CASE STUDY ON FLOORING

An example of chemical considerations for sustainable plastics design

A Chemicals Perspective on Designing with Sustainable Plastics: Goals, Considerations and Trade-offs

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Foreword

This case study was developed to provide input to and inform the development of guidance on General Considerations for Design of Sustainable Plastics from a Chemical Perspective. Four case studies were developed as concrete examples to inform these considerations. Two in the plastic packaging sector: biscuit wrapping and detergent bottles; two in the construction sector: flooring and insulation. For this purpose, the case studies start from the premise that plastic material will be used and therefore alternative material selection is not considered. They focus on environmental sustainability aspects related to chemical selection, taking into account health protection across the product life cycle. They do not address cost, performance and chemical/material availability information, which would need to be considered in an application scenario. They also do not consider a discussion of social and environmental justice impacts.

The examples of material selection within the case studies are developed in the context of the information gathered for the case studies to exemplify the sustainable design process and to highlight key considerations. To make actual decisions about material selection other factors would also need to be considered (as outlined above) and the analysis could be further informed by elements such as life cycle assessment comparing alternatives and a full review of regulatory restrictions.

This document is based on a draft report developed by the Healthy Building Network for the project and was reviewed by an OECD expert group supporting this project, which also provided a number of inputs. It was further reviewed by the OECD Working Parties on Risk Management and on Resource Productivity and Waste. Additionally the report was discussed at an OECD workshop on developing the general considerations for design of sustainable plastics from a chemical perspective held in March 2021.

This report is published under the responsibility of the OECD Chemicals and Biotechnology Committee in collaboration with the OECD Environmental Policy Committee.

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Executive Summary

The OECD is conducting a project on design of sustainable plastics from a chemical perspective which aims to identify the key considerations regarding environmental/health sustainability that should be examined along the product life cycle when chemicals are selected at the design stage, as well as the potential trade-offs between these considerations. Case studies on particular sector/product combinations have been elaborated to inform the development of the general considerations. This case study aims to increase the awareness of environmental and health impacts and potential policy interventions to lead to sustainable plastic products from a chemicals perspective using flooring as an example.

Building on the findings from the recent OECD report “Considerations and Criteria for Sustainable Plastics from a Chemical Perspective,” this case study lays out actionable Sustainable Plastic Goals that could be applied across the product life cycle to help develop sustainable durable plastic products.

Behind packaging, the building and construction industry is the second largest consumer of plastics, comprising 16% of global plastic production. For this reason, building products – in particular flooring products – are used as example durable plastic products for this case study. The three product types included are:

- Vinyl sheet and vinyl tile.
- Wood plastic composite (WPC).
- Polyethylene terephthalate (PET).

An analysis of the chemicals used in the manufacturing of the base polymer, the manufacturing of the product itself, the installation materials and recycled content highlighted many opportunities for mitigation of impacts from the use of hazardous substances. These opportunities include consideration of different designs, different materials, different manufacturing processes and various policy instruments that could reduce the impacts of the product throughout the life cycle.

This analysis also revealed trade-offs that exist between different material choices. For example, a flooring product that is designed to use adhesive to install typically requires less material use within the floor itself than one that uses a click tile system to install. However, adhesives may add hazardous substances to the product installation stage.

Finally the analysis highlighted data gaps that exist both in chemicals used and released at various life cycle stages and in the amount of hazard data available on those chemicals.

This analysis was used to generate a set of criteria to benchmark and compare material alternatives. Example criteria include:

- The base polymer chosen uses the least hazardous substances in the manufacturing and produces the least hazardous production emissions
- Additives are fully assessed for hazards and are the least hazardous available
- The product can be reclaimed and reused
- The material is recyclable at the end-of-life into products with equal or greater value

These criteria can be used by design teams, procurement professionals, or regulators to benchmark current practices, make material selections, and measure progress towards the aspirational sustainable plastic goals. While the criteria were developed with plastic flooring in mind, they are relevant for any durable plastic product.

The flooring product analysis and the sustainable plastic goals are used to define and align policy instruments that can encourage and reward work towards sustainability outcomes. For example, policies restricting the use of hazardous substances coupled with extended producer responsibility programs can facilitate circular product design.

The sustainable plastic goals are lofty. Current products are unlikely to meet all of the criteria. While they may not be immediately achievable, the criteria provide a pathway toward truly sustainable plastic products. This paper focuses on comparing plastic flooring products; however, additional flooring materials such as ceramic tile, carpeting and linoleum should be considered and compared from a sustainability perspective. In product design, innovation may require the consideration of vastly different materials versus making incremental improvements in chemistry for a particular type of product.

Project teams need to prioritise which sustainability elements are most important and relevant for their applications and how to deal with gaps in understanding. This report includes examples of how to use the criteria to compare different product types.

Chapter 1. Introduction

1.1. Purpose of case study

This case study aims to increase the awareness of environmental and health impacts and potential policy interventions to lead to sustainable plastic products from a chemicals perspective using flooring as an example.

Building on the findings from the recent OECD report "Considerations and Criteria for Sustainable Plastics from a Chemical Perspective" (OECD, 2018a), this case study lays out actionable goals that could be applied across the product life cycle to help develop sustainable durable plastic products. These goals are used throughout the rest of the case study to:

- Consider key potential environmental and health impacts at each life cycle stage (source materials, product manufacture, use phase, end-of-life) focused on chemical selection using three representative plastic flooring product types as examples.
- Compare results and discuss trade-offs between sustainable plastic goals.
- Generate common criteria for durable plastic product design.
- Identify policy instruments to facilitate progress towards sustainable plastic goals consistent with the OECD Policy Principles for Sustainable Materials Management (Box 1.1).

These criteria can be used by design teams to benchmark current practices, make material selections and measure progress towards the aspirational sustainable plastic goals.

