What’s wrong with PVC?

The science behind a phase-out of polyvinyl chloride plastics

GREENPEACE

Contents

1. Summary

Polyvinyl chloride (PVC) is one of todays most common plastics. Around 20 million tonnes were produced in 1995, making it second only to polyethylene in terms of volume produced.

PVC production involves the creation of many toxic chemicals, as feedstocks, as additives or as by-products. Dioxins, including TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin, one of the most toxic synthetic chemicals known[1]) and furans are inescapable by-products of the production of the basic feedstock of PVC, vinyl chloride monomer[2]. When PVC is incinerated it releases its chlorine content and again causes the release of dioxins which are formed when chlorinated organic compounds, or a mixture of inorganic chloride and organic matter are burned.

PVC needs a host of additives to make it useable. Lead, cadmium or organotins are used as stabilisers. Phthalates are used as softeners in PVC and other chemicals are used as colourants, fire-retardants and anti-oxidants. Many of these are released into the environment. Phthalates, for example, are the world's most common environmental pollutant[3] and 95% are made for use in the production of flexible PVC.[4] These additives can leach out, threatening water supplies if PVC is landfilled,[5] or even during a product's lifetime as has happened with lead in PVC blinds[6].

The toxic chemicals released during the production, use and disposal of PVC threaten the environment and human health. Dioxins - known carcinogens[7] and hormone disrupters,[8] persist for many years and accumulate in the fatty tissues of living organisms. Levels thus become concentrated as they travel up the food chain. Those at the top of the food chain - humans and other mammals - carry the largest burden. Because dioxins accumulate in breast milk, nursing infants may be exposed to 10 to 20 times more dioxin than adults per unit of body weight. A breastfeeding baby may take in 4 to 12 percent of its lifetime dose of dioxins during the first year of life.[9] Newborn infants are especially susceptible to the effects of hormone disrupting chemicals.[10] The recent discovery that phthalates are present in dried baby milk means that it is impossible to avoid feeding toxic chemicals to new born babies. Politicians assure us that levels are not harmful. Scientists are divided. But arguments about safe levels and tolerable daily intakes miss the point. Mothers should not be forced to feed any level of carcinogenic, or potentially hormone disrupting chemicals to their children.

Alternatives to PVC are readily available for almost every use.[11] It's phase-out as an everyday product would be no real loss except to those who profit from pollution. We all stand to gain as the environmental burden of toxic, persistent, bioaccumulative chemicals, of hormone disrupters and of heavy metals would be significantly reduced.

2. Introduction

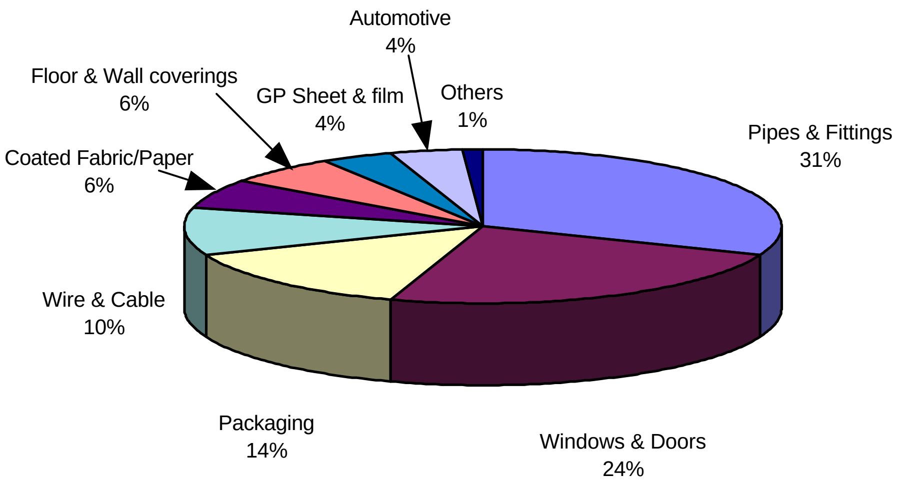
Most people are aware that plastics cause environmental problems. Their low biodegradability means that disposal always has environmental consequences and because they are made from oil or gas they are associated with all the pollution involved in the petro-chemical industry. The environmental hazards of PVC however go far beyond those associated with other plastics. Some of today's most worrying environmental contaminants are released during the production of PVC or its feed-stocks and when PVC products are disposed of.

This document draws together current scientific knowledge on the environmental contamination resulting from the production, use and disposal of PVC. It is intended to illustrate the real cost of a commodity that is so often used because it is perceived to be cheaper than alternatives.

3. What is PVC used for?

Although a wide range of products are manufactured from polyvinyl chloride, alternatives are available for virtually all of them. The biggest user of PVC is the construction industry which commonly installs PVC pipes and ducts, electric cables and wire insulation, windows, flooring, wall coverings, cladding and building membranes. Other products include electronic appliances such as computers, car components such as the interior upholstery and floor mats, medical products like surgical gloves and blood bags, many consumer goods for example toys, shower curtains, venetian blinds and much packaging including drinks bottles and sandwich cartons.

Figure 1. Estimated UK end-uses of PVC. From 'PVC - The Facts', British Plastics Federation 1994



4. How is PVC made?

Sodium chloride (salt) and natural gas or oil are the resources necessary to make polyvinyl chloride (See Figure 2). Electricity is passed through a salt solution to produce chlorine, while the oil or gas undergoes a ‘cracking’ process to produce ethylene. The next step involves causing a reaction between the two gases to produce ethylene dichloride, which then undergoes another cracking process to produce vinyl chloride monomer. This is then ‘polymerised’ - the molecules joined together - to produce a sludge which is centrifuged and dried to achieve polyvinyl chloride in the form of a white powder.

Because PVC is thermally unstable, stabilisers such as lead or organotins have to be added for virtually all applications. A host of other additives are necessary - softeners, colouring agents, strengthening agents, flame retardants, biocides, lubricants, impact modifiers - depending on the properties required in the final product.

