The polyvinyl chloride debate: Why PVC remains problematic material

Executive Summary

In 2020, the European Commission commissioned a study entitled *The use of PVC (Poly Vinyl Chloride) in the context of a non-toxic environment*.[1] It aims to identify and describe uncertainties (particularly from chemicals perspective), about PVC production, recovery, and end of life treatment and to help assess the role of PVC in the context of the European Green Deal and the Circular Economic Action Plan. The final report from this study is expected in November 2021.

Within this paper we present a detailed insight into the complexity of health and environmental issues associated with the entire life cycle of PVC – including production, use, and disposal. The paper also includes examples of already successful phase-outs of PVC for specific applications. The information presented here should be considered in the on-going study of the Commission, collecting and updating factual data on the status of PVC in the EU economy. Ultimately, we hope it will support informed decisions of EU policymakers to support the achievement of a non-toxic environment in Europe.

We note that the initial regulatory response to concerns about PVC focussed mainly on substitution and phase-out of phthalates, but failed to address wider health and environmental issues associated with PVC manufacture and use. While the impact of individual manufacturing plants can differ, global PVC industry impacts[2] include:

- Ozone depletion through the release of carbon tetrachloride
- Contributions to climate change and environmental degradation from burning of fossil fuels to produce chlorine or coal-intensive acetylene-route PVC
- Contaminating air and drinking water supplies
- Substances harmful to human health and the environment:
- Carcinogenic vinyl chloride monomer
- Bioaccumulative toxics e.g. mercury, dioxins, and furans
- Community and worker exposure to asbestos for chlorine production
- Plastic pellet and mercury contamination of waterways from dumping chemical waste

All current evidence supports the simple proposition that the use of PVC is problematic and that there are significant health issues at all stages in the lifecycle. The majority of key components used in the manufacture of PVC are well recognised for their toxicity and this is an inherent feature of PVC.

Key messages & recommendations

- PVC is the most environmentally damaging type of plastic and safer alternatives are already available for virtually all uses of PVC.
- The available methods to manage PVC waste are not adequate to keep pace with current and unsustainable PVC production and disposal rates.
- Eliminating PVC products is the best waste management option for both environment and human health.
- Eliminating PVC to the highest extent possible is necessary to fulfil the ambitions of the EU Zero-Pollution Plan and non-toxic environment initiatives.

The totality of issues revealed in relation to PVC presents a compelling case for a call for complete elimination of use of this material, and consequently we call on policymakers to develop a strategy for PVC phase-out in Europe.

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- Arnika - Toxics and Waste Programme
- Changing Markets Foundation
- Ecologistas en Acción
- ECOS
- European Environmental Bureau (EEB)
- Global Alliance for Incinerator Alternatives (GAIA)
- Gallifrey Foundation
- GLOBAL 2000 - Friends of the Earth Austria
- GREEN TRANSITION Denmark
- Health Care Without Harm Europe
- Health and Environment Justice Support (HEJSupport)
- NO PLASTIC IN MY SEA
- Plastic Change
- Polish Zero Waste Association (PSZW, Poland)
- Rethink Plastic alliance
- Society for Earth (TNZ, Poland)
- ZERO - Associação Sistema Terrestre Sustentável (ZERO – Association for the Sustainability of the Earth System)
- Zero Waste Europe (ZWE)
- Women Engage for a Common Future (WECF)

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Abbreviations used in this paper:	
ATBC- Acetyl Tributyl Citrate EVA - Ethylene-vinyl acetate BBP - Benzyl butyl phthalate BTHC – Butyryl tri-n-hexyl citrate CEH - Center for Environmental Health CMRs - Carcinogenic, mutagenic and reproductive toxic substances DBP - Dibutyl phthalate DEHP - Di-2-ethylhexyl phthalate DEHA - Bis(2-ethylhexyl) adipate DEHT - Bis(2-ethylhexyl) terephthalate DIBP - Diisobutyl phthalate DIDP - Diisodecyl phthalate DINA - Diisononyl adipate DINCH – Cyclohexane 1,2-dicarboxylic acid diisononyl ester DINP – Diisononyl phthalate DPHP - Dipropylheptyl phthalate DNA - Deoxyribonucleic acid ECHA - European Chemical Agency EDC - Ethylene dichloride EEA - European Economic Area EFSA - European Food Safety Authority EPA – Environmental Protection Agency ESBO - Epoxidised soybean oil EU – European Union EuRIC - European Recycling Industries' Confederation	FCM – Food contact materials HCB – Hexachlorobenzene IBA - incinerator bottom ash ILFI - International Living Futures Institute IPEN - International Pollutants Elimination Network IV – Intravenous LCA - Life cycle assessment MDR - Medical devices regulation MSW - Municipal Solid Waste NICU - Neonatal intensive care unit PAHs - Polyaromatic hydrocarbons PCBs - Polychlorinated biphenyls PE – Polyethylene PET - Polyethylene terephthalate PFAS - Per- and polyfluoroalkyl substances OPs - Persistent organic pollutants PP - Polypropylene PVC - Polyvinyl chloride SCENIHR - Scientific Committee on Emerging and Newly-Identified Health Risks TEHTM - Tris(2-ethylhexyl) trimellitate VCM - Vinyl chloride monomer WHO - World Health Organization

Introduction

Polyvinyl chloride (PVC) is a popular material as it has a number of useful technical properties, is relatively cheap to manufacture, and also easy to work with. In 2016 global PVC production capacity reached 61 million metric tonnes (T), (up from 53 million T in the year 2013), making it globally the fifth most highly manufactured plastic.[3] Global demand for PVC is expected to increase 3.2% per year.[4] In Europe, PVC is the fourth most common type of plastic.[5] In the EU, around 6.5 million T of PVC products are manufactured every year. Annual European consumption of PVC resin totals 5 million T - 10% of all plastics used in Europe.[6]

Two thirds of PVC in Europe is used in the building sector, but it is also commonly used in agriculture, sport and leisure, healthcare and many other sectors.[7] Many domestic and professional products are made of or contain PVC including:

- Furniture and upholstery
- Office supplies
- Toys and inflatable products (pools, water sports accessories, trampolines)
- Tubing (garden hoses, irrigation tubing, medical tubing, electric cable coating)
- Sheets and films (tarpaulin, banners, “vegan leather”, bags and suitcases, shower curtains)
- Packaging (including can coatings)
- Medical devices and products.[8]

The chemistry of PVC and related risks

PVC has many different formulations and configurations, often referred to by the industry as "the world's most versatile plastic". Its "versatility", however, is only due to the many, various additives used. Often toxic and used in high concentrations, these additives provide the desired characteristics for the products' application e.g. rigidity/flexibility or opaque/transparent. Achieving the desired functionality of PVC products is therefore associated with serious chemical risk.

Chlorine production

Polyvinyl chloride production is associated with the use and generation of chemicals of concern.[9] The final product is nearly 60% chlorine by weight.[10] The chlorine is obtained through an energy-intensive process that splits sodium chloride (NaCl) from seawater or brackish underground water into chlorine gas and caustic soda (sodium hydroxide, NaOH). This is accomplished through one of several technologies (described below).