Box 1.1. OECD Policy Principles for Sustainable Materials Management (OECD, 2010)

1. Preserve natural capital
2. Design and manage materials, products, and processes for safety and sustainability from a life cycle perspective
3. Use the full diversity of policy instruments to stimulate and reinforce sustainable economic, environmental, and social outcomes
4. Engage all parts of society to take active, ethically-based responsibility for achieving sustainable outcomes

This case study will not address all elements critical to sustainable products and processes. It is mainly focused on environmental sustainability aspects related to chemical selection, taking into account health protection across the product life cycle. It does not address, but should be considered in context with, information on cost, performance and availability. It also does not include consideration of non-plastic alternatives or discussion of social and environmental justice impacts. It should also be informed by life cycle assessment (LCA) comparing alternatives and a full review of regulatory restrictions. Cleaning and other maintenance practices used over the product life cycle could also have chemical impacts for different product types, but they are beyond the scope of this case study. In addition, it is acknowledged that there are data gaps in this analysis. Data gaps are likely to exist in the application of this framework to other material comparisons.

The Key Concepts and Definitions section includes definitions of key terms such as “hazardous substances” or “extended producer responsibility” and key concepts such as “life-cycle thinking” or “class-based approach” used throughout this case study.

Box 1.2. Key Concepts and Definitions Used in this Case Study:

Alternatives assessment. Alternatives assessment is a decision framework used to compare and select alternative chemicals, materials, products or processes. The objective of an alternatives assessment according to the Interstate Chemicals Clearinghouse Alternatives Assessment Guide “is to replace chemicals of concern in products or processes with inherently safer alternatives, thereby protecting and enhancing human health and the environment.” Alternatives may be chemicals, materials or disruptive product designs. Several frameworks exist that help users consider hazards, life cycle impacts, trade-offs, and uncertainties when comparing alternatives (OECD, no date a). Resources such as the OECD Substitution Toolbox can be used to identify tools for substitution and alternatives assessment.

Circular economy. Per the Ellen MacArthur Foundation, “A circular economy seeks to rebuild capital, whether this is financial, manufactured, human, social or natural. This ensures enhanced flows of goods and services.” A circular economy designs out waste and pollution, keeps products and materials in use, and regenerates natural systems (MacArthur, n.d.).

Class-based approach (Blum Arlene et al., 2015; Gore et al., 2015). Often, chemicals with similar chemical structures have similar functionality and similar inherent hazards. The class-based approach refers to the concept of moving away from regulating one problematic chemical at a time and toward reducing the use of entire classes of chemicals of concern. Regulating one chemical at a time is impractical and can foster regrettable substitutions. Examples of chemical classes might include molecules that share a common toxic element, such as lead compounds; halogenated organic compounds, such as brominated organic flame retardants; or chemicals that share a common function, such as antimicrobials (GSPI, 2013). Examples of such approaches implemented by policy makers include the U.S. Environmental Protection Agency’s (EPA) cumulative assessment of risk from pesticides and the European Union directive limiting total perfluoroalkyl substances (PFAS) in drinking water (O. US EPA, 2015; Directive (EU) 2020/2184, 2020).

For some chemicals in this case study, a class-based approach was used to highlight groups of chemicals identified by the scientific community as having structural or functional similarities that may contribute to negative human health and environmental impacts (DiGangi et al., 2010; Blum Arlene et al., 2015; Gore et al., 2015; Medicine et al., 2019; Kwiatkowski et al., 2020; Engel et al., 2021). Not all chemicals in a class are necessarily problematic. A comprehensive hazard assessment can be used to identify when specific chemicals may have different hazards than those associated with the class overall.

Common Product Profile. A Common Product profile is a list of substances that are most commonly present in a product type as delivered to building sites in North America. The profiles are not specific to any manufacturer. Common Products are organised by chemical function. The profiles provide the most common substance identified among the products surveyed serving each function in a given product type, a hazard screening for each substance, and a general description of the product type. Common Products are based upon a wide range of publicly available information, including product declarations, patents, and chemical suppliers' brochures that detail the functional uses of various additives. For a more detailed description of the research methodology see https://pharosproject.net/common-products/methodology.

Extended Producer Responsibility. Extended Producer Responsibility (EPR) refers to a policy instrument where producers must take financial and/or physical responsibility for the treatment or disposal of post-consumer products. The theory behind EPR is to incentivise product design for the environment, public recycling and sustainable materials management (OECD, no date b).

Hazard assessment. Very few of the tens of thousands of chemicals in use today have been fully assessed for health hazards. To enable informed decision-making, the expansion of publicly available chemical hazard assessments (CHA) is critical. A full hazard assessment method uses authoritative and screening hazard lists, results from regulatory tests, information from the toxicological literature, and data from new approach methods (NAMs) such as those from analogous chemicals and modelled data where needed to characterise or estimate the hazards associated with a particular chemical. Hazards include human health hazards such as carcinogenicity, endocrine disruption, acute toxicity and irritation; environmental hazards such as aquatic toxicity, bioaccumulation and persistence; and physical hazards such as flammability and reactivity. Several methodologies exist, all of which are based at least in part on the Globally Harmonised System for Classification and Labelling (GHS) (UNECE, no date). Methods include the Cradle to Cradle Material Health Methodology (Cradle-to-Cradle Products Innovation Institute, no date), the GreenScreen for Safer Chemicals (Clean Production Action, no date) and the U.S. EPA's Design for the Environment Program Alternatives Assessment Criteria for Hazard Evaluation (O. US EPA, 2014). Most CHA methods also identify where data gaps exist for particular hazard endpoints.

Hazardous substances. For the purpose of this case study "hazardous substances" are defined as Substances of Very High Concern for REACH (SVHC), those on the ChemSec Substitute it Now List (SIN), Persistent Organic Pollutants identified by the Stockholm Convention (POP), ozone-depleting substances (ODS), and hydrofluorocarbons (HFCs) or other substances with high global warming potential (GWP) identified by the Montreal Protocol unless otherwise noted (UNEP, 1987; Regulation (EC) No 1907/2006, 2006; United Nations, 2016; UNEP, 2018b; ChemSec, no date b, no date c). For the purposes of this study chemicals are defined as having high global warming potential if they appear in Annex F of the Montreal Protocol, or are defined as an ODS elsewhere in the Montreal Protocol and have a 100-year global warming potential on par with the substances listed in Annex F. These lists were chosen due to their international applicability and should be considered as a simple proxy for hazardous substances identification. There are many other hazards that could be relevant to specific product use and exposure scenarios. For example, chemicals that are respiratory irritants or sensitisers may not be on the hazardous substance lists cited above. However, they may still be substances of concern to those who manufacture or use plastic products. To view additional hazard lists identified by OECD that may be used to screen out problematic chemicals and alternatives see Exhibit 5 from OECD's Guidance on Key Considerations for the Identification and Selection of Safer Chemical Alternatives (OECD, 2021). The long-term goal should be to have chemical hazard assessments for all chemicals in the product life cycle and to use that information to eliminate the use of hazardous substances, especially those chemicals likely to result in exposure to humans or the environment. Full CHAs are preferred to list-based hazard identification. In the absence of full CHAs for all chemicals identified in this case study, and in an effort to identify those chemicals of highest concern, the five lists above were chosen for this case study.