Typically the chlorination of ethylene to make ethylene dichloride (EDC) and its conversion to vinyl chloride monomer (VCM) will take place on one site. This is called the VCM process. The VCM will then be transported to another site for polymerisation - the PVC process - and the resulting PVC resin transferred again for the introduction of additives.

5. PVC Chemicals, and how they get into the environment.

All stages of the PVC lifecycle involve toxic discharges.

PVC production involves many toxic chemicals; either as feed-stocks to make the PVC itself, as additives to make it useable, or as emissions from the various processes by which it is made. During use additives can leach out and PVC cannot be disposed of without serious environmental pollution.

Because of their exceptionally serious potential environmental consequences, we will concentrate here on two “families” of chemicals emitted during the PVC lifecycle - dioxins and phthalates. Other dangerous emissions will be outlined more briefly.

i. Dioxins.

The term “dioxin” refers to a class of compounds consisting of 75 polychlorinated dibenzo-p-dioxins (PCDDs) and 135 polychlorinated dibenzofurans (PCDFs). The 210 substances are toxic to varying degrees with TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) being the most potent. In fact TCDD is the most toxic synthetic molecule known.[12] Because dioxins are chemically stable they don’t degrade easily and because of industrial emissions they now exist in all environmental compartments. They are found in the atmosphere, soils, water, vegetation and all animals including humans.[13] They resist metabolic breakdown and TCDD has a half-life of at least 7 years in the human body.[14] Average concentrations of dioxin now found among the populations of the US and Europe are at or near levels associated with decreased testosterone production, altered glucose tolerance (a symptom of diabetes), and immune system

Figure 2: The PVC production process

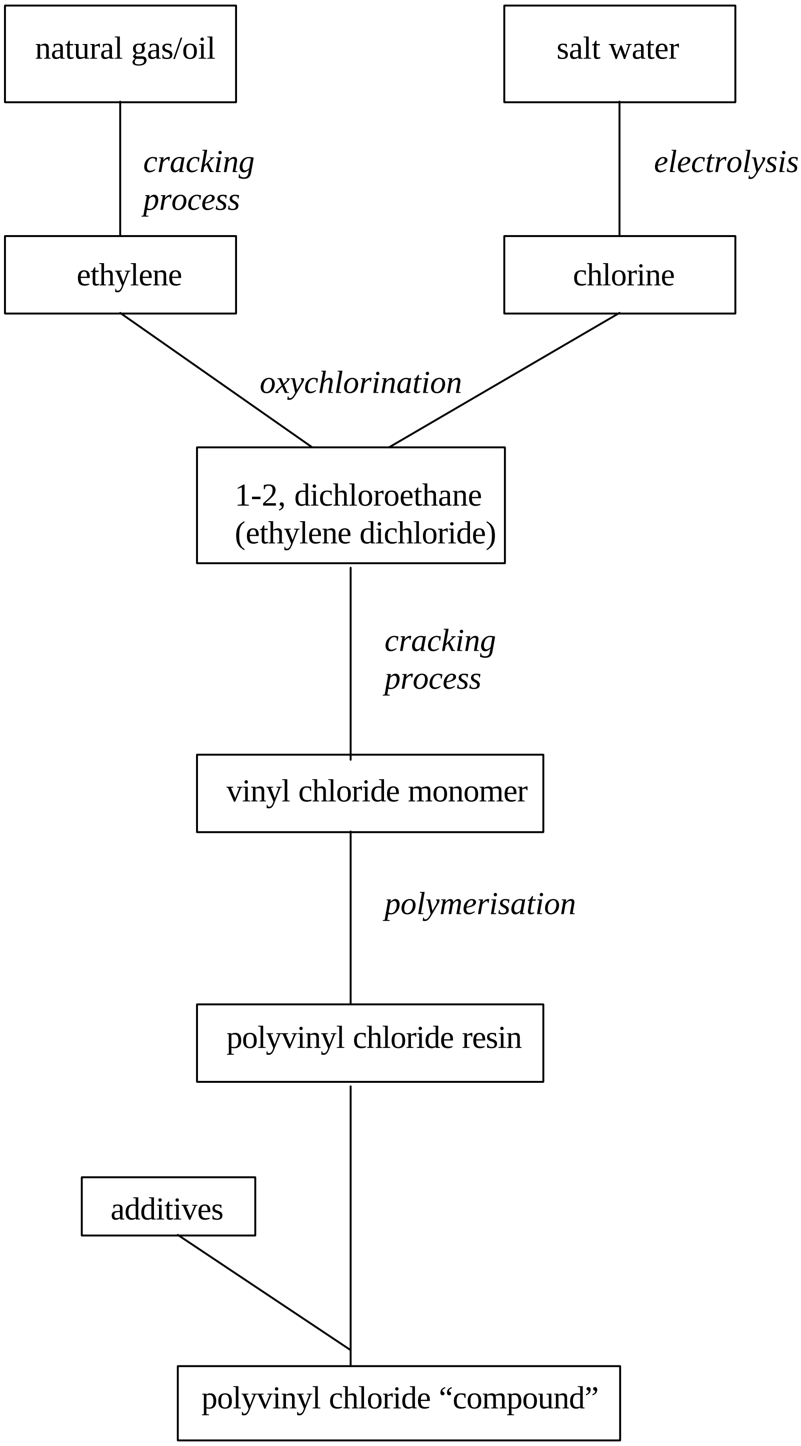


figure 2

changes.[15] Dioxins in a woman's body are able to pass through the placenta to the developing foetus or embryo,[16] and they also accumulate in breast milk. Levels of exposure that cause no discernible effects in adults may cause irreversible harm to the developing foetus and newborn child.[17]

Exposure to dioxin. While infants may take in up to 12% of their lifetime exposure to dioxins through breastmilk[18], the primary route by which adult humans and other mammals ingest dioxins is through food. Because they dissolve much more readily in fat than in water, dioxins build up in fats and oils in the environment, primarily in the tissues of living organisms. Roughly 98 per cent of human background intake of dioxins is through the consumption of meat, milk, fish and eggs. Direct air inhalation makes up the rest.[19]

Health effects of dioxin.