In elemental form, chlorine is a greenish yellow gas with a suffocating odour, which is fatal if inhaled in sufficient amounts, and is very toxic to aquatic life with long lasting effects (this substance is approved for use as a biocide in the European Economic Area and/or Switzerland). [11] Of all industrial uses, currently PVC manufacture is the most significant chlorine consumer with about 30% of elemental chlorine used in PVC.[12]

Chlorine is a strong oxidant, which means that it readily reacts with organic molecules to produce a variety of chlorinated compounds. Therefore, the use of chlorine for PVC production creates additional burdens, generating organochlorine waste (hazardous components of waste defined in Annex I to the Basel Convention) and by-products. Many of these chemicals also build up in the ecosystem, including fish, wildlife, and humans, and are toxic at low doses.[13] Chlorinated dioxins[14] and furans[15] are highly hazardous compounds that can have a range of adverse health impacts, even at very low levels of exposure. Low-level exposures are particularly hazardous for the developing foetus and infants. These widely acknowledged hazards and exposure pathways led to the inclusion of dioxins and furans in the Stockholm Convention. In addition to polluting the local environment near the facilities that release them, these chemicals can also be transported around the globe. One of them, carbon tetrachloride, is an ozone-depleting chemical and potent global-warming gas.

The use of chlorine is unavoidable in the production of PVC and though it is possible that, over time, producers of chlorine will develop better approaches, the health issues related to chlorine itself will remain.

Mercury

The oldest technology for chlorine production uses a mercury-cell to separate the sodium from chlorine. During the process, a significant amount of mercury can be released into the environment. In 2016, European chlorine producers released a total of 1.4 metric tons of mercury into the atmosphere.[16] Mercury can exist in the environment in various forms (species) such as elemental (or metallic) mercury, inorganic and organic compounds. Properties of some of those forms mean that it can remain in the environment for thousands of years. Organic mercury compounds are one to two orders of magnitude more toxic than inorganic mercury. Mercury can travel long distances when airborne and large amounts also end up in seas and oceans meaning that mercury emissions have a global impact.[17]

European Union regulations requiring companies to stop making chlorine via processes involving mercury came into effect in December 2017. Of the 21 mercury technology plants that were operating at the start of 2017, seven have closed and 14 have been converted—or are about to be converted—to other (mercury-free) membrane technologies (see below for more details).

In Europe, exemptions to regulations that otherwise prohibit mercury-based technologies allow at least five locations to continue using mercury into the foreseeable future.[18]

Unsurprisingly, the mercury process presents some hazards due to the potential for occupational exposure to mercury and mercury vapours, which are neurotoxins. Mercury is one of the World Health Organization (WHO)'s top ten chemicals of major public health concern.[19]

Asbestos

Another technology uses an asbestos diaphragm, which is then disposed of at the end of its useful life. Twelve plants in the United States and Canada use an asbestos diaphragm technology.[11] According to the report released in 2018, in Western Europe, where asbestos once accounted for a quarter of chlor-alkali technology, one plant continues to use asbestos diaphragms.[19] Despite asbestos ban regulations enacted by the European Union in 1999 and availability of asbestos-free alternatives, the most recent derogation (2017)[20] allowed for the continued use of chrysolite (white) asbestos in diaphragms for electrolysis installations until July 1, 2025 in Europe's largest chlor-alkali plant in Stade

(Germany) belonging to the Dow Chemical Company Ltd. Other EU chlorine production facilities have either closed or converted to membrane technology.

Asbestos is a very well known carcinogen.[21] Chlorine manufacturers point out that the asbestos is wet when used and, therefore, opportunities for inhalation exposure are minimal during the use-phase of the life cycle. However, asbestos that is not released during production is usually landfilled at the end of service life, which can be anywhere from 6 months to 10 years. There are also potential exposures to workers and communities in countries where asbestos is mined.

Fluorinated substances

Two other (newer) technologies use a Teflon-like coating of per- and polyfluoroalkyl substances (PFAS), to coat a membrane or diaphragm that separates the chlorine. PFAS membrane technology is sometimes combined with asbestos.[21] As concern about the environmental and health impacts of PFAS grows,[22] more research is needed to understand the environmental health impacts of these plants.

PFAS have been frequently observed to contaminate groundwater, surface water and soil. Primary emission sources of PFAS into the environment (water and air) are fluorochemical production plants, and once released into the environment via air or wastewater, PFAS distribute to other abiotic media such as soil and sediment and accumulate into biota including in human food chains. Environmental contamination and human exposure to PFASs near a fluorochemical production plant have been reported in Italy[23] and in the Netherlands.[24] Because PFAS are not regulated at the point of use at chlorine manufacturing plants, there are no reported PFAS emissions or waste. However, PFAS have been detected in the effluent from the main US manufacturer of membranes used in chlorine plants.[19]

PFAS are a large family of thousands of synthetic chemicals, which are highly persistent in the environment.[25] Cleaning up polluted sites is technically difficult and costly. If releases continue, they will continue to accumulate in the environment, drinking water and food.

Some PFAS are recognised carcinogens and reproductive and immune system toxicants. The toxicity profile of many others is poorly studied. Currently, the Netherlands, Denmark, Germany, Norway and Sweden are working on a proposal for a European ban on PFAS (a ban in this context is also referred to as a restriction).[26] The countries are proposing this restriction to limit the risks that these substances pose to people and the environment. The proposal focuses on the entire group of PFAS substances in order to avoid one PFAS being replaced by another.

Feedstock chemicals & toxic releases during production

In most of the world, the PVC production process combines ethylene – obtained from cracking naphtha or natural gas – and chlorine to produce ethylene dichloride (EDC). This is then converted to vinyl chloride monomer (VCM), and highly toxic waste[13] is produced in the process: for every tonne of EDC an approximate four kilograms of by-products are produced, which contain persistent toxic chemicals. This includes several organochlorine chemicals that are recognised as persistent organic pollutants (POPs): dioxins, furans, polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB). Finally, vinyl chloride (which is highly toxic, flammable, and carcinogenic) monomer, is polymerised into PVC.

