they are used for 50 % in rural areas (emission to soil) and for 50 % in urban areas, in places where the run-off from streets is collected (emission to water). For emissions to air, the emission factor of 0.01 % of Peijnenburg is used. Possible VOC-emissions from flexible PVC are neglected. The amounts of PVC are relatively low. Application of the emission factors for the use of flooring would lead to negligible VOC-emissions compared to other sources in the PCV-chain. Table 11.8.2 reviews the calculated emissions, making use of the estimated accumulated amount of plasticiser given in table 11.8.1.

Table 11.8.2: Emissions from the use of coated fabrics (in ton)

	In use 1994	To water	To soil	To air
Emission factor		0.025 %	0.025%	0.01 %
Artificial leather		(*50 %)	(*50%)	
- DEHP (55 phr)	11.000	1.37	1.37	1.1
- DIDP (10 phr)	2.000	0.25	0.25	0.2
Camouflage fabrics			(100%)	
- DEHP (55 phr)	8.250		2.06	0.8
- DIDP (10 phr)	1.500		0.375	0.15
Total	22.750	1.62	4.08	2.25

11.9 Medical applications and packaging

According to sections 4 to 10, several applications of PVC are used for packaging and medical applications. It is assumed that these are all short life applications, that do not accumulate in the society and are transferred to the waste stage in the same year. Due to the small amounts used and the fact that no accumulation takes place the possible emissions of plasticisers and VOC have been neglected. All medical applications will be disposed of as medical waste. Packaging waste will be partially domestic waste and partially non-specific industrial waste. Table 11.9.1 gives a review of these flows.

Table 11.9.1: Use stage for medical applications and packaging (in ton)

	In use 1994	New 1994	To waste	In use 1995
Packaging		1.500	1.500	
Grocery packaing		1.000	1.000	
Total packaging		2.500	2.500	
Medical packaging		300	300	
Medical tubes/hoses		600	600	
Total medical		900	900	

11.10 Other applications

11.10.1 Mass flows

Sections 4 to 10 mention several other applications, including office equipment. The use of such applications is listed in table 11.10.1, including the plasticisers that the products contain. The accumulated amount has been estimated at a life-time of 10 years and the assumption of a steady-state situation. This also means that the amount of waste is equal to the new use. The waste type will be mainly industrial waste.

Table 11.10.1: Use stage for other applications (in ton)

	In use 1994	New 1994	To waste	In use 1995
Manufacturing	23.000	2.300	2.300	23.000
Other rigid foil	45.800	4.580	4.580	45.800
Office equipment				
- PVC	15.000	1.500	1.500	1.500
- DEHP (25 phr)	3.750	375	375	3.750
Other flex.film and foil				
- PVC	28.200	2.820	2.820	2.820
- DEHP (25 phr)	7.050	705	705	705
Other plastisol				
- PVC	10.000	1.000	1.000	10.000
- DIDP (40 phr)	4.000	400	400	4.000
Other hoses/tubes				
- PVC	12.000	1.200	1.200	12.000
- DEHP	6.000	600	600	6.000
Total (PVC)	134.000	13.400	13.400	134.000

11.10.2 Emissions

A major problem in estimating the emissions of this category is that the percentage of outdoor use is not known. It seems reasonable that a certain amount of flexible foil and tube is used in outdoor applications. For outdoor applications, the emission factor of 0.5 % due to weathering etc. can be used for phthalates (Sundmark, 1995c; Peijnenburg, 1991). As with coated fabrics, we assumed that this emission factor can be used in 5 % of the applications: for foil and plastisol the most important specific outdoor uses are already given in the other segments. However, it is clear that here a mistake of a factor of 5 could easily be made. For emissions to air, the emission factor of 0.01 % of Peijnenburg has been used. Possible VOC-emissions from flexible PVC are neglected. The amounts of PVC are relatively low. Application of the emission factors for the use of flooring would lead to negligible VOC-emissions compared to other sources in the PCV-chain.

Table 11.10.2 reviews the calculated emissions to air, soil and water, making use of the estimated accumulated amount of plasticiser given in table 11.10.1.

Table 11.10.2: Emissions from other applications (in ton)

	In use 1994	To soil	To water	To air
Emission factor		0.025 % * 50 %	0.025 % * 50 %	0.01 %
Office eq. : DEHP	3.750	not relevant	not relevant	0.4
Flexible foil/film: DEHP	7.050	0.88	0.88	0.7
Other plastisol: DEHP	10.000	1.25	1.25	1
Hoses (DEHP)	6.000	0.75	0.75	0.6
Total	26.800	2.83	2.83	2.7

12 Waste management

12.1 Introduction

In the present situation, most of the PVC waste in Sweden is landfilled or incinerated. In the base year 1994 recycling still plays a minor role, partially since the recycling industry still has to be built up and partially since the majority of the PVC is applied in long-life applications, so that the amount of PVC in the waste stage is still rather limited. However, clear initiatives are taken to enhance the amount of PVC that is recycled, including for profiles/window frames and cables. Also a PVC recycling scheme for pipes has become available recently. These activities will certainly have their effect in the long term.

This section discusses the mass flows and emissions related to PVC in the waste stage. The next paragraph discusses the mass flows. After that, the emissions related to landfill and incineration are discussed.

12.2 Mass flows and composition

Section 11 indicates which amounts of PVC will be disposed of as waste. A review of the waste flows is given in table 12.2.1. This table also indicates very roughly the scarce literature data that are available for the PVC or plastic contents in the waste stage. For each waste category those data are discussed in this paragraph. The total waste volume is rather high compared to the production of about 100,000 tons. This is partially due to the fact that Sweden is a net importer of PVC in products, so that the actual PVC use is higher than the production. Also, for quite a lot of uses no specific data on accumulation and waste were available. In these situations, a steady-state approach has been used to estimate the waste volume. For sectors where in fact a net accumulation still takes place this might have resulted in an overestimation of the amount of PVC waste.

Domestic waste

In Sweden annually 3,200,000 tons of domestic waste is disposed of (SNV, 1995). This waste contains about 0.1 % chlorine from PVC. Since - depending on the additive content - PVC consists for 50 % of chlorine, this gives an estimate of 6,400 tons of PVC from domestic sources. Excluding plasticisers etc. this could be 5,000 to 6,000 tons pure PVC. This equals roughly the sum of the calculated packaging, electronic, and coated fabrics waste (the small amount of flooring waste is for the sake of simplicity neglected and totally allocated as building waste). It thus seems that the calculated amount of PVC in domestic waste is within reasonable agreement with the measured values. The amount landfilled is about the same as the amount incinerated. It thus can be assumed that 50 % of the PVC is incinerated and 50 % is landfilled.