Cancer. There is conclusive evidence that dioxin (2,3,7,8-TCDD) causes cancer in animals.[20] Although still the subject of some scientific controversy the balance of evidence now strongly suggests that dioxins are powerful human carcinogens. Studies of chemical workers in Germany[21] have confirmed earlier studies in the USA and report that exposure to TCDD increases the risk of cancer in humans. Recent epidemiology studies have also shown that exposure to dioxins is strongly associated with an increase in mortality of all cancers considered together.[22]

The epidemiology studies on dioxins have recently been reviewed by the US Environmental Protection Agency (EPA).[23] The review suggests that epidemiological evidence is consistent with experimental studies, and indicates that dioxins have the potential to cause many different types of cancer. Although the evidence was not considered sufficient to confirm that dioxin causes increased cancer incidence, the EPA concluded that dioxin (TCDD) probably increases cancer mortality of several types. In February 1997, 25 scientists from 11 countries met under the auspices of the International Agency for Research on Cancer to review the evidence on the carcinogenicity of dioxins. They decided to re-classify TCDD as a known human carcinogen.

Hormone disruption (See annex p.19). 2,3,7,8-TCDD is a known hormone disrupting chemical. TCDD and other dioxins have been shown to have adverse effects on the male reproductive system in animals and humans. Experiments on laboratory animals have shown that exposure to dioxin results in changes to the male reproductive system which include reduced levels of testosterone, decreased sperm production, decreased fertility and reduced testicular weight.[24] A single, very small dose of dioxin administered to rats on the fifteenth day of pregnancy (a critical time for the development of sexual differentiation in the rat foetus) caused male offspring to produce between forty and fifty-six per cent less sperm than those whose mothers had not been exposed to dioxin.[25]

It has been found that some Vietnam war veterans who were exposed to dioxins during the spraying of Agent Orange suffer from reduced testicular size, and that this effect is related to the amount of dioxins in their blood.[26] (These exposures were significantly higher than would normally occur in everyday life).

Emissions to the environment from the PVC production process

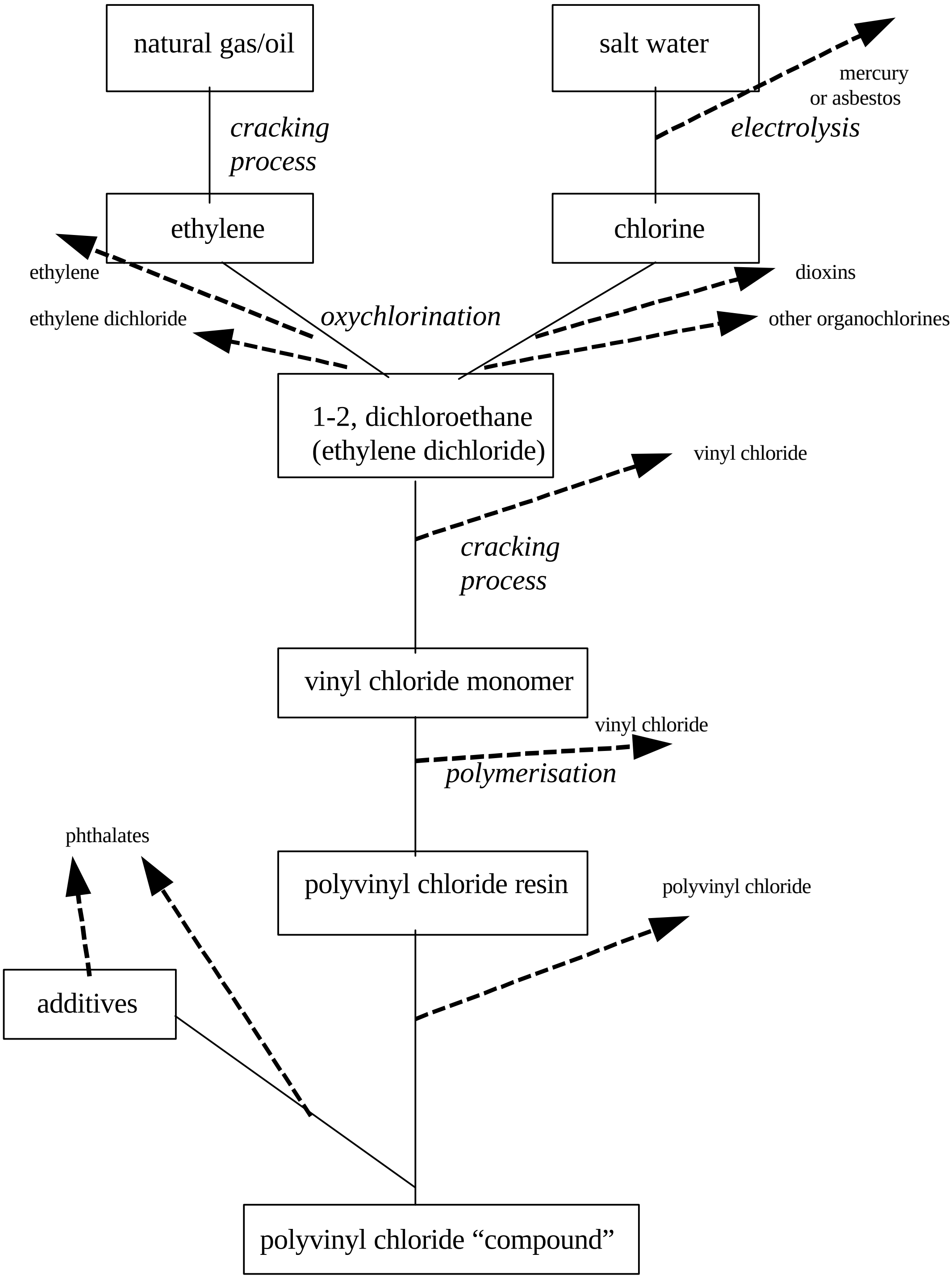


Figure 3

Immunotoxicity. Numerous animal studies have shown that dioxins attack the immune system. Low exposures to TCDD result in increased susceptibility to bacterial, viral and parasitic diseases.[27] These effects occur at body burdens similar to, or within an order of magnitude of current human body burden estimates.[28]