Another process for making VCM uses coal as its carbon source, rather than gas or naphtha. In this process, acetylene is obtained from calcium carbide, which comes from coal and limestone.[27] Acetylene and hydrogen chloride are reacted over a mercuric chloride catalyst to yield vinyl chloride. Some of the mercury is released into the environment. This practice, which was once nearly obsolete, is again widespread due to its use in new PVC plants in China.[28] This industry is one of the top two sources of mercury pollution in the world. The Healthy Building Network estimates that China produces more than one-third of the world's PVC.[30] Vinyl chloride monomer production is the largest user of mercury, accounting for over 60% of the total demand. In 2011, about 200 T of mercury from industrial processes in China had unknown fates.[29]

Ethylene dichloride is a colourless, oily, synthetic chemical, which releases toxic hydrochloric acid when heated. The EU has evaluated EDC as a *Substance of very high concern* requiring authorisation before it is used, due to its carcinogenic properties.[30] Currently, around 1–10 million metric T of ethylene dichloride are used per year in the European Economic Area alone.[31]

Vinyl chloride is a known human carcinogen.[32] Low levels of unreacted VCM can also leach out of PVC storage containers and tubing,[33] potentially directly exposing patients receiving therapy from those products, although more research would be needed to understand the actual risk from such exposure. The effect of exposure to VCM differs for acute and chronic exposure. Acute exposure to VCM has been linked to effects on the central nervous system, respiratory tract, and cardiovascular and gastrointestinal systems.[34] Chronic exposure to VCM has been shown to affect a number of biological systems in humans causing, among others, hypertension, hepatic (liver) damage and abnormalities, preeclampsia in pregnant women, effects on the immunological and on the central nervous system, mutagenicity and formation of DNA adducts.[13]

Despite the existing regulations for VCM exposure, understanding of its hazards is still developing. For example, recent research using biomarkers to measure individual exposure to VCM is indicating that cellular damage from VCM occurs at concentrations below the generally recommended levels; the increased presence of specific point genetic mutations that lead to liver cancer, was associated with cumulative exposure to VCM.[35] These recent studies suggest that new insights are still possibly going to change the current understanding of the VCM exposure. It has already been shown that for some well-recognised risks, such as lead and asbestos, medical understanding of the biological responses continued long after the initial bans of use of these substances.

Improvements in chemical management and production practices have reduced VCM releases per unit of PVC produced over the past twenty years. However, as PVC production has increased substantially over that timeframe, total VCM releases to air have only marginally improved. According to the EPA's Toxics Release Inventory Program over the past four years, VCM releases – mostly to air – have been relatively constant at about 600,000 pounds annually from U.S. facilities.

Additives

Before PVC can be made into products, it has to be combined with a range of special chemicals to improve the performance of the material (for instance durability, stability, colour, and flexibility as needed). Combinations of additives give formulations the characteristics needed for a wide range of PVC products. The quantity of additives required depends heavily on the final product. In unplasticised PVC, additives total into less than 10% by weight.[36] However, in plasticised PVC, plasticisers are also added to increase their flexibility and transparency, and are used in proportions as varied as 10–60% of the final PVC products.

The final mix of additives depends not only on the intended application but also on regulatory considerations and pressures to replace hazardous chemicals with those that are safer.[37]

Heat stabilisers are generally required. Historically, lead and cadmium were used, but these two toxic heavy metals are largely being phased out and replaced with alternatives. However, cadmium and lead have only recently been removed from PVC stabilisers. The deadline for voluntary removal of lead stabiliser from PVC in the EU was as recent as 2015. In 2017, however, the website of the European Council of Vinyl Manufacturers (ECVM) was still reporting on the long history, excellent properties, and cost-effectiveness of lead as a stabiliser of PVC.[12] Other common stabilisers include organotin (compounds of tin and hydrocarbons), calcium-zinc, and barium/zinc, organic based stabilizers and 1,3-dimetyl-6-aminouracil.[40] Unfortunately, these replacement substances have not been

thoroughly tested for their impact on human health; the impacts of stabilisers should therefore be included in assessments of the total health risks posed by various polymers and their recycling.
Lubricants, antioxidants (including bisphenol A in some applications),[38] and impact modifiers are added in various proportions. Some PVC products also contain significant amounts of flame retardants.[39]

There is a range of substances that can be used as plasticisers including phthalates, aliphatics, epoxy, terephthalates, trimellitates, polymerics, and phosphates.[40] However, because plasticisers are not part of the chain of polymers that make plastics, they can be slowly released from these products. A joint project by the European Chemical Agency (ECHA) and industry created a list of over 400 functional additives or pigments used in plastics, including information on the polymers where they are most commonly found and the typical concentration ranges.[40] Ortho-phthalates (phthalates) are a group of compounds long used as plasticisers to soften PVC and add flexibility.

Phthalates
Since 2008, the ECHA has included eight phthalates in their list of substances of very high concern.[41] The reason for including these chemicals is their toxicity for reproduction, with more specific reasons ranging from impairing fertility, causing harm to the unborn child, and being an endocrine disruptor (chemicals that disrupt hormone signal pathways). Diethylhexyl phthalate (DEHP) is the most researched and understood phthalate to date.

Extensive laboratory animal testing showed that exposures to DEHP during critical periods of development can interfere with testosterone production and disrupt normal male reproductive tract development. An expert committee convened at the U.S. National Toxicology Program’s National Institute of Environment Health Sciences reviewed this literature and, in their final report in 2006, expressed concern about the potential impacts of DEHP on the developing reproductive tract of infant boys.[42] Scientists from the Endocrine Society concluded that DEHP has the potential to act as an androgen disruptor and, in fact, does so under a number of conditions.[43]

More recent studies in human populations confirm some of the adverse impacts of DEHP on male reproductive tract development first identified in many experimental animal studies.[44] A systematic review also finds that higher exposures to DEHP are associated with sperm abnormalities and lower testosterone levels.[45] Recent studies also show that prenatal exposure to phthalates is associated with adverse impacts on neurodevelopment, including lower IQ, and problems with attention and hyperactivity, and poorer social communication.[46]

The European Union has determined that DEHP is a reproductive toxicant and endocrine disruptor for humans and the environment.[47] The European Commission recently adopted a decision to restrict the placing on the market of consumer products containing four phthalates: DEHP, benzyl butyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP).[48] ECHA estimated that this restriction will save approximately 2,000 boys each year from impaired fertility in later life.[49]

The primary routes of potential human exposure to DEHP are ingestion, inhalation, skin and through medical procedures; exposure levels are highest for medical procedures. PVC is currently used in healthcare-specific applications including intravenous (IV) bags, blood bags, urine bags, tubing, oxygen masks, catheters, and disposable gloves.

Concerns about phthalates in healthcare

High-level exposures of vulnerable patients to DEHP

Diethylhexyl phthalate (DEHP) is the phthalate most commonly used in medical products. Some medical products such as IV bags and tubing can contain up to 40% DEHP by weight.

This phthalate leaches to varying degrees from medical devices during certain medical procedures, directly exposing the patient. Patients in a neonatal intensive care unit (NICU) are exposed to phthalate mixtures through the complex materials used concurrently in NICU care: respiratory circuits, intravenous equipment, enteral feeding supplies, and incubators are likely vehicles of phthalate exposure. Premature neonates in intensive care units may receive even higher DEHP exposures than adults relative to their bodyweight. Such exposures may occur for a period of weeks or even months.

According to the SCENIHR (the EU Scientific Committee on Emerging and Newly-Identified Health Risks) premature neonates in neonatal intensive care units, infants subjected to repeated medical treatment using medical devices, and patients undergoing haemodialysis are at risk of DEHP-induced effects. The Committee recommended the use of medical devices with low DEHP release potential, whenever possible.