Hierarchy of controls (NIOSH, 2015). The Hierarchy of Controls ranks the most effective ways to protect workers by controlling exposures. Elimination, or physically removing the hazard, is the most effective way of controlling exposure. Use of personal protective equipment is the least effective method of controlling exposure and should be only used when more effective controls are not feasible.

Figure 1.1. The National Institute for Occupational Safety and Health (NIOSH) Hierarchy of Controls

Source: NIOSH, 2015. Figure © by NIOSH and available from https://www.cdc.gov/niosh/topics/hierarchy/default.html

Life cycle assessment. The International Standards Organisation (ISO) has defined LCA as: "A technique for assessing the environmental aspects and potential impacts associated with a product by:

- Compiling an inventory of relevant inputs and outputs of a product system,
- Evaluating the potential environmental impacts associated with those inputs and outputs, and
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study" (ISO, no date).

LCA technique examines impacts at each life cycle stage, typically including end-of-life. Standards such as ISO 14040 define the principles on how to conduct and report LCA studies (ISO, no date).

Life-cycle thinking. Life-cycle thinking considers potential impacts of a product or process at all stages of the product's life cycle. This approach helps identify key life cycle stages where impacts occur and avoids shifting impact burdens from one stage to another, from one country to another, from one impact category to another, or from one generation to another (Galatola, no date). Life-cycle thinking can be applied to considerations not typically included in life cycle assessment tools, such as exposure to toxic substances by humans or other receptors.

OECD Policy Principles for Sustainable Materials Management. Principles developed by the OECD as guidance for specific governmental policies to shift behaviour of government, businesses, organisations, and people towards meeting the needs of the society in a sustainable way. These principles include: 1) Preserve natural capital; 2) Design and manage materials, products, and processes for safety and sustainability from a life-cycle perspective; 3) Use the full diversity of policy instruments to stimulate and reinforce sustainable economic, environmental, and social outcomes; and 4) Engage all parts of society to take active, ethically-based responsibility for achieving sustainable outcomes (OECD, 2010).

Persistent Organic Pollutant (POP). Persistent Organic Pollutants (POPs) are defined by the Stockholm Convention as organic chemical substances that remain intact for many years and become widely distributed throughout the environment as a result of natural processes involving soil, water and air. They accumulate in the fatty tissue of living organisms, concentrating as they move up the food chain, and are toxic to both humans and wildlife (UNEP, 2018b, no date c).

Post-consumer material. U.S. Green Building Council defines post-consumer material as "waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose" (U.S. Green Building Council, 2009).

Pre-consumer material. U.S. Green Building Council defines pre-consumer material as "material diverted from the waste stream during the manufacturing process. Reutilisation of materials (i.e., rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it) is excluded" (U.S. Green Building Council, 2009).

Product content disclosure. Full disclosure of product contents, also known as product transparency, allows for more informed choices and helps prevent regrettable substitutions. Public disclosures of building products are available on the Health Product Declaration (HPD) Public Repository (HPDC, no date) or the International Living Future Institute's Declare database (ILFI, no date). Products with full materials disclosure move beyond those that disclose the minimum needed to produce a compliant safety data sheet, make claims the products are "free of" specific chemicals or materials, or "compliant with" certification standards or green building credits, toward the disclosure of all the substances that are in the product. HPD is the building industry's collaborative, user-designed open standard for disclosure of product contents and associated health hazards. Products with public HPDs that have all contents characterised, screened, and identified to 100 ppm can be considered "fully disclosed." Further, product content disclosures that have been third-party verified are typically of higher quality and are more complete than those that have not been verified.

Qualitative exposure assessment. A quantitative exposure assessment measures exposure to humans (via dermal, oral, or inhalation routes) or exposure to the environment (water, air or soil). In contrast, a qualitative exposure assessment screens chemicals for their potential for exposure based on, but not limited to, physical chemical properties of the chemical, how that chemical is used in a product, and how that product is used. Chemical release reporting can also be used as a proxy for volume. For the purposes of this case study, a simple example screening method was used to determine if release of the chemical could be considered negligible. This method was adapted from ECHA's recent publication "Describing uses of additives in plastic material for articles and estimating related exposure. Practical guide for industry" (ECHA, 2020). During product use, exposure to additives could be considered negligible if:

- Percentage in the product is below some threshold, i.e. <0.1%
- Substance has very high molecular weight, very low solubility in water, high octanol water partition coefficient, low vapour pressure and no reaction generating smaller molecules.
- Substance is reacted into a polymer chain and is known not to degrade into toxic environmental transformation products.
- Substances may not be considered to be of negligible exposure per criteria above if they are:
    - additives meant to move to the surface or to work as plasticisers.
    - additives in products that are subject to leaching promotion, abrasion or volatilisation due to use at high temperatures.

      Note: Qualitative exposure assessments can be sufficient to discriminate between alternatives and to minimise risk to human health and the environment. However, when more information is needed, a quantitative exposure assessment on a specific insulation product is recommended.

Regrettable substitution. When a single chemical is phased out due to known hazards, the replacement may be a chemical with similar or different and potentially worse hazards. For example, as Bisphenol A (BPA) was phased out of bottles, cans and receipts due to endocrine disrupting concerns, it was replaced by Bisphenol S (BPS) and Bisphenol F (BPF). Unfortunately, BPS and BPF are closely related structurally to BPA and have similar endocrine disruption concerns (Tragger, 2019). Another example of a regrettable substitution is the substitution of toxic chlorinated solvents in brake cleaners with n-hexane, a neurotoxicant.