There is increasing concern that many women of child bearing age may already be carrying body burdens of dioxins and dioxin-like-substances at which measurable effects can occur in offspring. Several recent studies have indicated that present levels of PCB's[29] and dioxins in the general female population may be sufficient to affect the thyroid function, immune suppression and intelligence of newborn children.[30]

Why does PVC produce dioxins?

PVC Production. Dioxins are never produced intentionally but arise as unwanted by-products of processes involving chlorine or combustion of chlorinated products.

The production of vinyl chloride monomer has been recognised as a source of dioxins for many years.[31] According to ICI the production of dioxins during the manufacture of PVC is unavoidable: "The processes used by ICI to produce vinyl chloride monomer.....include all the ingredients and conditions necessary to form PCDD/PCDF's, ie air or oxygen, a hydrocarbon, chlorine or hydrogen chloride, a copper catalyst, an ideal temperature and an adequate residence time. It is difficult to see how any of these conditions could be modified so as to prevent PCDD/PCDF formation without seriously impairing the reaction for which the process is designed."[32]

How much dioxin does PVC production produce? Figures for total dioxin releases from PVC manufacture are hard to ascertain. The picture is complicated by the use of different production technologies, and a lack of comprehensive data. Source reconciliation studies for dioxins from all sources, based on atmospheric release estimates can only account for approximately 10% of environmental loadings of dioxins.[33] However figures from ICI Chemicals and Polymers report to HMIP for their plant at Runcorn[•] show that the plant, quite legally, produces around 27g TEQ[*] of dioxins per year in solid and liquid wastes from vinyl chloride production process.[34] This may not sound like a lot, but dioxins exert their effects at tiny levels of concentration. The UK Department of Health use a figure of 0.00000000001g TEQ/kg of body weight as the Tolerable Daily Intake of dioxin. That is about $7x10^{-10}$g or less than one billionth of a gram per day for the average person. ICI's 27g TEQ per year is equal to 38.5 billion tolerable daily intakes.

Most of the dioxins generated at Runcorn are contained in the organochlorine waste which is buried in salt caverns at Holford, in Cheshire. Most of the rest are in effluent discharged into Weston Marsh Lagoons. ICI admit that some of these dioxins escape from the lagoons into the Weston canal.[35]

• Update - Ownership of the VCM plant at Runcorn was transferred to the European Vinyls Corporation in March 1997

* TEQ = Toxic equivalent. an international standard whereby quantities of dioxins are expressed in terms of toxic equivalence to the most potent dioxin 2,3,7,8-TCDD

Dioxin emissions from the VCM process at Runcorn amount to about 25gTEQ per 100,000 tonnes. The European Council of Vinyl Manufacturers claim that dioxin releases can be limited to 0.3gTEQ per 100,000 tonnes of VCM. However Greenpeace has published results which found similarly high concentrations of dioxins in all samples of chlorinated wastes obtained from a number of PVC and VCM manufacturing facilities in the USA.[36] In Germany the Environment Ministry of Lower Saxony found extremely high levels of dioxins in sludge's from the waste water treatment plant at EVC's PVC production facilities in Wilhelmshaven,[37] and in the Netherlands VCM manufacture was found to be the cause of extensive dioxin contamination of Rotterdam harbour.[38]

Such emissions of a chemical, that is described by scientists as "exquisitely toxic", that is a "deadly experimental poison",[39] a probable human carcinogen and a known hormone disrupter are unacceptable. As is the "out of sight out of mind" philosophy of burying dioxins and other organochlorines. Whilst ICI claim it is safe, even the Government is strongly critical of burying hazardous waste, on the grounds of "the potential environmental harm that could result" and the fact that it is "intrinsically not sustainable"[40].

Incineration of PVC also contributes to the environmental dioxin burden. According to HMIP (now the Environment Agency) municipal solid waste incinerators are the dominant source of dioxin emissions to air in the UK, contributing 53-82 per cent.[41] Dioxins are formed when chlorinated organic compounds, or a mixture of inorganic chloride and organic matter are burned. PVC with its high chlorine content is usually the main source of chlorine in the municipal waste stream and therefore is the main contributor to dioxin formation in incinerators.[42] In the United States and Canada municipal waste incineration contributes over 20 per cent of the total airborne dioxin emissions and about 50 per cent of the chlorine in waste is from PVC products.[43]

While some reports maintain that dioxin emissions depend on abatement measures and technology used in the incinerator rather than on the chlorine input,[44] several studies have found a direct relationship between the amount of PVC fed into an incinerator and the quantity of dioxin emitted.[45]

Dioxin from incinerators is not only emitted to atmosphere. It is widely distributed in the environment via contaminated ash, stack gases and waste water. Improved filter technology still leaves the problem of what to do with the contaminated flyash they collect and the filters themselves when they need replacing. The net result of decreased dioxin emissions to air is thus an increase in releases to land.

Accidental fires in homes and buildings involving large amounts of PVC also appear to be an important source of dioxin. PVC is used extensively in modern buildings, and high concentrations of dioxin have been found in residues around fires which have involved PVC.[46] Electrical cables are usually insulated with PVC, and in an electrical fire, the PVC plastic sheathing is often the first material to burn.

ii. Phthalates.