In France, legal provisions prohibiting the use of certain medical devices containing DEHP were adopted to minimise exposures in paediatric, neonatology, and maternity wards.[50] The EU regulation on medical devices (MDR 745/2017) will go into effect in May 2021. Annex I.II.10.4 introduces provisions that would help phase out endocrine-disrupting chemicals, carcinogenic, mutagenic and reproductive/developmental toxic substances (CMRs), and particular phthalates in medical devices if safer alternatives are available and technically feasible.

Alternative plasticisers (PVC-free vs. DEHP-free)

With growing concerns about DEHP toxicity, some product manufacturers are substituting alternative plasticisers for DEHP in various medical products rather than switching to alternative, non-PVC polymers that do not require plasticisers at all. [51] The toxicity of other plasticisers and their tendency to leach out of the PVC product can vary from DEHP. Some are less hazardous and have no-effect levels higher than DEHP. However, many have not been as extensively studied as DEHP and related phthalates, particularly with regard to reproductive toxicity and endocrine disruption. Four of these alternative PVC plasticisers (DINCH, BTHC, TEHTM, DEHT) are included in the European Pharmacopoeia, in order to provide manufacturers with alternatives to DEHP in medical applications.[52]

In 2007, HCWH Europe documented hospitals across Europe that had begun phasing out PVC medical devices to protect patients from DEHP and other alternative plasticisers.[53] Among the alternative plastics that can be used for various medical products and devices are polyolefins, including polyethylene and polypropylene; polyethylene terephthalate, a polyester; multi-layer laminate plastics; polyurethane; silicone; ethylene-vinyl acetate; polycarbonate; and polystyrene. Unfortunately, very few comparative life cycle assessment (LCA) studies exist for materials used in medical applications, and minimal environmental optimisation has taken place in medical products to date In the *Plastics Scorecard: Evaluating the Chemical Footprint of Plastics* report,[54] the chemical footprint of polyolefin and PVC in IV bags was compared. The results of the comparison showed that the substitution of PVC bags by polyolefin-based polymers greatly reduced the chemical footprint of the products. Taking this into consideration, together with the large amount of waste produced by hospitals as a result of waste medical products, the potential of comparative LCA studies identifying methods for environmental improvement is expected to be high.

Some of these alternative plastics are also used for food packaging and office supplies. For building products, there are a wide range of substitutes, including wood, linoleum, rubber, and a variety of other polymers suitable for various applications.

Each of these polymers also requires various additives depending on the intended application but at far lower levels than plasticisers used in flexible PVC. Life-cycle evaluations of the hazards of alternative plastics also vary, with some inherently safer than others.[54] For example, polyurethane is one of the more problematic polymers, produced by combining an isocyanate with a polyol.

The global market for non-PVC IV bags is estimated at $1.1 billion and is expected to rise steadily through 2025.[55] North America dominated the non-PVC IV bags market and is expected to dominate throughout the forecast period. On the other hand, Asia Pacific is expected to experience the fastest growth, fuelled by factors such as the emergence of a large number of local players and increasing foreign direct investment.

Health Care Without Harm recommends healthcare facilities avoid PVC and DEHP and replace them with safer alternatives without compromising patient safety or care.[56]

Hospitals in the Practice Greenhealth network, a sister organisation of HCWH situated in the US, have made eliminating PVC and DEHP a top priority. Practice Greenhealth offers step-by-step resources and product lists in the following product categories that will make it easier for any hospital to restrict the use of PVC and DEHP, and not only in medical devices:

- Medical products and devices[57]
- Healthy interiors and furnishings[58]
- Resilient flooring[59]
- Carpets[60]

Concerns about PVC in other sectors

Toxic releases during use

Other phthalate-containing PVC products include wall coverings, tablecloths, floor tiles, furniture upholstery, shower curtains, garden hoses, swimming pool liners, rainwear, plastic diaper covers, dolls, some toys, shoes, automobile upholstery, packaging film and sheets, and sheathing for wire and cable. DEHP or other phthalates have commonly been used in these applications, although alternatives are increasingly being substituted because of toxicity concerns. In 2005, the European Union adopted a directive (2005/84/EC) that bans some phthalates in toys (products designed or clearly intended for use in play by children) and childcare articles (products intended to facilitate sleep, relaxation, hygiene, the feeding of children or sucking on the part of children). Regulators recognised that these products are especially dangerous for babies and small children, because the absorption of phthalates may exceed the maximum daily dose and have a long-term impact on health.

The results of phthalates measurements in 4 companies producing or processing materials made of rubber and plastics showed that dimethyl phthalate, diethyl phthalate and dibutyl phthalate dominated in all the investigated companies in the gaseous phase of air sampling. The inhalable particle fraction was dominated by DBP and DEHP, and their total concentration was a significant percentage, on average over 83% of the sum of all phthalates determined in the inhalable fraction in the investigated companies.[61]

Children come into contact with DEHP released from a variety of products, including building materials, and flooring and wall coverings. In 2004, researchers in Sweden found that DEHP (and butyl benzyl phthalate) concentrations in dust were associated with PVC flooring and wall materials in their study of 390 homes.[62] In 2014, French researchers evaluated indoor air and dust in 30 French homes; again, phthalates, including DEHP, had the highest concentrations in both air and dust.[63]

Leaching of organic toxic compounds (carbon tetrachloride, toluene, chloroform, styrene, o-xylene, bromoform, dibromomethane, cis-1,3-dichloropropane, and trans-1,3-dichloropropane) from PVC water pipes has been reported.[64] The levels of some of these were found to exceed the WHO limits. This implies that these components are more likely to migrate from PVC pipe in home plumbing systems.

Food-contact materials (FCM)

There seems to be increasing awareness of the use of PVC in food packaging, and many companies are trying to avoid it or phase it out (e.g. Nestlé, Danone). But in general, PVC is still commonly used in FCM. Vinyl chloride is authorised for plastic-made FCM in the EU,[65] and ECHA's database points to more additives that may be used in PVC for food contact.[66]

Plasticised PVC can be found in food wraps, for both commercial and consumer use, in components of certain food processing equipment such as conveyor belts and tubing, as well as in the gaskets found in metal cap closures used on glass jars and bottles. Both phthalate and non-phthalate plasticisers can be added to the materials. Overall, it appears that manufacturers are switching away from phthalates as their primary plasticiser to alternate compounds such as ESBO, ATBC, DEHT, DINCH, DEHA and DINA.[67] [68] It is, however, important to emphasise that changing plasticisers does not address the fundamental problems with PVC, as described in this paper.