Building waste

Our calculated amount of PVC building waste is 23,030 tons PVC. The amount of building and demolition waste disposed of under municipal auspices amounts to about 1,200,000 tons a year (SNV, 1995). According to SNV the amount of plastics is 3 to 10 %, which would mean 36,000 to 120,000 tons of plastics. Since PVC is the dominant plastic used in the building area, this would mean an amount of PVC waste of at least 18,000 to 60,000 tons. The last figure especially seems too high. An amount of plastics waste of 120,000 tons is also high compared to the annual plastic use in the building sector of 125,000 tons (APME, 1996). APME estimates that only 15 % of the plastics consumption will end up in the waste stage, and calculates a figure of 19,000 tons. This number is also used in another report of SNV (1996). If PVC makes up 50 % or more, this would lead to 9,500 tons PVC in building waste. Given the fact that this figure is including additives, it is a low value compared to the amount calculated by us. No explanation is given by SNV or APME of why the amount of plastic waste could be so much lower than the use. In sum, the margin of error in the data on the composition of building waste is so high that they can neither confirm nor deny the calculated amounts of PVC in building waste. We assumed that virtually all building waste is landfilled. Only for flooring do we expect that a minimal amount (500 tons) is disposed of via the structure for domestic waste, resulting in 50 % (250 ton) incineration for this category.

Car wrecks

According to SNV (1995), the amount of auto salvage is about 100,000 tons. We assume this is the remainder of 25 to 30 % of car shredding after the ferro and non-ferro fraction has been removed. Assuming a life-time of 12 years, the 218,000 cars and 18,000 trucks sold in 1982 now will enter the waste stage (APME, 1996). With a weight of 1,000 to 1,500 kg per car or truck, and 25-30 % shredder residue the 100,000 ton is somewhat higher than theoretical expected. In an other report of SNV the amount is estimated at 50,000 tons (SNV, 1996). Of this amount, 30 % is plastic. Since 19 % of the plastic used in cars is PVC, this results in an amount of PVC of 3,000 to 6,000 tons of (formulated) PVC. This is in reasonable agreement with the 2,300 tons pure PVC estimated in section 10. At this moment, all waste from car wrecks is landfilled (SNV, 1995).

Sector specific waste

In principle, when PVC products are made a fraction of this PVC will become available as waste. Since these processes are discussed in the former sections, the amounts of waste should have been reported there. In general, in the other sections the production of PVC process waste is neglected. In the Dutch situation, due to internal recycling the total amount of PVC waste disposed of from production processes is about 2 % of the use (Caesar, 1992). With an annual use of 100,000 tonnes PVC in production processes in Sweden, this might mean that 2,000 tons of PVC waste have not been taken into account.

Other

The categories medical waste, waste from office equipment, camouflage coating and waste from other applications are in total about 16,550 tons of PVC waste. SNV (1995) reports an amount of 2,000,000 tons non-sector specific waste, of which 80 % is landfilled. This waste consists for 7 % of plastics, which means about 140,000 tons of plastics waste. According to APME (1996), in the total figure for post-user plastics waste for Europe PVC has a share of about 10 %. If this figure can be applied to the Swedish situation as well the calculated amount of PVC in non-sector specific waste is in reasonable agreement with the data on plastics waste of SNV. However, the uncertainties in these comparisons are high. SCB (1995a) published a survey on industrial waste, in which the total amount of non-sector specific waste was estimated at 205,000 tons, of which 16,000 tons were plastic waste. This does not correspond at all with the data mentioned before. APME (1996) estimates on the basis of theoretical calculations the amount of plastic waste from distribution and large industry on 65,000 tons. However, the calculated value of 16,550 tons PVC in non-sector specific waste seems at least not to be denied by those data. Therefore the 16,550 tons is taken as a basis for further calculations. As stated above, about 80 % is landfilled. We assume that the other 20 % is incinerated.

Table 12.2.1 reviews the PVC flows in the waste stage. We assumed that the PVC-formulation of the waste is identical to the PVC products produced in 1994 (see chapters 4 to 10). This way, we calculated the composition and caloric value of the PVC waste flows. We assumed that Ba/Zn and Ca/Zn consist of 50 % Zn and 50 % Ba or Zn. The caloric value of pure PVC was estimated on 17 MJ/kg and phthalates on 40 MJ/kg (comparable to oil). Components like pigments, processing aid and bonding agent had to be neglected, since no composition is available. Except for pigments the relative mass of potential toxic elements seems negligible for these components. The breakdown of flows of individual components to incineration and landfill shown in the table was calculated on the basis of the amount incinerated and landfilled of the individual PVC products and their composition.

12.3 Incineration

In its work to draft the Environmental Impact Assessment of the Dutch Hazardous Waste Management Plan, TNO has constructed mass balances and emission factors for Municipal Solid Waste Incinerators MSWIs (TNO, 1996). Such mass balances are necessary to calculate the fate of the input in the incinerator, in this case PVC. Due to the strict time restraints for the study in phase 1, it was decided to use these data and not to inventory specific data for Swedish incinerators. We found specific Swedish data are only available for a very limited number of interventions, like a small number of heavy metals and NO_x (Person, 1994; Finnveden, 1995b). Since both Sweden and the Netherlands have very stringent emission regulations, the differences can be regarded as relatively small. However, specific data for Sweden would have been preferable.

Table 12.2.1: The PVC waste stage in Sweden in 1994 (in ton)

	Waste flows			Composition						
	Total waste	Landfill	Incineration	Chlorine	DEHP	BBP	DIDP	Pb organotin	Ba/Zn*	Ca/Zn*
Building waste										
pipes	1000	1000	0	577	0	0	0	8	0	0
flooring	11700	11450	250	6746	3510	970	0	0	4	240
cables	6000	6000	0	3459	2700	0	300	168	0	0
window frames	66,7	66,7	0	38	0	0	0	0	0	0
pipes for elect. wire	66,7	66,7	0	38	0	0	0	0	0	0
coated building plate	80	80	0	46	20	0	0	0	0	1
roof covering	1500	1500	0	865	375	0	0	0	0	23
plastisol building plate	2250	2250	0	1297	900	0	0	0	25	0
other build. app.	66,7	66,7	0	38	0	0	0	0	0	0
wall paper	300	300	0	173	165	0	30	0	0	6
Car wrecks										
cables	55	55	0	31	9	0	18	2	0	0
foils	910	910	0	525	228	0	0	0	0	14
coated fabrics	910	910	0	525	501	0	91	0	0	18
undercoating	202	202	0	116	202	0	0	0	0	0
Tarpaulins	167	167	0	96	92	0	17	0	0	3
Domestic waste*										
electrical equipment	1127	563,5	563,5	650	50	0	100	12	0	0
packaging	1500	750	750	865	0	0	0	0	30	0
Grocery packaging	1000	500	500	577	250	0	0	0	0	15
Coated fabrics (50 %)	1000	500	500	577	550	0	100	0	0	0
Other waste										
manufacturing	2300	1840	460	1326	0	0	0	11	0	0
office equipment	1500	1200	300	865	375	0	0	0	0	23
other flex. f&f	2820	2256	564	1626	705	0	0	0	0	42
medical packaging	300	0	300	173	0	0	0	0	6	0
other rigid f&f	4580	3664	916	2641	0	0	0	0	93	0
other plastisol	1000	800	200	577	400	0	0	0	11	0
medical tubes/hoses	600	0	600	346	300	0	0	16	0	0
other soft tubes/hoses	1200	960	240	692	600	0	0	32	0	0
camouflage fabrics	1500	1200	300	865	825	0	150	0	0	30
other artif. leather (50 %)	1000	800	200	577	550	0	100	0	0	20
Total	46700	40057	6644	26925	13306	970	906	249	169	435
To incineration			6644	3830	1491	21	150	31	42	36
To landfill		40057		23095	11815	949	756	219	127	399
Comparison subtotals	This study			Other estimates						
Building waste	23030			9500-65000						
Car wrecks	2243			3000-6000						
Domestic waste	4627			3200-6400						
Other waste	16800			14000						