Substances of Very High Concern (SVHC). SVHCs are defined in Article 57 of Regulation (EC) No 1907/2006. These include substances that are 1) carcinogenic, mutagenic, or toxic to reproduction (CMR) in category 1A or 1B in accordance with section 3.6 of Annex I to Regulation (EC) No 1272/20082, 2) substances that are persistent, bioaccumulative, and toxic (PBT) or very persistent and very bioaccumulative (vPvB) according to the criteria in REACH Annex XIII and/or 3) substances that are identified, on a case-by-case basis, that cause an equivalent level of concern as CMR or PBT/vPvB substances (Regulation (EC) No 1907/2006, 2006).

Substitute it Now List (SIN List). The SIN List identifies hazardous chemicals used in a range of products and processes around the world. It is developed by the non-profit organisation ChemSec in collaboration with scientists and technical experts, as well as environmental, health, and consumer organisations, and, according to ChemSec, represents a "preview" of chemicals that may be designated as Substances of Very High Concern, based on the REACH criteria (ChemSec, no date b).

Sustainable Materials Management. The OECD defines Sustainable Materials Management as "an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life cycle of materials, taking into account economic efficiency and social equity" (OECD, 2010). Sustainable materials management grew out of OECD work on waste management. It takes a holistic approach that is intended to align and integrate policies that reduce negative impacts from chemicals and materials in environmental, industrial and societal systems.

1.2. Flooring Landscape

Plastic production has increased exponentially over the last 70 years, reaching 430 million tons in 2019 (OECD Plastics Outlook database). Behind packaging, the construction industry is the second largest user of plastics, comprising 17% of global plastic production (OECD Plastics Outlook database).

Flooring covers a large portion of the interior surface area of a building. In 2019, in the United States alone, floor covering sales surpassed 23.5 billion square feet and $27 billion USD (almost 23 billion euros) (Floor Covering Weekly, 2020). Flooring materials provide aesthetic value and comfort in buildings. They can also provide acoustic value, insulation and water resistance. A wide range of materials can be used as floor coverings, and each has human health and environmental impacts at various stages of the product life cycle. Common materials used for floor coverings include wood, linoleum, ceramics, rubber and plastic. Resilient plastic products account for over 22% of all floor coverings sold in the United States (Floor Covering Weekly, 2020). Polyvinyl chloride (PVC), also known as vinyl flooring, constitutes the majority of this market (Grand View Research, 2019a). Other plastics that can be used in floor coverings include ethylene vinyl acetate, polyolefins, polyesters, thermoplastic polyurethane and acrylics (Healthy Building Network, 2019b).

Frequency of replacement depends on the type of flooring and the application. Reported life expectancies for flooring products range from 5-100 years, with plastic flooring life expectancy typically in the range of 5-25 years (Forbo, 2019; Armstrong Flooring, Inc, 2020; Aspecta N.A., 2020; Crossville, Inc., 2020; Mafi, 2020; Metroflor Corporation, 2020; Novalis, 2020). Changing aesthetic desires or other factors can lead to flooring replacement before the end of the product's useful life.

1.3. Product Types Selected for Case Study

Traditionally, PVC has dominated the plastic flooring market, but while the global market for PVC flooring continues to expand, new plastic alternatives to traditional PVC flooring are emerging (Grand View Research, 2019b). For this reason, this case study considers three options:

1. Vinyl sheet and vinyl tile. Vinyl flooring represents the dominant product type in the marketplace. For the purposes of this case study PVC-based resilient flooring was selected that is homogenous or composed only of PVC-based layers (excluding the finish), installed with an adhesive.
2. Wood plastic composite (WPC). WPC is a multilayer resilient flooring which contains a PVC wear layer and a rigid expanded or foamed core that is commonly composed of PVC ('MFA Formalizes Nomenclature for Rigid Core Vinyl Products', 2017; Moore, 2018). WPC flooring also commonly includes an acoustic underlayment, which could be cork or polymeric. Contrary to what the name implies, WPC floors may not contain any wood or cellulose-based fillers (Healthy Building Network, 2019a). They are generally manufactured as interlocking tiles with a tongue and groove or click installation system. This product type was selected to represent a different installation approach that may have chemical exposure implications because it does not require the use of adhesives.
3. Polyethylene terephthalate (PET). Numerous different polymers or combinations of polymers can be used in non-PVC, non-elastomeric resilient flooring, each with its own unique impacts. No specific polymer is more common than the others within the universe of commercially available products. For this case study, polyester-based flooring products is considered for the following reasons: in a market that has seen products come and go, a polyester floor has been available for a number of years, there is potential for bio-based content in the polymer, an additional product based on recycled polyester is under development, and polyester illustrates trade-offs and opportunities for green chemistry. Details regarding the chemicals used in the life cycle of the specific polyester used in flooring are limited. The product under development is known to use recycled polyethylene terephthalate (PET), so this is used as a specific polyester as an example (Shaw Contract Introduces PET Resilient Sustainable Flooring, 2018). Non-PVC, non-elastomeric resilient flooring is commonly installed with an adhesive.

Plastic flooring products typically contain about 11-35% by weight of the polymer itself, the remainder being fillers and additives (Healthy Building Network, 2015, 2016, 2019a, 2019b). Vinyl sheet and tile flooring is composed of PVC and fillers like calcium carbonate. Because vinyl flooring needs to be flexible, durable and aesthetically pleasing, it requires the addition of plasticisers, stabilisers, and other additives like pigments. Many vinyl flooring products also have a polyurethane acrylic finish for durability and abrasion resistance (Novalis, 2018; NOX Corporation, 2020; TEKNOFLOR®, 2020). Some finishes may additionally contain stain repellent additives like per- and polyfluoroalkyl substances (PFAS) (Congoleum Flooring, no date).

WPC flooring contains a layer of PVC flooring on top of a rigid polymeric core. Both layers are similar in composition to vinyl sheet or tile, but the core is typically not plasticised and requires a blowing agent. A blowing agent is a substance that creates a cellular structure in the resin using a foaming process. These layers and the acoustic underlayment are adhered to one another with adhesives.