The substance (triethanolamine-perchlorate, sodium salt) dimer is used as a thermal stabiliser at up to 0.15% w/w in rigid PVC for repeated use bottles in contact with water.[69]

PVC use as coating for cans in the food sector has also grown in the wake of concern about endocrine disruption from BPA epoxy coatings, and is an example of regrettable (toxic) substitution. In 2017, the Center for Environmental Health sampled 252 cans from four main supermarket chains, finding 19% of them used PVC coating on the inside.[70]

PVC also comes into contact with food through the use of single-use PVC gloves in the food service industry. In 2019, the Ecology Center found that 14% of 60 sampled vinyl gloves for food-handling sourced from different suppliers contained phthalates (including DINP, DIDP, DEHP and DPHP), and that 2 out of 3 of 56 restaurant locations visited used PVC gloves for food handling, rather than gloves made from other types of plastics.[71]

Buildings and construction

With the increasing emphasis on sustainable construction, it has become important to better understand the impacts of common building materials. In a recent study aimed at comparative data analysis of the embodied energy consumption of three types of polymers i.e. Polyvinylchloride (PVC), Polyethylene (PE) and Polypropylene (PP), PVC has been shown to have higher energy consumption and greenhouse gas emissions.[72] Thus, use of PVC in constructions contributes more to global warming in comparison to other types of polymers.

Phthalates, adhesives and other chemicals in PVC used in buildings can react with moisture and form chemicals that contaminate indoor air and cause *sick building syndrome*, or contribute to phthalate-contaminated dust, which is inhaled by building occupants or may irritate their eyes or respiratory systems.[73]

Risks and impacts associated with use of PVC pipes in municipal water and sewer infrastructures include benzene emissions from pipes into water, particularly when exposed to high temperatures in the context of wildfires. Such was the case in 2018 in Santa Rosa, California, following the Sonoma County fires, leading to benzene contamination of drinking water, and the risk is repeated during yearly wildfires that reach residential areas.[74] The use of PVC in building materials also triggers the release of hydrochloric acid during fires, injuring fire fighters and other persons exposed to smoke and fumes. Dioxin formation from fires and other accidental combustion is also a significant concern.[75]

The Center for Environmental Health (CEH) published a report in 2018 examining the impact of PVC pipes on human health and the environment.[76] This report outlines the adverse public health and safety risks, environmental impacts, and costs of widespread PVC usage in municipal water and sewer infrastructure. The report concludes that *"here is no way to safely manufacture, use, or dispose of PVC products".*

PVC is on the Red List of the International Living Futures Institute (ILFI).[i] The list represents the "worst in class" materials, chemicals, and elements known to pose serious risks to human health and the greater ecosystem that are prevalent in the building products industry. ILFI believes that these materials should be phased out of production due to human and/or environmental health and toxicity concerns. While there are certainly other items that could be added, this list was determined by selecting items with the greatest potential impact if they were significantly curbed or eliminated from the building industry.

The recent article *Improving the Healthiness of Sustainable Construction: Example of Polyvinyl Chloride (PVC),* presents a transdisciplinary review of adverse health impacts associated with PVC highlighting a number of issues - some that could be eliminated through design, but also some which appear inherent to the material itself and therefore unavoidable.[12]

The totality of issues revealed in relation to PVC presents a compelling case for complete elimination of use of this material in sustainable construction.

End of life

Disposal (incineration and landfilling)

For a material to be truly sustainable, it should have minimal adverse impacts during the disposal stage. However, the prominent PVC disposal options are waste incineration or landfilling. This may change in the future as more stringent regulations to protect the environment are enacted.
When PVC is burned in waste incinerators, cement kilns or industrial boilers, highly hazardous dioxins and furans are formed and released directly into the environment or sequestered in ash that must then also be disposed of (a new waste disposal problem in itself). Higher PVC concentrations in the fuel mix result in higher dioxin formation.[77] PVC is an important contributor to dioxin/furan formation in poorly controlled incineration and building or landfill fires.[78]

In the EU, regulations of waste incinerator emissions have significantly reduced dioxin and furan releases to the air from those sources in recent years, although incinerator ash containing these compounds remains a serious problem.[79] About

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[i] The Red List contains substances defined as those that pollute the environment, or bio-accumulate up the food chain and can reach toxic concentrations or harm construction and factory workers

20–25 wt% of the waste input to incineration is transferred to so-called incinerator bottom ash (IBA).

Almost 500 municipal solid waste incineration plants in the EU, Norway and Switzerland generate annually about 20 million T of IBA.[80] On average, 2.1 million tons of municipal solid wastes are incinerated each year in Belgium. Around 400 kilotonnes (kT) of bottom ash residues are generated in Flanders, of which only 102 kT are utilised in Belgium, with the rest exported or landfilled due to non-conformity to environmental regulations.[81]

The disposal of IBA in an "eco-friendly" way is a global issue of concern. Since there is no uniform regulation for IBA utilisation at EU level, countries developed their own rules with varying requirements for utilisation.[82] The overall utilisation rate of IBA in construction works is approximately 54% by weight. It is revealed that the rate of utilisation does not necessarily depend on how well regulated IBA utilisation is, but rather appears to be a result of political commitment for IBA recycling and economically interesting circumstances.

IBA contains minerals and metals. The heavy metals usually present in this ash are arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), tin (Sn), antimony (Sb), selenium (Se) and zinc (Zn).[83] The presence of toxic metals is of great concern due to their leaching potential in landfills.[84] The presence of heavy metals in IBA and its leaching into groundwater has been a problem for a long time.

Heavy metals accumulate more readily in fly ashes than bottom ashes, except Cu, Cr and Pb due to their low volatilities. Certain fly ashes from municipal solid waste incinerator plants are classified as hazardous waste due to their dioxin and other persistent organic pollutants (POPs) content - chlorinated precursors such as chlorine contained in PVC are the main precursors of those POPs. A recent IPEN report showed that the amount of dioxins released (contained) in waste incineration fly ash is highly underestimated (its content is 3 – 10-times more than previously estimated), and the scope of the problem is greater than previously thought.[85] The report also concludes that all existing technologies that have the capacity to treat PVC lead to increased formation of dioxins in waste incineration processes; therefore substitution of PVC can lead to decreased risk of contamination of the environment from municipal waste incineration processes.

The waste industry claims that incineration using highly advanced emission control technologies provides clean energy that reduces climate impacts and toxicity. And indeed, those technologies have the potential to significantly reduce air pollution. However, the pollutants are mostly transferred to the ash instead, and the evidence clearly demonstrates the harmful short- and long-term effects of waste incineration’s emissions and by-products.

Below are two examples from EU Members States, highlighting poor waste management:

1. Incinerators have mismanaged highly toxic ash in several cases; in 2015, Sweden was found to have sent 500,000 T of highly toxic fly ash from waste incinerators to a small island in Norway for five years, creating risks of heavy metal leakage into the Oslo fjord and explosions on the island.[86]
2. The most recently installed incinerator in the Netherlands was recently shown to be far from clean; long-term tests reveal that emissions of dioxin, furan, and persistent organic pollutants are far beyond legal limits.[87] From the uncontrolled combustion of 19 T of undefined waste: “*An official conservative estimate of dioxin emissions is 33 mg, but this figure is probably much higher, since the waste was wet and likely to have a Polyvinyl Chloride, PVC, content above 2% because of an impossibility of pre- separation of PVC*.”