Explanation:

All additive flows have been calculated on the basis of the recipes for new PVC (see chapter 4 to 10). Only for cables a correction was made for the fact in the past DEHP was the main plasticiser instead of the now used DIDP (see chapter 11)

* In the further calculations it is assumed that Ca/Zn and Ba/Zn stabiliser consist for 50 % of zinc

In the work for the Dutch EIA even important differences between several Dutch incinerators were found (Tukker, 1996a). Finnveden (1995b) published a mass balance for the Uppsala incinerator plant. In general, his emissions of heavy metals were about a factor of 2 to 3 higher than used here. Another indication of the uncertainties are the LCA Inventory data for PVC incineration used by Person et al. (1994). They adopt an emission of 2.9 kg NO_x per ton PVC, apparently a value for an incinerator without DeNO_x. For the average Dutch incinerator equipped with DeNO_x this would be 0.45 kg. On the other hand, Person's CO₂-emission values are virtually the same as ours. In brief, our approach will lead to an uncertainty factor from 2-3 up to a factor of 6 at most in emission figures.

In the calculations a distinction is made between *process-related* and *component-related* emissions. The component-related emissions are a function of the composition of the waste. By a mass balance approach, it is calculated which part of the component is emitted to the air, to water and which part ends up in the fly ash or slag. The process-related emissions like VOS, NO_x can not directly be allocated to an individual waste stream. In general, such emissions are allocated on the basis of the flue gas volume created by the waste. Since flue gas volumes are not always known, as a second approximation the caloric value of the waste is widely used. The idea is that high caloric waste in general will contribute most to the formation of CO₂, that is the most important for the stack gas volume. Table 12.3.1 gives a review of the mass balances and interventions for MSWIs used in this study. The process-related values in the table are valid for average Dutch Municipal Solid Waste with a caloric value of 10 MJ/kg. Other assumptions in the calculations are:

- 21.5 % of the caloric value can be converted into electricity (which might be too high a value for Sweden, since not all MSWIs produce electricity);
- 27 % of the caloric value is used to generate heat ;
- the electricity needs of the MSWI itself are 500 MJ/ton waste, mainly for flue gas cleaning;
- for flue gas cleaning NaOH and CaOH is needed; the volume is related to the amount of acidifying components in the waste (like chlorine or sulphur);
- slag and fly ash are (in contrast to the Dutch situation) **totally landfilled**. Very rough estimates, only to be used for preliminary calculations, are that under these conditions 0.1 % of the metal leaches out to the soil over the whole lifetime the material is landfilled (Tukker, 1996; AOO, 1995). In this SFA, there is the additional problem that the emissions in 1994 (from all PVC landfilled) have to be estimated. For simplicity's sake, we assumed here that the emissions in 1994 from the metals accumulated in landfills in the last 30 years will be more or less the same as the emissions that can be expected from the amount of metals landfilled in 1994 during the surveyable time period that this material is landfilled. The surveyable time period is defined as the time to reach a pseudo-steady state in a landfill, and is at this moment provisionally set at 100 years (Finnveden, 1995b). Finnveden gives some estimates for emission factors for metals we decided to use here instead of AOO's values.

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Table 12.3.1: Process- and component-related emissions from MSWIs.

Subst.	Mass balance			Comp. waste (ton/ton)	Mass balance (in ton/ton waste)		
	% Resid.	% Air	% Water		Air (ton/ton)	Water (ton/ton)	Inc. Residue (ton/ton)
Ag	-	-	-	-	-	-	-
As	99.95%	0.05%	0.00%	2.32E-06	1.20E-09	3.50E-11	2.32E-06
Ba	100.00%	0.00%	0.00%	1.60E-06	-	-	1.60E-06
Cd	99.75%	0.22%	0.03%	1.46E-05	3.20E-08	4.55E-09	1.45E-05
Co	99.96%	0.04%	0.00%	2.54E-06	9.00E-10	-	2.54E-06
Cr	99.97%	0.02%	0.01%	3.97E-05	9.00E-09	3.15E-09	3.97E-05
Cu	99.99%	0.01%	0.00%	4.69E-04	2.80E-08	3.85E-09	4.69E-04
Fe	100.00%	0.00%	0.00%	1.00E+00	-	-	1.00E+00
Hg	81.66%	18.34%	0.00%	6.00E-07	1.10E-07	1.68E-11	4.90E-07
Mn	99.99%	0.01%	0.00%	1.25E-04	7.50E-09	-	1.25E-04
Mo	100.00%	0.00%	0.00%	3.75E-06	-	-	3.75E-06
Ni	99.85%	0.09%	0.06%	2.58E-05	2.30E-08	1.47E-08	2.57E-05
Pb	99.92%	0.07%	0.00%	3.76E-04	2.80E-07	8.40E-09	3.76E-04
Sb	100.00%	0.00%	0.00%	2.74E-05	-	-	2.74E-05
Se	100.00%	0.00%	0.00%	3.25E-07	-	-	3.25E-07
Sn	100.00%	0.00%	0.00%	6.42E-05	-	-	6.42E-05
Sr	100.00%	0.00%	0.00%	6.00E-06	-	-	6.00E-06
V	100.00%	0.00%	0.00%	1.38E-05	2.50E-10	-	1.38E-05
W	-	-	-	-	-	-	-
Zn	99.92%	0.08%	0.00%	7.92E-04	6.00E-07	1.54E-08	7.92E-04
Dust	-	-	-	-	-	-	-
AOX/EOX*	-	-	-	5.95E-10	-	4.90E-10	1.05E-10
Cl	76.92%	0.05%	23.03%	3.13E-03	2.00E-06	9.38E-04	3.13E-03
F	99.06%	0.30%	0.64%	1.01E-04	3.00E-07	6.51E-07	7.06E-05
S (SO4)	97.80%	0.45%	1.75%	4.31E-03	2.00E-05	7.70E-05	4.31E-03