Phthalates are a group of chemicals that are added to flexible PVC as softeners. The most commonly used is di(2-ethylhexyl) phthalate (DEHP) which accounts for 50% of all phthalate production. Some phthalates are known hormone disrupters (see Annex), others are under suspicion[47]. Others are thought to be carcinogenic. Phthalate esters are one of the most common industrial chemicals in the environment and their tendency to bioaccumulate in animal fat is well known.[48] They are produced almost entirely for use as plasticisers in PVC,[49] yet some 850,000 tonnes are used every year in western Europe alone.[50] It is not surprising therefore that they are found in many foods and have recently been discovered by the Ministry of Agriculture to be in powdered baby milk.[51]

Exposure to phthalates. The entire human and wildlife population is exposed to low doses of DEHP and other phthalates. The primary routes of potential intake are through inhalation, ingestion and through the skin on direct contact.[52] The most likely route of exposure for most of the population is through contaminated food. On average an individual consumes 0.3mg of DEHP per day via the food they eat. Those who eat a lot of fatty foods like milk and cheese can consume up to 2 mg per day.[53] DEHP has been found in animal and human tissues, in soil sediments, in marine life,[54] even in areas far removed from industry such as the Antarctic.[55]

Health effects of phthalates. There are serious concerns relating to the suspected reproductive toxicity and other hazards of DEHP. Target organs include the liver, kidney and reproductive tracts.[56] Many phthalates have not yet been tested for hormone disrupting effects but at the time of writing five have been found to be oestrogen mimics. Five phthalates - Diisononyl phthalate (DINP), butyl benzyl phthalate (BBP), diisobutyl phthalate (DIBP), Diethyl phthalate (DEP) and di-n-butyl phthalate (DBP) - have been found to be oestrogenic. DEHP appears not to be oestrogenic, though it does interact with the oestrogen receptor and hormone disrupting effects cannot therefore be ruled out.[57] All are used as plasticisers to make PVC flexible. There are two reasons why it is imprudent to assume that low doses of hormone disrupting chemicals are safe. Firstly it appears that timing and not dose is the critical factor when chemicals disrupt development. A small dose that may have no effect at one point of development may have devastating consequences for example a few weeks earlier.[58] Secondly, mixtures of the hormone disrupting chemicals (which is a more accurate picture of actual human exposure than single chemical exposure) may have additive[59] or greater than additive effects. In one study mixtures of oestrogenic chemicals were found to produce synergistic (i.e. greater than additive) effects when tested on alligator oestrogen receptors.[60] This could have profound environmental implications.

Why does PVC cause the release of phthalates? Phthalates can be released to air and water during production, use and disposal of PVC products.

During the production of PVC compound and later when more plasticisers may be added to produce flexible applications, releases occur as a result of evaporation,[61] other fugitive emissions (bleeding across valves, pumps etc.) and contaminated waste water. It has been estimated that 90 per cent of these emissions are to atmosphere and 7 per cent directly to water.[62] Airborne phthalates are deposited when rain washes them out of the atmosphere or when the particles to which they attach themselves settle.[63]

Leaching. Additives to PVC do not form a chemical bond with the plastic but exist within the PVC as a mixture. As a result plasticisers and other additives can migrate from the PVC polymer into the environment or fatty products that come into contact with the PVC.[64] Phthalates are no longer used in food contact packaging in the UK (although they are still used in printing inks used on the packs) after significant amounts of the plasticisers were found in food wrapped in clingfilm and other PVC packaging.[65] Plasticiser is known to be extracted from flexible PVC (e.g. vinyl flooring) during washing,[66] and figures from Sweden indicate that in that country leaching of DEHP from PVC floors amounts to between 30 and 60 tonnes per year.[67] In Switzerland the use of DEHP (the most common phthalate) in toys for children under three years has been banned since 1986 because of fears about leaching when sucked.[68]

When PVC is landfilled phthalates and other additives can be lost from the plastic through leaching and biological action in the upper layers of landfill.[69] These chemicals may then migrate through the soil and contaminate ground water.[70]

iii. Other toxic PVC chemicals.

Ethylene Dichloride (EDC), also known as 1,2-Dichloroethane is an intermediate chemical in the production of PVC resin. Classified by the International Agency for Research on cancer and the US Environmental Protection Agency (EPA) as a possible/probable human carcinogen,[71] exposure to high levels is also known to damage the heart, central nervous system, liver, kidneys and lungs in humans.[72] Health effects from repeated exposure to low doses of the chemical are not known. Ethylene dichloride is persistent in both air and water,[73] it may travel long distances once it is in the air and has been found in urban and rural air samples, in indoor samples taken near hazardous waste disposal sites and in surface water, ground water and drinking water.[74] Ingestion of contaminated drinking water is thought to be a significant route of exposure for 4 to 5% of the US population.[75] Figures are not available for the UK.

Vinyl Chloride Monomer (VCM), also known simply as vinyl chloride is a colourless flammable gas, made by subjecting ethylene dichloride to a cracking process. It is the basic building block of PVC. It is transported in liquid form either under pressure or refrigerated, by road rail and sea. Vinyl chloride is classified as a human carcinogen by both the International Agency for Research on Cancer and the US EPA. It is one of the top twenty hazardous substances on the EPA/ATSDR priority list.[76] Liver cancer is a well established risk from chronic exposure and it has also been found to affect immunological, neurological, reproductive and development systems.[77]

The primary routes of potential human exposure to vinyl chloride are via inhalation and contact with the skin. People living in the vicinity of emission sources - mainly PVC factories - are potentially exposed by breathing contaminated air.[78] According to the US Department of Health and Human Services new car owners are potentially exposed to relatively high levels due to evaporation of vinyl chloride from vinyl polymers in the car interior.[79] In the United States vinyl chloride has been found in concentrations as high as 380 µg/l in ground water and 10µg/l in drinking water.[80] This figure for drinking water is five times the maximum contaminant level for vinyl chloride determined by the US EPA under the safe drinking water act.[81]