The reported emissions of dioxins and furans in the EEA-33 countries decreased by about 70% between 1990 and 2017.[88] In 2017, 32% of dioxin and furan emissions were from sources in the 'Waste' sector, 25% were from the 'Commercial, institutional and households' sector and 22% were from the 'Energy production and distribution' sector.

Like the majority of other petrochemicals, PVC could theoretically be used as a fuel. However, any heating of VCM can lead to release of dioxins, and it has already been established that burning of PVC leads to the release of dioxins. Some work has reported that, under controlled combustion conditions at a sufficiently high temperature, some of the dioxin formation could be mitigated.[79] Unfortunately, the same work did not report on the fate of PVC additives during this combustion, leaving it open to speculation that stabilisers, such as possibly cadmium and lead, or plasticisers could potentially be released during this process.

To date, there is no certainty surrounding the eventual decomposition of disposed PVC. Some countries in Europe have already banned PVC from landfills (e.g. Germany,[89] Sweden and Finland[90]). In 2000, the European Commission reviewed landfilling of PVC and established that it shows only very modest degradation decades after disposal.[91] However, it was also reported that the additives were released, with heavy metal stabilisers presenting greater problems due to their biopersistence than phthalate plasticisers, which chemically reacted with other surrounding material. It has also been recognised that accidental fires of general landfills continue to be likely, and they might contain unknown amounts of PVC.[98] An increasing occurrence of fires in MSW (Municipal Solid Waste) and landfills worsens environmental and human health effects.[92] [93] Some of the key findings of

INTERPOL's strategic report on global plastic waste management include an increase in illegal waste fires and landfills in Europe.[94]

The absence of known safe ways of disposing of used PVC, and recognition of the likely problems associated with burning and release of additives, lead to a conclusion that disposal should be recognised as one of the undesirable aspects of PVC.[12]

It is also important to emphasise that, because of how problematic management of PVC waste is, there is an increased chance for illegal waste shipments and dumping.[101]

NOTE: Burning plastics as fuel in waste-to-energy plants designed to produce heat, steam, or electricity is sometimes called "recycling" but it is a misuse of the term and the technologies carry risks similar to waste incineration.

Mechanical recycling

In general, plastics' recycling is preferable to single-use and disposal, although without proper safeguards, recycling technologies can pose occupational, public and environmental health risks. For example, mechanical recycling is often a labour-intensive activity in which workers hand-sort waste streams and disassemble products, resulting in their exposure to hazardous chemicals if they are not properly protected.[95] Emissions from poorly operated recycling facilities can also contaminate air, water, and soil.

Among the various plastic polymers, very little post-consumer PVC is recycled. It is challenging for several reasons:

- When waste streams of various kinds of plastic are mixed without sorting and separation, PVC content of more than 10-15% can make this material much less useful and sometimes destroy its value completely, e.g. a high recycling processing temperature for PET will accelerate the dehydrochlorination of PVC.[96] Recycling facilities therefore need to meticulously separate PVC from mixed plastic through hand sorting or automated systems, e.g. using magnetic density separation or x-ray detection.
- PVC can be difficult to recycle in part because of additives. Moreover, recycled PVC often contains hazardous additives including metals, phthalates, and other toxicants that make their way from the recycled source into new consumer products. For successful recycling, PVC products need to be "super-separated" by product type to keep them from going to an incinerator or landfill.[97]

- The costs of PVC recycling can be particularly high. In 2018, a specialised PVC recycling facility in Italy was closed after 15 years of losses and collapsing demand for their product.[98]

In Europe, VinylPlus, a PVC industry consortium, has set a target of recycling 800,000 T of waste per year by 2020.[99] VinylPlus' definition of recycling combines post-industrial and post-consumer waste, so it is not possible to identify which waste streams are by-products of current production, and which are coming from discarded products. Germany and the UK are responsible for about half of the European recycling.[100]
Regardless, the figure of 771,000 T of recycled PVC[101] represents still a small share (12%) of 6.5 million T of PVC products manufactured in the EU every year - and window frames are probably the largest and the only consistently recycled waste stream (mainly down-cycled in fact). We are not aware of any product-to-product high quality PVC recycling.

No evidence can support the industry's claim about "endlessly recyclable plastic waste".[102] Most plastics can only be recycled once or twice into a new plastic product before being down-cycled (where the recycled material is of lower quality and functionality than the original material).[103] To make the recycled plastic usable for preparation of new products, virgin material must often be added again. This means that when the plastic is recycled more than two or three times, its quality becomes so poor that it is no longer usable.

The possibilities of release of toxic fumes during PVC recycling and health concerns with some of the historical additives create potentially compelling disadvantages. Operations that recycle scrap-containing DEHP release this phthalate into the environment.[104] In the U.S., Baxter - the leading distributor of DEHP-containing medical supplies to hospitals - distributed DEHP waste to its subsidiary in Mexico.[105] Plasticos Del Caribe, a plastics packaging company in Santo Domingo, Dominican Republic received the fifth-most DEHP waste. But far more PVC scrap generated from the U.S. is being recycled overseas than domestically.[105]
Although PVC is a thermoplastic, and therefore potentially well-suited for recycling, the totality of added stabilisers, plasticisers and any other hazardous substances during its manufacture all play a role in the recyclability of the material at the end of its life. Quality concerns are constricting the growth of PVC recycling.[105] Major flooring manufacturers restrict the use of non-flooring post-consumer PVC. One restricts the use of any recycled PVC except a limited subset of postconsumer tile floors.

And as public awareness about contamination in recycled PVC rises, more building product manufacturers may refrain from using recycled PVC, especially in interior products. There has been a rise in discussion of possible toxicity implications of PVC recycling. In 2015, the EU Parliament recommended that the European Commission should not authorise the recycling of plastics which contain the phthalate DEHP, saying 'recycling should not justify the perpetuation of the use of hazardous legacy substances'.[106] However, DEHP is not the only problem additive commonly found in PVC available for recycling - as the previous section explained, a number of additives to PVC present serious health risks.

More recently, in January 2020, the Environment Committee of the EU Parliament rejected the European Commission's proposal to allow up to 2% lead by weight in recycled PVC, seeing increased levels as unsafe and unnecessary given available PVC alternatives, and arguing that recycling should not justify continued use of hazardous substances.[107]

In February 2021, EU Advocate General Kokott found that the European Commission illegally disregarded the hormone-disrupting risks posed by the phthalate DEHP when it approved its presence in PVC materials and products.[108] At best, mechanical recycling can lower the need for new PVC production and 'dilute' PVC toxicity through the addition of new material.

Chemical recycling

Chemical Recycling is often referred to as a solution for the most contaminated PVC compounds. Chemical Recycling converts polymeric waste by changing its chemical structure to produce substances that are used as products or as raw materials for the manufacturing of products. Products exclude those used as fuels or means to generate energy; the use of the output as a fuel in Europe is excluded from the definition of chemical recycling.[109]

The position paper on chemical recycling from EuRIC (The European Recycling Industries' Confederation) raises awareness on the diversity of technologies covered by the term "chemical recycling", and the limits of those technologies with regards to the objectives of circular economy.[110] It underlines that chemical recycling cannot be considered as the silver bullet solution, and that chemical recycling covers a large number of different technologies, in some cases at early stages of industrial development and with different abilities to recycle complex waste plastic streams of mixed polymer types. Those different processes will most likely be hampered by the same waste-specific issues that mechanical recycling is facing. Besides, some of the technologies understood as chemical recycling are actually producing fuel from plastics and as such not complying with the definition of recycling as stated in the Waste Framework Directive.