PET resilient flooring products are also composed mostly of polymeric binders, fillers, pigments, and other additives and have a similar top coat finish as vinyl flooring and WPC, typically urethane acrylic polymers. The primary difference, besides the polymer itself, is that PET flooring does not use a plasticiser.

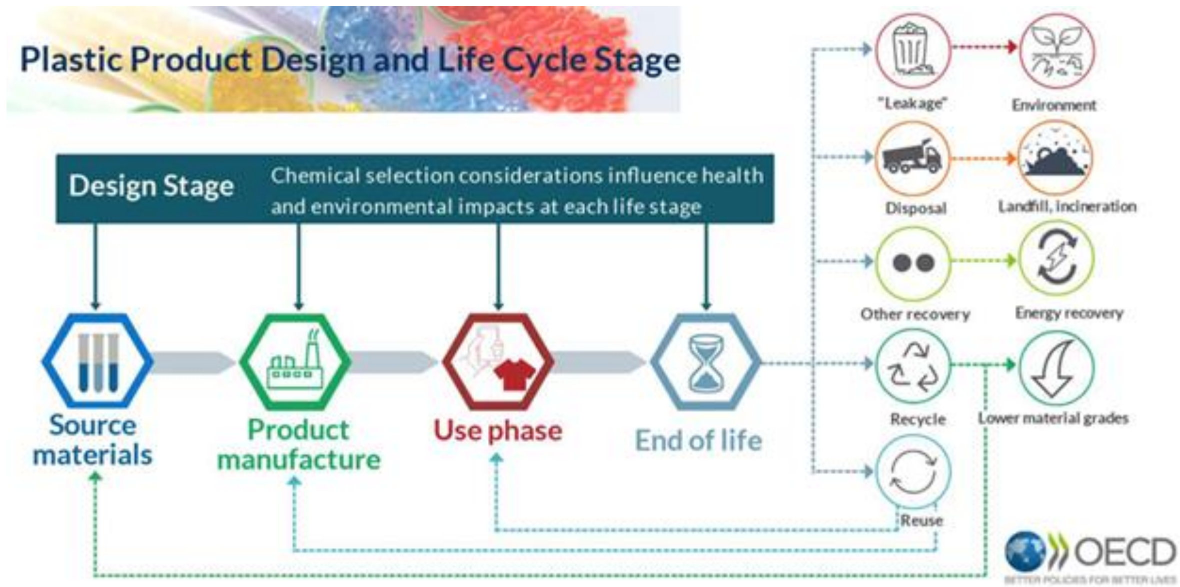
Product content and process chemistry information provided throughout this case study is based on Common Product research unless otherwise noted. See the key concepts section for a definition of Common Products and a description of the research process. Details on the typical chemical content, the functional roles of that content, and percentage in the product is provided in Annex A for each flooring type.

Chapter 2. **Chemical Considerations Throughout the Life Cycle**

Building products of any type have potential human health and environmental impacts from chemical exposure at every stage of the product life cycle, including production, installation, use and end-of-life disposal or recycling. Life-cycle thinking, defined in the key concepts section above, considers potential impacts of a product or process at all stages of the product's life cycle. This approach helps identify key life cycle stages where impacts occur and avoid shifting impact burdens, for example, from exposure to users during product use to exposure to workers during manufacture. The different feedstocks, monomers, catalysts and functional additives used in different plastic products may result in exposures to a variety of substances. The type of polymer and additives also impacts the recyclability of flooring materials and associated chemical releases at end-of-life. Figure 2.1 illustrates how life-cycle thinking is used to consider impacts from a chemical perspective throughout the stages of a plastic product life cycle and how design choices can change these impacts.

The goal of life cycle thinking is to reduce impacts across the full life cycle and to advance sustainable materials management. One can intervene at any point in the life cycle. Sustainable materials management is inherently circular. For simplicity, the considerations in this case study are presented starting with the design stage because that is where the full system is likely to be considered. Interventions at any life cycle stage may result in changes in impacts at other life cycle stages. While this is inherently circular, it is difficult to communicate if not laid out step by step in a linear fashion.

Figure 2.1. Plastic Product Design and Life Cycle Stage



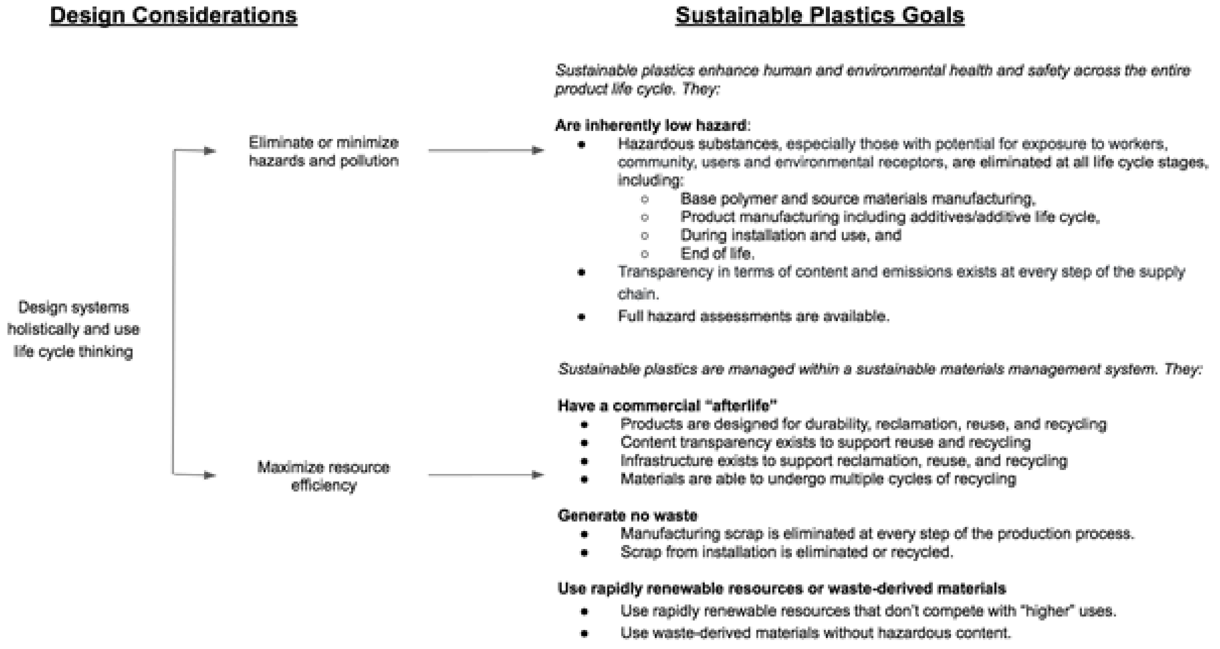
Risk is a function of both hazard and exposure. Exposures to chemicals can occur at any of the life cycle stages. Exposure assessments may be quantitative or qualitative. Exposure is dependent on many factors including, for example, the physical chemical properties of the chemical of interest, its volume of use, the product properties, manufacturing conditions, use of personal protective equipment, how and where the product is installed and used, and how the product is managed at the end of its useful life. For the purposes of this case study, a simple qualitative exposure screening approach is applied based on inherent chemical properties and product design. See Key Concepts and Definitions for a definition of a qualitative exposure assessment and a description of the screening process. In addition, occupational exposure to chemicals used to make the base polymers and products is assumed.