Workers in the PVC industry face additional risks. Occupational exposures generally occur as vinyl chloride monomer is piped to storage or transportation, during maintenance or during polymerisation to form PVC when vinyl chloride escapes into the air.[82]

As well as being highly toxic in its own right, VCM production causes other toxic emissions and residues. For example, for every 100,000 tonnes of vinyl chloride output at the Norsk Hydro plant in Stenungsund, Sweden, by-products include more than 2,700 tonnes of organochlorines (including dioxins).[83]

Lead: PVC is thermally unstable and cannot be formed into products without the use of heat stabilisers. Both rigid PVC and flexible PVC may be stabilised with lead and in Europe lead stabilisers account for some 60% of the market.[84]

It has been demonstrated that blood lead levels of 10-15μg/dl in new-born and very young infants result in cognitive and behavioural deficits, and it is now thought that there may be no level of blood lead that does not produce a toxic effect.[85]

Under EU directive 67/548/EEC (nineteenth adaptation) lead stabilisers must carry the toxic label with the risk phrase “May cause harm to the unborn child”.[86] Under the twenty first adaptation of 67/548/EEC, from September 1996 the label must also carry the warning “Possible risk of impaired fertility.”

There are many sources of lead in the environment as well as PVC. However lead is of concern here because when PVC is exposed to sunlight it can start to disintegrate and release lead in the resultant dust. For example PVC blinds have been withdrawn from sale in several countries after children were found to have high levels of lead in their blood as a result of contact with dust from PVC blinds in their homes.[87] [88] There are an estimated eight million lead containing mini blinds in Canada alone.[89]

Organotins Organotin stabilisers are commonly mixtures of di-alkyl Tin bis-salts and mono-alkyl Tin tris-salts.[90] Dialkyltins and monoalkyltins are highly toxic organometals. They are irritants to skin, eyes and mucous membranes and can damage lung tissue and the liver.[91] Within these alkyl groups are dibutyltin and dioctyltin stabilisers that are used in PVC. According to the Danish Technological Institute dibutyltin may cause foetal abnormalities at dose levels where only slight effects on the mother might be expected.[92] Very little is known about the effects of dioctyltin compounds.

Cadmium. Because of potential environmental and human health hazards cadmium is banned from use as a stabiliser in Europe except in cases where suitable alternatives do not exist.[93] In practice this means applications which are exposed to the weather such as window frames. Outside Europe cadmium stabilisers are still used in a range of applications.

Inhalation of fumes or dust of cadmium compounds affects the respiratory tract and kidneys. Brief exposure to high concentrations may result in pulmonary edema and death.[94] (Such high concentrations are not likely to be encountered as a result of using PVC products such as window frames.) Cadmium is known to cause cancer in animals and may reasonably be anticipated to be carcinogenic to humans.[95]

Organochlorines are substances that contain chemically combined chlorine and carbon. Many synthetic organochlorines are toxic, persistent and bioaccumulate in the environment. Because of this they are arguably the most dangerous group of chemicals to which natural systems can be exposed. Some 11,000 synthetic organochlorines are produced intentionally for use in products such as pesticides, plastics and solvents. Many more are produced accidentally as by-products of other processes involving chlorinated compounds. As a result synthetic organochlorines are now spread throughout the global environment. They are found in the stratosphere, in the deep oceans, in the Arctic and in the Antarctic. Some may take 100 years to break down completely[96] while others do not degrade at all.[97] Since the vast majority of organochlorines are foreign to nature, living organisms have developed few methods to detoxify them.[98] Very few "accidental" organochlorines (that is those that are produced as unintentional by-products) have been characterised. One group that has been well studied is dioxins.

PVC production results in the release of many organochlorines including dioxins (see Figure 3. p8).

Releases of ethylene dichloride, vinyl chloride monomer, heavy metals and organochlorines.

The Code of Good Operating Practice for Vinyl Chloride and Polyvinyl Chloride Manufacturing Operations acknowledges that fugitive emissions are generally the result of normal operations of a chemical plant or refinery.[99] (Fugitive emissions might for example occur as gas bleeds across the glands of a pump). It has been suggested that accidental releases and spills are the major sources of vinyl chloride monomer and polyvinyl chloride to the environment.[100]

Figures from Britain. At Runcorn in Cheshire EDC and VCM are produced by ICI[•] and on the same site the European Vinyls Corporation polymerise the vinyl chloride to form PVC resin. From these two processes 180 vents release ethylene dichloride, vinyl chloride monomer and ethylene to the atmosphere via stacks up to 60 meters high. Emissions to water containing EDC and mercury take the form of effluent discharged via outfall pipes.[101] To land, 9000 tonnes of organochlorine wastes are dumped into underground salt caverns every year.[102] These wastes arise from contaminated lime used for VCM purification, from the emptying of vessels and other general process wastes.

According to ICI's own figures in the nine month period from 30th March to 31st December 1994, the stacks from the EDC/VCM/PVC process at Runcorn released 184 tonnes of EDC, 62 tonnes of VCM and 55 tonnes of PVC to the atmosphere.[103] These figures do not take into account fugitive emissions or other accidental releases and apply to only one UK plant. In the same nine month period, 491kg of VCM, 126kg of

[•] Update - in March 1997 ownership of the VCM plant was transferred to EVC

EDC and 0.49kg of mercury were released from ICI's Runcorn plant to the Weston Canal and Weston Marsh Lagoons.[104]

Figures from the USA. According to industry statistics, in the United States 1.3 million pounds (590 tonnes) of vinyl chloride monomer are released to air every year. Another 0.6 million pounds (272 tonnes) are shipped for off site waste disposal.[105] Workplace air in some manufacturing plants in the USA was found to contain 100-800 mg/m^3 of vinyl chloride. The US EPA estimated that approximately 40 million pounds (18,144 tonnes) of ethylene dichloride (0.2% of total production) was released to atmosphere in the USA from fugitive sources, storage tanks, secondary sources (e.g. emissions from waste water treatment processes), process vents and shipping operations.[106]