Subst.	Mass balance			Comp. waste (ton/ton)	Mass balance (in ton/ton waste)		
	% Resid.	% Air	% Water		Air (ton/ton)	Water (ton/ton)	Inc. Residue (ton/ton)
S (H2S)*							
N (NO3-)					2.50E-04		
NH4						2.52E-06	4.28E-07
CO2					7.81E-01		
CZV						4.90E-06	1.05E-06
CO					1.30E-04		
CxHy							
TCDD TEQ					5.00E-13		2.99E-10
PCB					2.50E-09		3.51E-13
HCB					9.00E-08		
PAK						6.02E-11	
Benzene					1.10E-05		
Toluene					6.50E-06		
Eth-benz					9.00E-07		
Styrene					3.30E-07		
t-chl-eth					5.50E-06		
tri-chl-eth					1.10E-06		
Cal val (MJ)				1.00E+04			
Ash resid.				2.50E-01			

Legenda:

- From the total mass flow in slag, fly-ash, gas cleaning residue (Gcr) and sludge the mass flow in MSWI-residues is calculated. Emissions to air and water have been taken from (AOO, 1995)
- From these mass balances in tons the theoretical composition of the waste input is calculated. Also on this basis a mass balance in % is shown.
- The leaching of MSWI residues to soil is 1 % in materials re-used and 0.1 % in material landfilled. Slag is assumed to be 100 % and fly ash for 72 % re-used.
- The emission of EOC1 and H2S is assumed to be proportional with the Cl and S contents of the waste.
- The own electricity used is estimated on 500 MJ/ton. The flue gas cleaning needs 3 kg NaOH en 4,5 kg CaO per ton afval at the given Cl and S content of the waste and is assumed proportional with the acid forming potential related to the Cl and S content of the waste
- The use of NH3 and active carbon for flue gas cleaning is neglected.

The emission factor for lead is $6 \cdot 10^5$ kg/kg to water. For most other metals he gives estimates of about $1 \cdot 10^{-4}$ kg/kg, e.g. for zinc $2 \cdot 10^{-4}$ kg/kg. Finnveden's estimated uncertainty is up to a factor of 100. We used his factors to calculate the emissions from metals out of the incinerator residues. No leachate treatment is assumed, though for quite a lot of landfills this might result in a worst case estimate since they actually treat their leachate.

- The volume of slag is calculated on the basis of the ash content of the waste. The volume of the dry residue, the flue gas cleaning residue is calculated on the basis of the chlorine content, since this amount is mainly influenced by the amount of salt created in the flue gas cleaning. Since the chlorine is released as HCl in the incineration process, and is neutralised with NaOH, landfilling of the Na-ions is causally related to the incineration of PVC. We therefore allocated the Na also to the landfill volume. To be as complete as possible, we added the amount of stabilisers in the incinerated PVC to the landfill volume. The mass balance of Tukker (1996) shows that virtually all metals like Zn and Pb end up for almost 100 % in the incinerator residues.

12.4 Landfill

The behaviour of PVC in landfill in the long term is not well known. For the short term, most authors state that virtually no leaching of stabilisers or degradation of PVC takes place (Plinke, 1994, Sundmark, 1995a and 1995b, Tukker, 1995a). Other authors mention a 1 to 5 % degradation in the 'surveyable time-period', even with HCl or VCM formation (Sundqvist, 1995). Since in our case we have to deal with PVC that is at maximum landfilled for 30 years, we assumed a zero degradation here. No serious judgement can be given on the long term behaviour at this stage. This is, by the way, not important for this SFA since only the actual emissions in the year 1994 are taken into account. The emission and transformation of plasticiser is more likely. Here only degradation of plasticiser is taken into account. Some very rough methods have been developed that allocate emissions from landfills to the input of a specific waste (Mingarini et al. 1995; Eggels et al., 1995; Finnveden et al. 1995d). In this SFA, there is the additional problem that the emissions in 1994 (from all PVC landfilled) have to be estimated. For simplicity's sake, we assumed here that the emissions in 1994 from the plasticisers accumulated in landfills in the last 30 years will be more or less the same as the emissions that can be expected from the amount of plasticisers landfilled in 1994 during the surveyable time period that this material is landfilled. Sundqvist (1995) and Mingarini et al. (1995) give some rough rules of thumb by which emissions from plasticisers can be estimated:

- 70 % of medium degradable carbohydrates will degrade. We have assumed that phthalates, that consist for about 75 % of carbon, are medium degradable components;
- about 1 % of the degraded carbon will flow out with the leachate. The amount of COD is 3 times the amount of carbon in leachate. The amount of BOD is

- 0.75 times the amount of carbon in leachate;
- of the remaining 99 % degraded carbon, according to Mingarini et al. (1995) for carbohydrates in general 50 % is transformed into CH_4 and 50 % is transformed into CO_2 ;
- 50 % of the methane formed is recovered and used for energy production;

Finnveden (1995a) gives some estimates for emission factors for metals. The emission factor for lead is $6 \cdot 10^5$ kg/kg to water. For most other metals he gives estimates of about $1 \cdot 10^{-4}$ kg/kg. Finnveden's estimated uncertainty is up to a factor 100. We used these factors to calculate the emissions from metals out of the PVC. No leachate treatment is assumed, though for quite a lot of landfills this might result in a worst case estimate since they actually treat their leachate.

Tables 12.3.1 and 12.3.2 review these data. It has to be stressed that all these data are only a very rough estimation of the reality, and that uncertainties in the calculated emissions could be one order of magnitude or more. Specifically the methane formation for plasticisers is quite questionable. Plasticisers indeed degrade reasonably under aerobic circumstances, which would give indeed mainly CO_2 . But under anaerobic circumstances phthalates seem quite poorly degradable (Peijnenburg, 1991), which would mean that methane formation in the methanogenic phase of a landfill is not probable. A consequence, though, would be that relatively high amounts of phthalate would stay present in landfills.