In cases where qualitative exposure assessment does not help discriminate between materials, a quantitative exposure assessment can be performed. However, these assessments can be costly and highly context-specific. Qualitative exposure assessment can provide strong indicators of a chemical's exposure potential and help identify opportunities for mitigation of risk from exposure to hazardous substances. The Hierarchy of Controls (see definition in Key Concepts and Definitions section) presents a spectrum of options to reduce primarily worker exposure to chemicals of concern. Based on the Hierarchy of Controls, it is more effective to eliminate chemicals of concern or substitute them with safer alternatives than it is to reduce exposure by using process controls or personal protective equipment. Understanding the inherent exposure and hazard potentials of chemicals in products can help design teams prioritise reducing the use of the most hazardous substances and the use of hazardous substances with highest potentials for exposure.

In the OECD report "Considerations and Criteria for Sustainable Plastics from a Chemical Perspective," sustainable plastics are defined as "...plastic materials used in products that provide societal benefits while enhancing human and environmental health and safety across the entire product life cycle. To be considered sustainable, plastics must be managed within a sustainable materials management system (a circular economy) (MacArthur, n.d.) to avoid the creation of waste, toxics and pollution" (OECD, 2018a). Further OECD defines sustainable materials management as "An approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life cycle of materials, taking into account economic efficiency and social equity."

In Figure 2.2 below, the OECD definition of sustainable plastics and sustainable materials management are combined with the American Chemical Society Green Chemistry Institute's Design Principles for Sustainable and Green Chemistry and Engineering to generate a set of actionable Sustainable Plastics Goals. The goals are further broken into measurable subgoals that can be used to work toward sustainable plastic products (American Chemical Society (ACS) Green Chemistry Institute (GCI), 2015).

Figure 2.2. Design considerations used to work towards sustainable plastics goals



The sustainable plastics goals cited above are lofty, however, having these goals in mind allows scientists, product design teams, and policy makers to ask questions that will help to create both supply and demand for more sustainable plastics. These goals serve as the framework for analysis for comparing the three plastic flooring products in this case study. The sections below present key considerations for sustainable plastic flooring products from a chemicals perspective at different life cycle stages following the goals from the figure above. On the path toward sustainable plastic products, this is an approach that can be applied to identify trade-offs and data gaps and to measure progress in any plastic building product.

2.1. Design

Flooring materials must meet a myriad of performance and aesthetic requirements from the user perspective. These include a look and feel to match the application (residential, commercial, etc.), durability, acoustics, water resistance and ease of installation and maintenance. Designers can also consider sustainability goals, for example, to eliminate or minimise the use or generation of hazardous substances and pollution throughout the product's life, incorporate recycled content and design for reuse and recyclability. It is these latter design features that will be explored in this case study.

2.1.1. Key Considerations - Design

In general, products are designed to meet product use requirements, minimum performance standards and scenarios (commercial, residential, healthcare, etc.). Design considerations may include: What conditions will it need to withstand (traffic, cleaning protocols, etc.)? How long is the product intended to last? What is the intended end-of-life plan and what are the available options for value recovery? Below are some key considerations related to this initial design phase based on the three high-level design considerations for sustainable plastic products.

- Design systems holistically and use life-cycle thinking
    - Were project team members trained on safe and circular design principles and life-cycle thinking?
    - Is there a process in place to consider, test, develop and encourage innovative designs to achieve sustainability goals?
    - Is the product designed for a commercial afterlife?
    - Is the designed end-of-life reasonable given the available regional infrastructure for recycling, material take back programs, etc.?
    - Can the product undergo multiple cycles of recycling, and is the recyclate a viable alternative to virgin materials?
    - Does the product design minimise material diversity/complexity (heterogeneous vs homogeneous)?
- Maximise resource efficiency
    - Were alternative product designs compared based on resource use? For example, designs that minimise energy consumption, material use and waste production?
    - Are measures in place to track energy consumption, material use and waste production throughout the supply chain? Are there goals to reduce energy consumption, material use and waste production?
- Eliminate and minimise hazards and pollution
    - Were different designs considered and compared based on ability to minimise the use or generation of hazardous substances at each life cycle stage? See each life cycle stage section for more details.

2.1.2. Example Trade-offs - design

It may not be possible to meet all sustainability goals simultaneously, and trade-offs may be necessary. For example, a flooring product that is designed to use adhesive to install typically requires less material use within the floor itself than one that uses a click tile system to install. However, adhesives may add hazardous substances to the product installation stage. During the design stage, manufacturers can prioritise impacts and trade-offs early in product development. Teams can prioritise which sustainability elements are most important to incorporate into their design and how to deal with gaps in understanding. These sustainability elements may be tied to specific brands and corporate sustainability policies.