Figures from Germany. According to the German Federal Office of the Environment the Manufacture of VCM and EDC created 40,000 tonnes of organochlorines in the Federal Republic of Germany in 1990. Three quarters of these were used to produce other chlorinated chemicals (tetrachloromethane and perchloroethylene). The remaining 10,000 tonnes was burned in hazardous waste incinerators.[107] The production of PVC in the Federal Republic of Germany (before amalgamation with the German Democratic Republic) accounted for emissions of approximately 330 tonnes of VCM per annum "most of which escapes from diffuse sources into the environment."[108] Over the last 20 years 5000 tonnes of cadmium and 200,000 tonnes of lead were incorporated into PVC as stabilisers in the FRG. From these figures the German Office of the Environment estimates that an annual load of products containing approximately 10,000 tonnes of lead and 250 tonnes of cadmium will have to be disposed of over the medium term.[109]

PVC production thus accounts for an enormous amount of toxic emissions to air, water and land on a worldwide scale. But production is only the first stage of a life cycle that involves pollution at every stage. During use and disposal PVC also releases dangerous chemicals.

6. Accidental fires.

Although the chlorine in PVC tends to suppress fire, once it starts to smoulder, dangerous chemicals can be released. The German Federal Office of the Environment have drawn attention to the dangers arising from PVC in fires, in relation to the formation of hydrogen chloride gas - which creates corrosive hydrochloric acid on contact with moisture.

"The high chlorine content of PVC products may give rise to major hydrogen chloride emissions. Hydrogen chloride...may cause burns in affected persons and considerable material damage through corrosion of buildings and installations..."[110]

The hydrogen chloride given off during a fire also reacts with the many additives present in PVC, creating other toxic fumes[111] and heavy metals contained in PVC stabilisers can be released.[112]

7. Disposal of PVC.

Can PVC be disposed of safely?

In addition to the problems of dioxin releases from incinerators (see p.10) heavy metal additives such as lead, organotins and cadmium from PVC will be found both in the slag and flyash after incineration. For example PVC currently accounts for an estimated 20 to 30 per cent of all cadmium entering incinerators.[113] Incineration slag and flyash are normally landfilled which potentially leads to leaching of heavy metals and groundwater contamination.[114]

Landfill. PVC products do not biodegrade. With global production of PVC standing at 20 million tonnes per annum attempting to bury waste PVC is not a sensible or sustainable option. Moreover additives - phthalates and heavy metals - can leach out of landfilled PVC and may contaminate ground water.[115]

Recycling. PVC is a thermoplastic material and as such is theoretically recyclable, via a process of crushing, grinding and melting. However the actual recycling of PVC is severely constrained by several factors:

* Recycling of polymer products requires sorting of the waste into generic materials. The quality of the recyclate depends heavily on the level of impurities - such as other polymers or reinforcement materials. The composition of the PVC, i.e. which additives have been used, is also important. However it is not possible, visually or mechanically, to ascertain this. Thus PVC waste streams are a complex mix of materials from a variety of sources. This makes recycling technically and economically very difficult. For example end of life vehicles have a significant plastics content some of which is PVC (the dash board for example). According to the British Plastics Federation the plastic however is “unmarked, from a variety of sources and in a form where disassembly would be very costly if not impossible.”[116]

* To recycle PVC it must first be melted. This releases hydrogen chloride which causes other splitting processes in the PVC to speed up. This is known as ‘autocatalytic corrosion’ and the net result is a drop in quality of the end product. This is why most ‘recycling’ of PVC is actually ‘downcycling’ and the reason why most recycled PVC is unsuitable for its original purpose. As the British Plastics Federation admit, it also limits the number of times PVC can be recycled, and means that the problem of disposal is merely postponed.[117]

* The market for plastic recyclate is very small. In a 1993 report on general plastics recycling, *Plastics and Rubber Weekly* reported that “processors are reluctant to accept recycled material” and that “it is clear that unsubsidised recyclate cannot really trade against virgin material.”[118] The British Plastics Federation reports that there are “serious restrictions in the market opportunities for recycled plastics, regardless of cost”[119] and that there is a “continuing need to find financially viable means of addressing waste management issues to allow recyclates to be sold at market price.”[120]

The British Plastic Federation suggests that as a solution “new markets (for plastics recyclate) must be created”[121] What this would lead to in the case of PVC is new PVC applications, the possible crowding-out of more environmentally sound chlorine free alternatives and the inclusion of toxic chemicals and heavy metals like cadmium, lead and tin, in products where they have hitherto not been present. This sort of recycling has no environmental value.

* PVC recycling itself results in emissions. During crushing and grinding, hydrogen chloride and benzene can be released.[122] Organochlorines are released when the PVC coating is burnt off copper cables.[123] Contamination by PVC results in increased dioxin emissions from recycling of other materials. According to HMIP figures dioxin emissions from scrap metal with “no chlorine” is 0.7 μg I-TEQ per tonne compared to a figure of 20.0 μg I-TEQ per tonne for scrap metal with PVC.[124]
Even though the PVC industry has felt itself under intense pressure to prove the recyclability of its products, because of the limitations outlined above, recycling of PVC is negligible. According to figures published by the Association of Plastic Manufacturers in Europe in 1993, post-user PVC plastic waste recycled was a meagre 0.6%. (NB. Post-consumer material recycling should not be confused with pre-consumer waste or ‘offcut’ reprocessing. This reprocessing of plastic industry scrap creates less problems than post-consumer recycling and quoted figures for recycling sometimes include this. Even when this dubious definition of recycling is used the figure only rises to somewhere between 1 and 3 per cent.)[125]

In short there are both technical problems - regarding the small proportion of recyclate that can be used in a product and the number of times PVC can undergo recycling - and economic problems involving the incompatibility of the market value of recyclate with the cost of collection, identification, separation and processing, that mean that PVC recycling cannot solve the disposal problems inherent in PVC as a material and certainly cannot justify its continued production.