Apart from the emissions of the degradation processes, the interventions related to handling the waste at the landfill site are also given. This is mainly diesel and electricity for landfill-handling activities. Values of 42.5 MJ/ton diesel use and 4.14 MJ/ton electricity use have been taken from Eggels (1995). His data are rather good and in agreement with those of Person (1994). The rather high diesel use of 800 MJ/ton given by Mingardi et al. (1995) is not in accordance with those authors and has been neglected. The energy use given has to be allocated *both to the plasticisers and the PVC* that is landfilled. The fact that PVC does not degrade has of course no influence on the fact that the PVC has to be transported and compacted in the landfill. The *direct exhaust gas emissions* related to the 42.5 MJ diesel per ton needed for compacting have been calculated making use of an inventory table from the EIA on the Dutch Waste Management Plan 1995-2005 (AOO, 1995). Emissions related to the winning and production of oil are not included, since they take place (partially) outside Sweden and have been excluded from the system under study in the SFA.

² Both Sundquist (1995) and Finnveden (1995b) give a more sophisticated formula to estimate the relative amounts of breakdown products like methane, CO_2 and water as a function of the chemical formula of the component. Given the very provisional state of the art with regard to modelling landfill emissions in LCA, it is unlikely that using that formula will significantly improve the quality of our emission estimates.

Norrthon (1994) estimates that the total amount of PVC flooring, coated fabrics and soft foil that has been landfilled is 230,000 tons. With 25 to 50 phr plasticiser this means 60,000 to 115,000 tons phthalates in landfills. Since the amount of PVC and of plasticiser accumulated in landfills, particularly with flooring, is thus relatively high, the knowledge gaps related to PVC and plasticiser degradation can have serious consequences.

Table 12.3.2: Tentative inventory table for from 1 ton landfilled plasticiser (in kg substance)

Substance	Fraction	Fraction of the original carbon content	For 750 kg carbon in 1.000 kg plasticiser
COD to water	70 % degraded 1 % to leachate 1 ton C = 3 ton COD	$0.7 \cdot 0.01 \cdot 3 = 0.021$	15 kg/ton plast.
BOD to water	70 % degraded 1 % to leachate 1 ton C = 0.75 ton BOD	$0.7 \cdot 0.01 \cdot 0.75 = 0.0075$	5.6 kg/ton plast.
CO ₂ to air	70 % degraded 99 % to air 50 % to CO ₂ 1 ton C = 3.66 ton CO ₂	$0.7 \cdot 0.99 \cdot 0.5 \cdot 3.66 = 1.26$	945 kg/ton plast.
CH ₄ to air	70 % degraded 99 % to air 50 % to CH ₄ 50 % to air 1 ton C = 1.33 ton CH ₄	$0.7 \cdot 0.99 \cdot 0.5 \cdot 0.5 \cdot 1.33 = 0.231$	173 kg/ton plast (hvery uncertain).
CH ₄ to energy recovery	see CH ₄ to air	0.231	173 kg/ton plast. (very uncertain)

Table 12.3.2: Emission factors for from 1 ton landfilled material (in kg substance)

Substance	
Pb (to water)	$6 \cdot 10^{-5}$ kg/kg landfilled
Zn (to water)	$2 \cdot 10^{-4}$ kg/kg landfilled
Emissions related to 42,5 MJ/ton on-site diesel use	
- CO	0.02 kg/ton landfilled
- SO ₂	0.004 id.
- CO ₂	3.23 id.
- C _x H _y	0.01 id.
- NO _x	0.05 id.
Electricity use	4.14 MJ/ton landfilled

13 Processes outside the system of the PVC-SFA

13.1 Introduction

As explained earlier, this SFA concentrates on an inventory of the emissions in a system limited to the processes in the PVC-chain in Swedish territory in 1994. Only the production of the precursors chlorine, EDC and VCM have been included, as far as this production takes place in Sweden. In essence, this SFA tries to identify environmental priorities related to the use of a substance in a *region*: the so-called regional approach as defined by van der Voet (1996). As a consequence, not all processes have been included that contribute to a *functional unit* of a product made with PVC. Our approach is thus fundamentally different to the *functional* approach followed in LCAs.

In order to gain a certain insight into how important the neglected processes are, this chapter reviews the environmental impacts related to the production of the other main materials and ancillary materials used in the Swedish PVC-chain. We used some common available data from LCA-databases. It has to be stressed that these inventory tables in principle *can not be used* directly in this SFA. The LCA-data are aggregations of emissions of a number of processes that take place in geographically very different locations. E.g. an inventory table of ethene may contain average data for oil winning in the North Sea, data for an oil refinery in Holland, and data for cracking to ethene in Sweden. In a purely regional approach, only the cracking process should be included in the SFA.

When using LCA-inventory data, in fact one has to create a (non-existing) hypothesis: that *all processes* included in the inventory table hypothetically take place in Sweden. We used this approach only to get insight in the *potential* importance of processes in the upstream chains related to the processes in the PVC-chain in Sweden.

All previous chapters list the amount of electricity and other resource uses in the processes in the Swedish PVC chain. Table 13.1.1 reviews these data and gives the totals. Table 13.1.1 shows that the most important substances and resources are:

- electricity;
- ethene;
- plasticiseres;
- stabilisers and pigments.

The impacts related to the production of these substances are reviewed in the next paragraphs.

Table 13.1.1: Resources used in the Swedish PVC-chain, not included in the system of this SFA

	amount	allocated to the PVC chain (%)*	allocated to the PVC chain	unit
Production				
chlorine				
salt	198775	17	33846	ton
hydrochloric acid, 30%	2375	17	404	ton
sulphuric acid, 98%	1623	17	276	ton
CO ₂	33,05	17	6	ton
Nitrogen	75500	17	12856	Nm ³
steam	5320	17	906	ton
desalted water	231100	17	39350	m ³
electricity	4,17E+09	17	710671257	MJ
EDC/VCM				
ethylene	98871	85	83760	ton
steam	82135	85	69582	ton
feed water	197025	85	166913	m ³
nitrogen	5229419	85	4430189	Nm ³
NaOH, 100%	2677	85	2268	ton
methane (fuel gas)	8757	85	7419	TOE
fuel gas	27565	85	23352	GJ
methane	29658	85	25125	GJ
VCM-tar, EDC-tar, light ends	142000	85	120298	GJ
electricity	0	85	0	MJ
PVC				
steam	214719	100	214719	ton
nitrogen	1555715	100	1555715	Nm ³
process water	545069	100	545069	m ³
water	25920	100	25920	m ³
chemicals	3677	100	3677	ton
Electricity	0	100	0	MJ
Manufacturing of PVC intermediate products				
pipes				
impact modifier (MBS)	0-1728	100	0-1728	ton
processing aid	0-144	100	0-144	ton
filler (CaCO ₃)	576-1152	100	576-1152	ton
electricity	115200000	100	115200000	MJ
flooring				
Ba/Zn stabiliser	587	100	587	ton
Ca/Zn stabiliser	35	100	35	ton
electricity	200200000	100	200200000	MJ
cables				
Ca/Zn stabiliser	193	100	193	ton
filler (CaCO ₃)	6450	100	6450	ton
electricity	51600000	100	51600000	MJ
profiles				
Ca/Zn stabiliser	313	100	313	ton
impact modifier (MBS)	797	100	797	ton
prod. modifier	100	100	100	ton
filler and pigment (CaCO ₃ , TiO ₂)	900	100	900	ton
lubricant	16	100	16	ton
electricity	42000000	100	42000000	MJ
foils/films				
Ba/Zn stabiliser	86	100	86	ton
ESO	173	100	173	ton
impact modifier (MBS)	518	100	518	ton
product modifier (PMMA)	86	100	86	ton
wax, pigment	104	100	104	ton
electricity	86400000	100	86400000	MJ
paint/plastisol				
Ca/Zn stabiliser	70	100	70	ton
pigments	45-4500	100	45-4500	ton
antimonytrioxide	225-450	100	225-450	ton
electricity	22500000	100	22500000	MJ
soft tubes/hoses				
Ca/Zn stabiliser	20	100	20	ton
filler CaCO ₃	650	100	650	ton
electricity	5200000	100	5200000	MJ
coated fabrics				
Ba/Zn stabiliser	46	100	46	ton
ESO	69	100	69	ton
pigments	46	100	46	ton
bonding agent	23	100	23	ton
electricity	18400000	100	18400000	MJ