2.2. Production of the Base Polymer

Base Polymer Source Materials

The inputs used in the production of a base polymer for plastic flooring include the monomer(s) and catalysts. This case study also considers the primary chemicals, often derived from petroleum or natural gas, and intermediates used to produce the monomer. Impacts from a chemicals perspective include the consideration of the hazards of these inputs as well as releases of hazardous chemicals from the manufacturing facilities. The primary chemical inputs and chemical emissions for the manufacture of PVC and PET are described below and included in Tables 2.1. and 2.2. Whether comparing products for exposures to hazardous chemicals using life-cycle thinking or using full life cycle assessment, it is essential to draw clear system boundaries to allow for consistent and equivalent comparisons.

Table 2.1. Chemicals that may be used in production of PVC base polymer source materials

	Chemical Name	SVHC‡	SIN List	POP	ODS	High GWP
Primary Chemicals	Chlorine					
	Ethylene					
	Hydrogen					
	Calcium carbide					
Intermediates	Hydrochloric Acid					
	Ethylene Dichloride	○	○			
	Acetylene					
Monomers	Vinyl Chloride		●			
Catalysts/ Process Chemicals for Different Stages	Mercury[a]		○			
	Asbestos[a]		○			
	PFAS Diaphragm or Membrane[a]	○*	○*	○*		
Recycled Content	Certain Orthophthalates[b]	○*	○*			
	Lead-based stabilisers[c]	○*	○*			
	Cadmium-based stabilisers[c]	○*	○*			
	PCBs			○*		
	Nonylphenol phosphite (3:1)	○	○			
Hazardous Substance Outputs/Emission (based on US Toxic Release Inventory and Canada's National Pollutant Release Inventory)[d]	Ethylene Dichloride	○	○			
	Vinyl Chloride		●			
	Other Organochlorine Chemicals					
	Dioxins			●		
	Carbon Tetrachloride		●		●	●
	Chloroform		●			
	HCBD		○	○		
	PCBs			○		
Exposure Scenarios to Consider	• Occupational exposure. During the manufacturing stage, occupational exposure potential is assumed for all primary chemicals, intermediates, monomers, and process chemicals. • Human and environmental exposure to hazardous substances in water and air emissions.					

Notes:
● The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.
○The chemical is identified on the hazard list indicated. Chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.
‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.

* This SVHC, SIN List or POP association is identified based on a chemical class-based approach. Not every chemical in these groups will appear on the indicated hazard list, but the list does contain multiple CASRNs within the chemical class. Cobalt compounds are identified on the SIN List.
a These technologies are alternatives to each other, but no alternatives to these technologies were identified.
b Several chemicals within the orthophthalate class are known to be hazardous. 13 unique CASRNs are SVHCs and 22 unique CASRNs appear on the SIN list. Certain orthophthalates have been phased out of use in flooring in certain markets and regions such as North America and Europe, but are included here because they may still be used in some regions and may be in recycled vinyl flooring or other recycled PVC.
c Historically lead- and cadmium-based stabilisers were common in PVC. Industry data suggest that they have mostly been phased out in North America (Vinyl Sustainability Council, no date). These may still be present in post-consumer PVC waste streams, and may also be present in virgin materials manufactured in other regions.
d See (Healthy Building Network, 2018; Government of Canada, no date; US EPA, no date)
Source: Sources for Tables 2.1. and 2.2. (US EPA, 1991; Biodegradable Products Institute, 2010; Franklin Associates, 2011; Lithner, Larsson and Dave, 2011; Welle and Franz, 2011; Deconnick and De Wilde, 2013; Rossi and Blake, 2014; Eagle, 2015; Healthy Building Network, 2015; Selke et al., 2015; Healthy Building Network, 2016; Vallette, 2018; Healthy Building Network, 2019b, 2019a; Vallette, 2019; Healthy Building Network, no date c; Teijin, no date)

Table 2.2. Chemicals that may be used in production of PET base polymer source materials

	Chemical Names	SVHC ‡	SIN List	POP	ODS	High GWP
Primary Chemicals	P-Xylene					
	Methanol					
	Ethylene					
Intermediates	Acetic Acid					
	Ethylene Oxide		●			
	Ethylene Glycol					
	Terephthalic Acid					
	Dimethyl Terephthalate					
Monomers	Bis(2-hydroxyethyl) terephthalate					
Catalysts/ Process Chemicals for Different Stages	Zinc Oxide					
	Antimony Trioxide		○			
	Titanium-based catalyst					
	Germanium-based catalyst					
	Data Gap					
Recycled Content	UV stabilisers					
	Oxo-degradation and Biodegradation additives: ex. Cobalt-based salt		○*			
	Antimony trioxide		○			
Hazardous Substance Outputs/Emission	Data Gap					
Exposure Scenarios to Consider	• Occupational exposure. During the manufacturing stage, occupational exposure potential is assumed for all primary chemicals, intermediates, monomers, and process chemicals. • Human and environmental exposure to hazardous substances in water and air emissions.					

Notes:

● The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.

○The chemical is identified on the hazard list indicated. Chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.

‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.

* This SVHC, SIN List or POP association is identified based on a chemical class-based approach. Not every chemical in these groups will appear on the indicated hazard list, but the list does contain multiple CASRNs within the chemical class. Cobalt compounds are identified on the SIN List.

Source: Sources for Tables 2.1. and 2.2 (US EPA, 1991; Biodegradable Products Institute, 2010; Franklin Associates, 2011; Lithner, Larsson and Dave, 2011; Welle and Franz, 2011; Deconnick and De Wilde, 2013; Rossi and Blake, 2014; Eagle, 2015; Healthy Building Network, 2015; Selke et al., 2015; Healthy Building Network, 2016; Vallette, 2018; Healthy Building Network, 2019b, 2019a; Vallette, 2019; Healthy Building Network, no date c; Teijin, no date)

PVC Production - reagents and process chemicals

The plastic component of vinyl flooring products (including vinyl tile, vinyl sheet and WPC) is polyvinyl chloride (PVC). The production of PVC starts with the production of chlorine gas. Production of chlorine gas relies on one of four different technologies. Older technologies utilise mercury cells or asbestos diaphragms. Newer technologies either use per- and polyfluoroalkyl substance (PFAS) diaphragms or PFAS-coated membranes. While most chlorine production utilises the latter two technologies, all four methods of production are still widespread (Vallette, 2018, 2019).[1] Each production technology has trade-offs from a chemical hazard perspective. Mercury and asbestos are on the SIN list. The dominant PFAS membrane cell technology utilises a perfluorosulfonic acid membrane (e.g. Nafion®) in the manufacturing process. The membrane is manufactured with perfluorocarboxylic acid and perfluorosulfonic acid (PFOS), and can degrade to perfluorinated octanoic acid (PFOA) at high temperatures or when incinerated (Feng et al., 2015). While Nafion is not a POP or on the SIN list, both PFOS and PFOA are POPs.