The main conclusions from GAIA 2020 report *Chemical recycling - Technical assessment,* and *Chemical Recycling: Research briefing* (Distraction, Not Solution) are that chemical recycling:[111]

1. Releases toxic chemicals into the environment.
2. Has a large carbon footprint.
3. Has not yet been proven to work at scale.
4. Cannot compete in the market.
5. Does not fit in a circular economy.

The recent policy briefing released by a group of NGOs, including HCWH Europe, warns about putting too much expectation on a solution whose potential is yet to be proven.[112] It highlights 7 key steps to effectively regulate chemical recycling so as to avoid a scenario whereby chemical recycling becomes a loophole preventing the achievement of objectives related to the EU circular economy, climate and sustainable chemical policies.

One of the often-forgotten elements in the discussions around chemical recycling is that it is crucial to have a complete and correct understanding of the true human health and environmental impacts of these technologies. A review of some of the most commonly cited chemical recycling and recovery LCAs, reveals major flaws and weaknesses regarding scientific rigour, data quality, calculation methods, and interpretations of the results.[113]

One of the arguments used by the industry is that chemical recycling can play a key role in eliminating hazardous chemicals from recycled materials. However, a serious problem is the lack of verified environmental performance data for the majority of technologies.[114] Some evidence points to high concerns about toxicity related to chemical recycling; an examination of polyaromatic hydrocarbons (PAH) formation and chlorine distribution in the oil, gas, and char yields from PVC pyrolysis by Cao et al. (2019) found that the PAH content in pyrolysis oil was 'amazingly high' at 95.3%, while chlorine was retained in both oil and char at far greater concentrations than predicted.[115] The issue of contaminants has been also clearly demonstrated in Solvay's efforts to purify PVC waste.[115]

In addition, the presence of PVC requires special treatment to remove hydrogen chloride (HCl)[97] formed during pyrolysis[ii], a toxic compound (sensory and

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[ii] A process that breaks plastics down into simpler hydrocarbon compounds by heating them without oxygen between 300ºC - 600ºC. The process can be used on mono- or mixed/contaminated feedstocks, but PVC should be avoided for safety. Degradation is not controllable and outputs are largely hydrocarbon mixes. Turning plastics processed this way back into plastics is unlikely as it requires additional, and energy intensive steps.

pulmonary irritant). The presence of this acid will impose severe constraints on the equipment material. Pyrolysis at lower temperature can be used to remove chlorine, but this involves additional environmental impacts using new additives, and extra operating costs. Hence, conventional pyrolysis has low tolerance to PVC.[116] Other chemical recycling processes do not accommodate PVC either. Catalytic cracking is highly sensitive to feedstock contamination, such as from chloride and nitrogen in waste that can deactivate the catalyst. And hydrocracking cannot use PVC due to risks of poisoning. Chemical recycling thus requires a high level of waste separation, which PVC can hinder.

Feedstock recycling can incur higher costs than landfilling, primarily due to the low value of the recovered products. This provides currently little incentive for recyclers to pursue PVC recycling.

Chemical recycling applies technologies that use hydrolysis, high heat, gasification, or other means to produce basic feedstock compounds that can be reused. Chemical technologies typically require economic subsidies because of the relatively low prices of virgin feedstock materials compared with plant and processing costs incurred by breaking down the plastics.[117]
The PVC industry brochure focused on recycling technologies outlines some of the challenges and solutions for extending recycling of PVC waste, initiatives on chemical recycling, and the emerging technologies that can access the 'more difficult to recycle' waste streams; however, such "emerging" technologies are mainly incineration with energy recovery technologies.[118]

A chemicals industry lobby group set up in 2019, Chemicals Recycling Europe,[119] called last year for "*a faster recognition and legislation review to unlock the potential of chemical recycling.*" The group admits that today, this technology has many obstacles, including regulatory barriers and legal uncertainty.

The PVC industry is listing some more recent new projects related to chemical recycling – they seem, however, to be small scale and at an early stage of development so it is uncertain if their results will effectively remove existing technical obstacles.[120] In fact, many previous projects failed to do so.

The following issues relate to the chemical recycling of PVC:

- **Unclear recycling status:** Company Vynova claims "circular-attributed" PVC through chemical recycling, but in reality, produces new PVC from ethylene monomers made from pyrolysis oil (which may or may not have been 'fed' with PVC).[121]

- **False claims:** Companies using flexible mass balance approach[122] might in reality have recycled no PVC at all, but simply attributed the recycled amount from recycling other plastic types and claiming it as recycled PVC
- **Unproven financial viability and previously failed projects:** Virgin is cheaper to produce and studies show that recycling is even more expensive than landfilling, primarily due to low value of recovered materials. In general, poor input quality can lead to the presence of unwanted substances of concern.
- **Technical viability:** Pyrolysis has low tolerance to the PVC present in the feedstock (because of HCl generation). Chlorinated compounds can then be formed in the pyrolysis oil which makes its use (other than for burning to produce energy) problematic.
- **Contamination/toxicity issues:** PVC and other waste inputs containing halogens (chlorine, bromine etc.), are also highly problematic as their breakdown leads to the production of acidic halogen gases such as hydrogen chloride. These have serious impacts being both toxic and causing thermal decomposition of the depolymerisation equipment. This, therefore, necessitates extensive purification to effectively remove them. Even where these contaminants are successfully separated, they are often too contaminated themselves to allow reuse and as such require safe disposal.

Alternatives to PVC

The industrial transition towards elimination of PVC can be accomplished in a manner that is fair to all involved — the plastic manufacturers, industrial workers, and host communities. PVC can be replaced with safer materials in virtually all cases. Substitutes for PVC include "traditional" materials such as clay, glass, ceramics, linoleum, and wood. In those cases, where traditional materials cannot be used as a replacement, a variety of other polymers (chlorine-free plastics) are preferable to PVC.