* Remark: Allocation on the basis of economic value of the products of a multiple-output process (see part II)

13.2 Phthalates, stabilisers and pigments

Information on the environmental interventions related to the production of phthalates, stabilisers and pigments is extremely difficult to get. Most studies concentrate on the effects related to the *use and waste management* of (products containing) these materials (e.g. KemI reports, Stuurgroep PVC en Milieu 1990, 1991a and 1991b, Moller et al, 1995, etc.). Even for these phases, LCA-studies in most cases neglect emissions of these substances totally (e.g. the VITO-study on PVC-packaging; see Lindeijer and Reijnders, 1995) or partially (v.d. Berg, 1996).

The latter so-called Gastec study (on pipes) included the production of stabilisers and pigments. Emissions were very roughly estimated by using a default loss of 1 % to water of each primary material used in the production (v.d. Berg, 1996). TNO (1992) estimates the losses of cadmium pigments or stabilisers during the production *and application in the manufacturing of PVC-products* on 0.1 % to water and 0.2 % to air. Losses in the application (manufacturing) stage could be about 0.1 % to air (Eijssen, 1993). It is unclear whether from these data it can be concluded that losses for the production stage alone could be in the order of magnitude of 0.1 %. Nor is it clear whether such losses can be expected for other than cadmium-containing pigments and stabilisers. For comparison: the emissions to air by the Dutch pigment industry are about 2.6 ton zinc and 9.2 ton lead on a total pigment production of 55,000 ton. VOC emissions are about 189 tons (0.3 % VOC per ton pigment), Nitrogen emissions to water are 778 tons (1.4 % N per ton pigment) and COD to water 112 tons (0.2 % per ton pigment) (Etman, 1994). A breakdown to individual pigments is not available. However, if losses up to 0.1 % were to occur in the production stage of stabilisers and pigments containing lead, organotin and zinc, they are significant compared to other losses in the PVC-chain. Also VOC and nutrifying emissions could be significant.

The major amount of ancillary material used in the PVC chain are phthalates. These are produced by a reaction between C_7-C_{10} alcohols with phthalic anhydride. Table 13.2.1 gives emission and energy-use data for a Dutch phthalate plant with a production volume of 220,000 tons a year for 1992 (v. Ewijk, 1992). Both the alcohols and the phthalic anhydride are produced on location. Olefines for the alcohol production and orthoxylene for the phthalic anhydride production are obtained from third parties; since the site is phthalic anhydride deficient, about 50 % of this material is obtained from third parties as well. Energy use is only known for the phthalic anhydride production. For these reasons, table 13.3.1 does *not* give a complete inventory table for the phthalate production. However, taking into account the yearly phthalate use in Sweden is about 10 % of the capacity of the Dutch plant, table 13.3.1 can be used to estimate whether the environmental interventions of the phthalate production are significant. It seems that emissions are not totally negligible compared to those from the PVC-chain study, but that they are of relatively minor importance. Exceptions might be the emissions of organic carbon and cobalt to water.

Table 13.2.1: Preliminary inventory table for the production of phthalates (excluding the production of olephines and orthoxylene)

Substance	Emission/intervention Dutch production (220,000 ton)	Emission/intervention for 22,000 ton (10 %)
Air		
VOC (ton)	101	10.1
NOx (ton)	76	7.6
SO ₂ (ton)	15	1.5
phthalates (ton)	0.4	0.04
Water		
Organic carbon (ton)	83	8.3
Cobalt	1.8	0.18
phthalates	1	0.1
Waste		
Solid waste	1720 ¹	172
Energy		
Electricity (MJ)	103 E+06 ²	10.3 E+06 ²
Gas (MJ)	6 E+06 ²	0.6 E+06 ²
Steam (42 atm; MJ)	-257 E+6 ²	-25.7 E+6 ²

¹ Excluding phthalic anhydride production

² Excluding alcohol- and final phthalate production

13.3 Electricity and ethene

For electricity and ethene generally accepted quantitative data were available. The inventory tables used are given in table 13.3.1. For ethene data from Frischknecht (1994) have been used. The data for electricity have been taken from Vattenfall (IVF, 1995).

With regard to electricity, the emissions per MJ are very low compared to e.g. average European or Dutch emission data. This is caused by the fact that in Sweden virtually no fossil fuel is used for electricity generation. About 50 % of the electricity is generated by hydropower, the other 50 % is generated by nuclear power (SCB, 1996). Of course this gives Nordic production processes with an important electricity use an apparent, but also quite questionable, advantage over production processes elsewhere in Europe. The main question is whether it is permissible to allocate the benefits of a (coincidental) favourable electricity generation on national level to the processes in this nation, or in fact a regional average like the European Grid has to be used. On this allocation problem no consensus is available. We decided to use the specific Swedish data, since imports and exports of electricity from Sweden seem rather unimportant and to indicate the consequences of this choice in the conclusions of the study.