As we have seen PVC cannot be incinerated without releasing dioxins and if the unsustainable option of landfilling is chosen there is a risk of plasticisers and heavy metals leeching out and contaminating ground water.

8. Conclusions

Because of the persistent, bioaccumulative nature of many of the chemicals released by PVC production their effects are irreversible. They will effect not only us and our children, but our children’s children and their children. Likewise they will go on contaminating every part of the earth and poisoning wildlife for many generations. The potential consequences are immense, threatening not only our health but also our reproductive health. To take such risks with the future is unacceptable under any circumstances. When these risks are unnecessary and entirely avoidable, it is indefensible.

In Article 2 of the OSPAR Convention, the signatories - including the UK - agreed that : The Contracting Parties shall apply:

a) the precautionary principle, by virtue of which preventative measures are taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship between the inputs and effects;

b) the polluter pays principle, by virtue of which the costs of pollution prevention, control and reduction measures are to be borne by the polluter

These principles should not only be applied to the marine environment. They should be applied now to all industrial processes in order to move towards the ideals of clean production and sustainable development.

Some governments have already started to act against the use of PVC.[126] Inaction is also a political decision. To allow the PVC industry to continue to emit chemicals that are known to be highly toxic, in quantities of thousands of tonnes every year, in the face of scientific uncertainty about the environmental and human health consequences of such emissions, is a decision to grant industry rights above and beyond those of its potential victims. While industry attempts to delay legislation with calls for more and more evidence, we all become part of a great global experiment to determine the effects of toxic chemicals dispersed into the environment.

PVC is a source of large quantities of a variety of carcinogenic, hormone disrupting and otherwise toxic chemicals. It cannot be part of an ecological society and it should be phased out speedily.

9. Annex. Hormone disruption and reproductive problems.

For many years now researchers have been noting aberrant behaviour and reproductive problems in a variety of wildlife populations. Decreased fertility in birds, fish and mammals, decreased hatching success and birth deformities in birds, fish and turtles, metabolic abnormalities in birds, fish and mammals, behavioural abnormalities in birds, compromised immune systems in birds and mammals, thyroid dysfunction in birds and fish, feminisation of fish....[127] It wasn't until Dr. Theo Colburn, a scientist working on pollution of the Great Lakes, drew together papers on the many apparently diverse problems and realised that there was a common factor - they were all related to processes regulated by the endocrine system - that scientists began to suspect there might be a common cause.

The endocrine system (or hormone system) is a chemical messenger system that by releasing specific quantities of hormones at specific times, regulates vital functions such as the development of reproductive and immune systems. The similarity of the endocrine system across species is remarkable. "Whether in a turtle, or a mouse, or a human, the endocrine system produces a chemically identical estradiol that binds to an estrogen receptor."[128]

Many organochlorine chemicals which have been released into the environment over the past 50-60 years are known to disrupt the functioning of the endocrine system.[129] There is much evidence which suggests that organochlorines are responsible for breeding problems in many wildlife populations in areas contaminated with these chemicals and many of the observed reproductive and development effects have been confirmed in laboratory experiments.

Evidence is now emerging which suggests that similar effects may be occurring in humans. Studies from several parts of the world have shown that human sperm counts have decreased by as much as 50 per cent in the last fifty years.[130] There has also been an alarming increase in other male reproductive disorders in several different countries. These disorders include a rising rate of testicular cancer, an increase in the incidence of hypospadias (an abnormality in which the opening of the urethra is at the base of the penis instead of at the end), and of cryptorchidism (undescended testes).[131] All these disorders can be caused by disruption of the hormone system in prenatal life. Because of this and because they are reported to be occurring simultaneously in several countries, it is probable that there is a common cause.

Prime suspects in the search for this cause are man-made environmental chemicals, which can disrupt the functioning of the endocrine system by mimicking or blocking the action of the body's hormones during foetal development. For example certain chemicals mimic the female hormone, oestrogen, and trigger an inappropriate response in the developing foetus. Other chemicals can attach themselves to the body's hormone receptors and prevent the messages genetically encoded in the hormones from getting through. The appropriate development thus does not take place. The result may be disorders of the reproductive organs, some of which may not reveal themselves until the individual matures. There is a growing list of compounds known to be able to this. They are known as hormone disrupters.

Many known hormone disrupting chemicals are organochlorine compounds. Other chemicals suspected of having the capability to disrupt the endocrine system are those in the phthalates group. As we have seen above, PVC production, use and disposal is the reason for the production and environmental release of large amounts of organochlorines and phthalates, in particular dioxin and DEHP.

Cadmium, lead, tributyltin and organotin are all compounds found in PVC that are also known to disrupt the endocrine systems of animals and humans.[132]

More information on hormone disruption, including abstracts from current research can be found on the Greenpeace UK science internet site at : http://greenpeace.org/~uk/science and in the Greenpeace publication "Taking Back Our Stolen Future".

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[126] In Novermber 1995 the the Swedish parliament concluded that “PVC is not part of an ecological society” The Environment Minister Anna Lindh said “the question is not whether to phase out PVC but how PVC should be phased out.” Denmark is currently considering a proposal to phase out PVC by 2000. Many federal states and local authorites in Germany now have PVC restrictions in place. Other countries which have regional restrictions include Austria, Australia (for the Sydey Olympics 2000), Japan, Luxembourg, the Netherlands, Norway and Sweden. The Channel Tunnel between the UK and France was built without the use of PVC cable and London Underground has banned the use of PVC and other halogenated cables because of the fire hazards.
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