The Center for Health, Environment and Justice, which calls PVC the "most environmentally harmful plastic", has created a list of common products — in categories such as apparel, kitchen items and office supplies — that are made from or packaged in PVC. The organisation also listed PVC-free alternatives to common materials.[123]

As consumers increasingly demand PVC-free products, and as the environmental and health costs of PVC are recognised, practical alternatives are becoming more economically viable.[124]

Examples of PVC phase-outs

Many actors from governments to corporations and civil society groups have called for or implemented PVC phase-out, including the Ellen MacArthur Foundation and the over 400 organisations that have signed its *New Plastics Economy Global Commitment*.[125]

Several European jurisdictions have adopted phase-out of certain PVC products for certain applications, recognising PVC's heavy health and environmental burden across its lifecycle and associated waste-management costs, including[iii]:

- During the 1990s in Spain, over 60 cities declared themselves PVC-free by passing procurement policies ending the purchase of food and beverages in PVC packaging, and by supporting efforts by local businesses to phase out PVC.[126]
- In the Netherlands, the cities of Amsterdam, Den Haag, Rotterdam and Utrecht have listed PVC as a material to avoid in construction.[127]
- In Austria, seven of the country's nine regional governments have policies restricting the use of PVC including in the construction sector, while several cities such as Vienna, Linz, Salzburg, Innsbruck, Bregenz, Klagenfurt, Graz, SanktValentin, Traun, Bruck an der Leithha, Judenburg, Hoechst, Wolfurt, Ludesch, Feldkirch, Dornbirn, Wolfsberg, and Klosterneuburg have passed broader policies restricting the use of PVC. Vienna's public transport system is also PVC-free.[130]
- Since 1992, the City of Vienna has been following PVC avoidance policy.[128] Whenever suitable alternatives are available, they are used instead of PVC. In order to protect the most vulnerable from hazardous chemicals, the Vienna Hospital Association aims to limit the use of medical devices containing PVC in neonatal intensive care units. Purchasing PVC-containing devices is prohibited when PVC-free alternatives exist. As a result of this approach, the amount of PVC found in their medical waste has decreased from approximately 10% of total weight in 1992 to 0.6% in 1999. At present, the vast majority of invasive medical devices are free from PVC. At the hospital level, there are also efforts to eliminate PVC in other areas including construction, when it is economically and technically justifiable.
- In 1997, the Czech Republic banned PVC packaging at national level, following a series of local bans and phase-outs,[129] although it had to abandon this regulation upon joining the EU.

HCWH Europe's factsheet from 2007 showed that PVC/DEHP phase-out is possible anywhere in Europe.[130] This factsheet describes the common lessons learned from

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[iii] This is not an exhaustive inventory of PVC phase outs, and does not include bans that only target PVC with certain additives such as organotins or phthalates.

across Europe to show how PVC phase-out is possible, whatever the political and economic climate. It also lists hospitals, which are phasing out PVC and the devices with which they are having most success. Our non-toxic healthcare report from 2014 showed more examples of PVC-free initiatives of European hospitals.[131]

At the global level, the Republic of Korea banned PVC for some food-packaging applications in 2004, extending the ban in 2019 to include all PVC food and beverage packaging (also laminates, labels and coatings).[132] Korea's policy decisions were informed by an acknowledgement of the issue of dioxin and furan releases during incineration as well as challenges with recycling, and a conscious decision to phase out difficult-to-recycle products.[133]

The cities of Rahway, New Jersey, USA and Glen Cove, New York, USA, have banned use of PVC food containers and utensils by retail food vendors, recognising its low recyclability and toxic emissions when incinerated, and associated burdens on municipal waste-management.[134] Rahway has also mirrored this ban in the city's procurement policies, prohibiting the purchase of food in PVC packaging, as well as the city's sponsorship of events that use such packaging. Other cities such as Boston, Seattle, San Francisco, Buffalo, Berkeley and Oakland have passed similar procurement measures mandating the purchase of alternatives to PVC where possible, or eliminating PVC purchasing in order to minimise their contribution to dioxin emissions.[135]

In 2021, Sri Lanka banned the use of PVC for agrochemicals packaging (including pesticides, growth regulators and liquid fertiliser).[136] Large private sector actors have also phased out PVC including:

- In 2008 Bed Bath and Beyond committed to phasing out PVC shower curtains, following shareholder pressure, and have since substituted PVC with EVA vinyl.[137]
- In 2009, electronics manufacturer Apple phased out PVC from all new products.[iv] Google has also successfully phased out PVC from its products.[138]
- In 2010, car manufacturer General Motors phased out PVC from car interiors.[139]
- In 2013, toy manufacturer Hasbro phased out PVC from packaging.[140] Toy manufacturer Lego progressively phased out PVC from toys and packaging.[141]
- Since 2020, household consumer and personal care products manufacturer Church & Dwight no longer uses PVC in its packaging.[142]

[iv] With the exception of power cords in India Thailand, and South Korea due to delays in obtaining government permission of the use of alternative materials. Apple (2021) Environmental Progress Report

- Supermarket chain Target is working to phase out PVC from its own-brand product packaging.[143]

A longer list of jurisdictions and corporations who have phased out PVC can be found in Greenpeace's *PVC-Free Future: A Review of Restrictions and PVC free Policies Worldwide*[144] and in the Center for Health, Environment and Justice fact sheet *PVC Policies Across the World*.[145]

An analysis of options for PVC phase-outs in different sectors including construction, automotive, packaging and electronics can also be found in Overseas Development Institute's report Phasing Out Plastics.[146] In particular, the Overseas Development Institute concluded that in the construction sector, which uses the most PVC, it is possible to phase out PVC from all pipes, guttering, tubing, flooring, and window and door profiles (frames) immediately, while phase-out for cable coating and sheeting applications will be possible by 2035.[147]

Conclusions

Since the 1990s progress has been made to address some of the particular environmental and health concerns associated with PVC manufacture, use, reuse and disposal, and all current evidence points at the simple proposition that all use of PVC is problematic.

The information on PVC shows that there are significant health issues on a number of levels - during the production, while in use, and after use. The majority of key components used in the manufacture of PVC are well recognised for their toxicity and this is an inherent feature of PVC.

Therefore, the main issue with PVC is how much it is used — the more of PVC, by volume, that is used, the more harm that results. This again places a great importance on the way all different sectors act to use or avoid this material.
The totality of issues revealed in relation to PVC presents a compelling case for a call for complete elimination of use of this material in sustainable **applications**. Arguably, elimination of PVC from applications in direct contact with humans, food and feed medical applications, children's toys and food packaging should be prioritised. However, because of the relevancy of volumes used, this is where the construction industry could show some real leadership and help decrease the total use of toxic components of PVC.

Civil society organisations argue against the fundamental idea that PVC can be labelled as sustainable and see this approach as "greenwashing and misleading”.[148] PVC is the most environmentally damaging and the least recyclable of all plastic. Sustainable production and use of PVC is just not possible.

Recommendations

The totality of issues revealed in relation to PVC presents a compelling case for a call for complete elimination of use of this material, and **we call on** European policymakers **to develop a strategy for PVC phase-out in Europe.**

We recommend that such a strategy will include the following steps:

1. Replacement of PVC in applications that pose a risk to human health via direct exposure (such as medical devices, applications for food, food packaging, feed, and children's toys) by 2025.
2. Replacement of PVC in applications that pose a risk to human health via indoor exposure (such as flooring, furnishing, furniture) by 2030.
3. Replacement of PVC in applications that pose mainly an environmental risk during their production and disposal (such as applications in construction, automotive and transportation, sport) as well as during extreme events such as fires (which increase in frequency in some parts of Europe due to climate change), by 2040.

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