Environmental interventions related to the ethene production have been taken from Frischknecht (1994). We analysed which substances from which sub-processes made the most important contributions to environmental theme scores. The following conclusions were possible:

- global warming is caused for 92 % by CO₂ and for 7 % by methane emitted from various steps in the production chain;
- smog formation is mainly caused by ethane;
- acidification is mainly caused by sulphur- and nitrogen oxide in the refining process;
- nutrification is mainly caused by nitrogenoxide from the refining process;
- aquatic ecotoxicity (AETP) is for 80 % caused by phenol emissions during oil winning and for 11 % caused by nickel emissions due to incineration of oil residues in refineries;
- terrestrial ecotoxicity (TETP) is for 64 % caused by cadmium emissions to the air during oil winning and for 30 % caused by vanadium emissions due to incineration of oil residues in refineries;
- human toxicity (HTP) is mainly caused by vanadium (53 %) and nickel (26%) emitted to air due to incineration of oil residues in refineries;

Table 13.3.1: Inventory table of aggregated proces of ethene production (Frischknecht, 1994).
Various nuclear emission not taken into account

environmental input			(emissions to air -ctd.)			
	2.54E-03	m3yr	reservoir content	1,16E-09	kg	aldehyde
	5.25E-01	m3	watermass turbine	2.22E-05	kg	alkanes
	1,11E-01	MJ	potent. energy water	1,10E-06	kg	Al
	7.28E-17	kg	Cl2	2,10E-07	kg	NH3
	5,31E-06	kg	Cr	5,09E-10	kg	Sb
	6,05E-11	kg	Co	3,85E-08	kg	As
	2,72E-05	kg	Cu	1,34E-08	kg	Ba
	6,70E-03	kg	Fe	5,30E-11	kg	benzaldehyde
	1,64E-06	kg	Pb	9,37E-05	kg	benzene
	1,45E-06	kg	Mn	2,46E-10	kg	benzo(a)pyrene
	1,52E-04	kg	mine gas	7,09E-07	kg	B
	1,89E-09	kg	Mo	4,61E-08	kg	Br2
	3,38E-06	kg	Ni	2,93E-07	kg	halon_1301
	1,23E+00	kg	crude oil	8,76E-08	kg	Cd
	1,95E-06	kg	Sn	6,52E-01	kg	CO2
	2,77E-07	kg	Zn	5,71E-04	kg	CO
	2,08E-02	kg	crude hard coal	6,05E-08	kg	Cr
	1,97E-02	kg	browncoal	9,28E-08	kg	Co
	1,45E-06	kg	U	1,83E-07	kg	Cu
	4,17E-04	kg	wood	2,48E-10	kg	CN-
	2,29E-03	kg	natural gas	8,06E-06	kg	N2O
	8,97E-03	m3	H2O	7,64E-08	kg	acetaldehyde
	8,26E-05	kg	bauxite	2,13E-05	kg	ethane
	1,34E-02	kg	limestone	1,52E-07	kg	ethanol
	1,73E-04	kg	stone salt	4,17E-06	kg	ethene
	5,50E-09	kg	Pa	2,10E-06	kg	ethylbenzene
	6,20E-09	kg	Pt	3,45E-09	kg	C2F6
	3,85E-09	kg	rhenium	1,38E-05	kg	HCl
	5,85E-09	kg	rhodium	1,44E-06	kg	HF
	3,52E-06	kg	Ag	1,79E-07	kg	H2S
	5,82E-03	kg	barite	1,36E-06	kg	Fe
	2,13E-03	kg	bentonite	2,21E-07	kg	Pb
	1,10E-04	kg	zeolite	5,64E-08	kg	Mn
	5,97E-02	kg	oil gas	8,03E-09	kg	Hg
	1,61E-03	m2yr	space III-IV	3,75E-07	kg	formaldehyde
	1,13E-02	m2yr	space II-IV	4,80E-03	kg	CH4
	2,27E-05	m2yr	space IV-IV	2,18E-07	kg	methanol
	9,65E-02	m2yr	space II-III	4,85E-10	kg	MTBE
economic output				1,25E-05	kg	toluene
emissions to air	1,00E+00	kg	(aggreg) ethene	4,43E-08	kg	Mo
	2,94E-06	kBq	various nuclear emissions	1,83E-09	kg	vinylchloride
	1,55E-06	kBq	various nuclear emissions	8,52E-05	kg	butane
	3,18E-03	kBq	various nuclear emissions	2,01E-05	kg	n-heptane
	9,66E-07	kg	N2	4,24E-05	kg	hexane
	1,11E-08	kBq	various nuclear emissions	1,07E-04	kg	n-pentane
	3,52E-05	kBq	various nuclear emissions	2,63E-06	kg	Na
	3,13E-06	kBq	various nuclear emissions	2,93E-06	kg	Ni
	1,43E-10	kBq	various nuclear emissions	2,84E-03	kg	NOx
	1,31E-01	kBq	various nuclear emissions	2,81E-10	kg	phenol
	7,11E-05	kBq	various nuclear emissions	6,88E-08	kg	P
	2,22E-08	kBq	various nuclear emissions	4,37E-09	kg	PAH
	7,57E-07	kBq	various nuclear emissions	2,38E-09	kg	propionicacid
	8,88E-07	kBq	various nuclear emissions	5,30E-11	kg	propionaldehyde
	3,94E-06	kBq	various nuclear emissions	8,42E-05	kg	propane
	3,55E-07	kBq	various nuclear emissions	4,04E-06	kg	propene
	6,31E-05	kBq	various nuclear emissions	4,71E-03	kg	SOx
	1,74E-05	kBq	various nuclear emissions	2,76E-08	kg	CF4
	1,20E-05	kBq	various nuclear emissions	3,25E-10	kg	Sn
	2,29E-07	kBq	various nuclear emissions	4,32E-08	kg	Ti
	3,55E-07	kBq	various nuclear emissions	1,19E-05	kg	V
	5,46E+01	kBq	various nuclear emissions	3,15E-07	kg	Zn
	3,70E-06	kBq	various nuclear emissions	3,76E-10	kg	U
	9,86E-07	kBq	various nuclear emissions	1,36E-03	kg	particles
	9,33E-06	kBq	various nuclear emissions	3,55E-07	kg	Mg
	1,11E-06	kBq	various nuclear emissions	1,21E-07	kg	K
	3,41E-06	kBq	various nuclear emissions	9,80E-07	kg	Ca
	4,47E-07	kBq	various nuclear emissions	1,36E-10	kg	Be
	7,15E+01	kBq	various nuclear emissions	4,22E-08	kg	Se
	1,13E-12	kBq	various nuclear emissions	1,55E-13	kg	Pt
	4,05E-08	kBq	various nuclear emissions	3,96E-10	kg	La
	2,82E-07	kBq	various nuclear emissions	1,08E-07	kg	alkenes
	1,68E-06	kBq	various nuclear emissions	9,15E-03	kg	NMVOC
	2,82E-12	kBq	various nuclear emissions	2,01E-06	kg	butene
	1,45E-06	kBq	various nuclear emissions	4,04E-15	kg	TCDD
	5,07E-03	kBq	various nuclear emissions	2,22E-08	kg	iodium
	2,20E-05	kBq	various nuclear emissions	2,55E-06	kg	Si
	1,76E-08	kBq	various nuclear emissions	1,42E-10	kg	Zr
	3,20E-09	kg	ethylene dichloride	1,50E-10	kg	Sc
	8,46E-06	kg	xylene	1,60E-08	kg	Sr
	7,65E-08	kg	acetone	8,54E-10	kg	Th
	1,02E-10	kg	acrolein	6,03E-05	kg	He
	3,23E-07	kg	acetic acid	4,87E-08	kg	aromatic hydrocarbons
	1,30E-06	kBq	various nuclear emissions	5,78E-09	kg	ethyne
				3,81E-11	kg	Tl

Table 13.3.1: Inventory table of aggregated proces of ethene production (Frischknecht, 1994).
Various nuclear emission not taken into account (continued)

			(emissions to water, ctd.)			
heat	1.77E+01	MJ	heat waste to air	3.05E-07	kg	Cu++
	1.33E+00	MJ	heat waste to water	2.71E-07	kg	CN-
	3.84E-02	MJ	heat waste to soil	5.43E-08	kg	methylene chloride
Emissions to soil				1.48E-06	kg	ethylbenzene
	2.83E-06	kg	mineral oil	1.19E-06	kg	F-
Emissions to water	6.63E-09	kg	plant oil	1.39E-08	kg	CxHy
				7.10E-09	kg	H2S
	6.57E-06	kBq	various nuclear emissions	5.03E-05	kg	Fe++
	2.11E-03	kBq	various nuclear emissions	4.00E-07	kg	Pb
	1.60E-04	kBq	various nuclear emissions	4.14E-06	kg	Mn
	5.81E-04	kBq	various nuclear emissions	9.01E-10	kg	Hg
	1.20E-06	kBq	various nuclear emissions	4.68E-12	kg	formaldehyde
	1.18E-06	kBq	various nuclear emissions	9.87E-12	kg	MTBE
	2.11E-04	kBq	various nuclear emissions	7.25E-06	kg	toluene
	4.22E-04	kBq	various nuclear emissions	1.49E-07	kg	Mo
	3.34E-04	kBq	various nuclear emissions	3.48E-07	kg	Ni
	4.92E-04	kBq	various nuclear emissions	3.82E-05	kg	NO3-
	7.92E-07	kBq	various nuclear emissions	1.16E-04	kg	N
	2.49E-03	kBq	various nuclear emissions	1.13E-03	kg	fats and oils
	1.12E+00	kBq	various nuclear emissions	9.60E-06	kg	phenol
	3.52E-06	kBq	various nuclear emissions	5.65E-07	kg	PO4---
	4.93E-05	kBq	various nuclear emissions	1.99E-06	kg	P
	7.12E-05	kg	salts	8.00E-07	kg	PAH
	2.48E-06	kBq	various nuclear emissions	1.20E-03	kg	SO4--
	7.22E-05	kBq	various nuclear emissions	1.08E-08	kg	SO3--
	3.70E-05	kBq	various nuclear emissions	3.32E-10	kg	Sn
	9.50E-04	kBq	various nuclear emissions	1.99E-06	kg	Ti
	1.94E-05	kBq	various nuclear emissions	1.35E-09	kg	tributyl tin salts
	1.31E-04	kBq	various nuclear emissions	2.23E-07	kg	V
	2.29E-06	kBq	various nuclear emissions	9.51E-07	kg	Zn
	6.57E-06	kBq	various nuclear emissions	3.03E-04	kg	K+
	6.14E-03	kBq	various nuclear emissions	2.13E-03	kg	Ca++
	5.05E-06	kBq	various nuclear emissions	1.84E-11	kg	Be
	3.07E-03	kBq	various nuclear emissions	2.15E-07	kg	Se
	3.40E-02	kBq	various nuclear emissions	1.99E-02	kg	Na+
	6.34E-06	kBq	various nuclear emissions	3.68E-08	kg	Ag
	5.05E-06	kBq	various nuclear emissions	1.13E-03	kg	barite
	1.23E-02	kBq	various nuclear emissions	7.25E-07	kg	alkenes
	5.63E-05	kBq	various nuclear emissions	2.21E-07	kg	AOX
	5.02E-09	kBq	various nuclear emissions	4.72E-08	kg	DOC
	2.23E-10	kBq	various nuclear emissions	4.96E-04	kg	TOC
	1.60E-09	kg	ethylene dichloride	6.14E-06	kg	I-
	5.78E-06	kg	xylene	2.70E-08	kg	Si
	7.98E-06	kg	alkanes	2.74E-10	kg	trichloroethylene
	3.39E-05	kg	Al	2.65E-10	kg	W
	8.05E-05	kg	NH3	3.72E-04	kg	Sr
	8.60E-10	kg	Sb	1.83E-06	kg	S-
	1.14E-07	kg	As	3.70E-05	kg	aromatic hydrocarbons
	1.57E-04	kg	Ba	2.21E-05	kg	Volatile organic compounds as C
	7.99E-06	kg	benzene	3.55E-08	kg	acids
	4.30E-06	kg	BOD5	6.14E-08	kg	Cesium ions
	1.87E-06	kg	B	1.40E-05	kg	dissolved substances
	6.72E-08	kg	Cd	3.12E-04	kg	fatty acids (total C
	1.22E-04	kg	COD	1.40E-07	kg	glutare aldehyde
	3.28E-02	kg	Cl-	2.22E-07	kg	HOCL
	6.59E-09	kg	Cl-	1.19E-04	kg	Mg++
	1.40E-10	kg	chlorobenzene	2.22E-07	kg	OCL-
	8.85E-07	kg	Cr3+	6.14E-07	kg	Rb
	6.36E-11	kg	Cr6+	3.51E-03	kg	unsolved substances
	6.64E-08	kg	Co			

Table 13.3.2: The environment load to produce 1 MJ of electricity (IVF, 1995)

Materials used			
	1.5	g	Oil
	1.5	g	Coal
	0.18	g	Gas
	0.003	g	Gas
	0.21	g	Peat
		g	Water
Emissions to air			
	3800	mg	CO ₂
	2,1	mg	CO
	6,7	mg	SO ₂
	9,2	mg	NO _x
	0,42	mg	N ₂ O
		mg	VOC
	0,14	mg	CH ₄
	1,1	mg	HC
		mg	HF
	0,07	mg	Dust
Emissions to water			
		mg	Cl ⁻
		mg	F ⁻
		mg	FE
		mg	NH ₃
		mg	NO ₃ ⁻ -N
		mg	Na ⁺
		mg	SO ₄ ⁻
		mg	CsF ₆
		mg	Nuclear waste
Emissions to land			
	70	mg	Ashes
	30	mg	Nuclear waste