While one might not immediately think of hazardous exposures in association with a membrane, a recent study reports blood serum levels of "Nafion by-product 2" in residents living downriver from a Nafion manufacturing plant in Wilmington, North Carolina. 100% of children tested and 99% of adults tested had detectable levels of Nafion by-product 2 as well as a number of other PFAS chemicals (Kotlarz et al., 2020). The Nafion plant discharged these chemicals into the Cape Fear River, the main drinking water source for Wilmington residents, from 1980-2017. Nafion, PFOA and PFOS all belong to a class of chemicals called per- and poly-fluoroalkyl substances or PFAS. While only a handful of these chemicals have been studied for toxicity to humans, and even fewer regulated, these chemicals all have similar properties that make them very persistent in the environment. The emissions associated with chlorine production illustrate variables that may be relevant when comparing materials. Even the same reagent may have different production pathways and subsequently different emissions.

PVC Production - Monomer

Vinyl chloride monomer (VCM) used in PVC synthesis is produced via either an acetylene or ethylene route. The former route employs calcium carbide from coal, acetylene and mercury-based catalysts, and the latter uses ethylene from natural gas or crude oil and generates ethylene dichloride (EDC) as an intermediate in the production of VCM. Vinyl chloride itself is listed as carcinogenic on the SVHC list, and both routes utilise hazardous substances, with mercury as a reproductive toxicant on the SIN List and EDC as a carcinogen listed as a SVHC (ChemSec, no date a; ECHA, no date a).

PVC Production - Emissions

Based on a review of the supply chain from chlorine to VCM to PVC as well as US Toxic Release Inventory and Canada's National Pollutant Release Inventory data, a range of hazardous chlorinated chemicals may be emitted through the manufacturing process. Regulated emissions in the US are reported by occurrence. Additional non-regulated emissions are possible. Different plants report different levels of hazardous emissions for a given production output (Vallette, 2018). Emission data for production in other countries was not available. The extent to which hazardous emission can be and will be controlled should be considered in the design process, because these emissions can directly impact communities adjacent to manufacturing sites – often called fenceline communities – as well as the broader environment.

PET Production - reagents and process chemicals

No SVHCs or POPs were identified in the process chemicals for PET. The intermediate ethylene oxide and common catalyst antimony trioxide are on the SIN list. Alternative catalysts include titanium and germanium-based materials (Welle and Franz, 2011; Teijin, no date). There is limited transparency around the specific polyesters used for flooring and the chemicals used to produce them, but within polyester polymers there is a range of possible chemistries. For example, a patent identifies dibutyltin bis-lauryl mercaptide as a catalyst for polyester polymers used in flooring, and alternative process chemicals such as 1,3-propanediol may avoid ethylene oxide for particular manufacturing routes (Tian et al., 2008; Davies and Tian, 2013; National Center for Biotechnology Information, no date). 1,3-Propanediol may also be manufactured from renewable, bio-based content (Tian et al., 2008). Less information was identified with respect to PET manufacturing when compared to PVC manufacturing, in particular with respect to additional process chemicals that may be used at earlier manufacturing stages. To compare the two base polymers farther back in the supply chain, additional data in this particular area is needed for PET. This should not be considered as evidence of lack of hazardous substances, but rather as a data gap.

PET Production - Monomers

Bis(2-hydroxyethyl) terephthalate is the monomer used to manufacture PET. It is not an SVHC, POP, or SIN List chemical. Looking further into potential hazards, this chemical has not been identified on authoritative hazard lists, but a full hazard assessment was completed in 2013 and identified significant data gaps (ToxServices, 2013).

PET Production - Emissions

Supply chain and emission data equivalent to that used for the PVC analysis are not available for PET and represent a data gap in this case study analysis. Development of a similar supply chain and emissions understanding is necessary for a more complete understanding of the life cycle impacts of the two materials. This is a key piece of data because these emissions can directly impact fenceline communities and the broader environment.

Recycled Polymers

Some or all of the base polymer used in a product may be sourced as recycled content. Use of recycled feedstock can eliminate impacts from the production of virgin base polymer. However, with recycled polymers comes the potential for unintentional content in terms of additives from the original product or contaminants introduced during the product’s life. Current technologies that remove legacy chemicals are being evaluated to support recycled polymers for use.

PVC - Unintentional content from recycled feedstocks

Some vinyl flooring incorporates recycled PVC content (Krock and Tarnell, 2015). While there may be life-cycle benefits, legacy hazardous substances can be present in recycled PVC, unintentionally adding certain hazardous orthophthalates and hazardous stabilisers to the new product. Non-flooring sources of recycled PVC, such as old PVC-coated wires or electrical components can introduce additional hazardous content such as polychlorinated biphenyls (PCBs) (Vallette, 2015a). The introduction of hazardous legacy chemicals into flooring products can be reduced or avoided when manufacturers verify that a closed-loop recycling process is used or the feedstock is tested regularly for common contaminants of concern. Current technologies that remove legacy chemicals are being evaluated to support recycled polymers for use.

PET - Unintentional content from recycled feedstocks

Post-consumer PET bottles could be used in PET flooring, which seems to be the case for a recently announced but not yet commercially available flooring product (Ehrlich, 2018). One of the primary concerns with PET historically has been the use of antimony trioxide as a catalyst during production (Filella, 2020). It is not known to what extent antimony trioxide may be present in PET flooring products from virgin PET, or to what extent it may leach from the product resulting in exposure to users, but products incorporating recycled content from plastic water bottles may introduce some residual catalyst. Another potential concern with recycled PET is the use of oxo-degradation-promoting and biodegradation-promoting additives in some plastic packaging (Eagle, 2015; Selke et al., 2015), which could impact future performance of a flooring product. These additives can also have associated hazards, as with cobalt-based salts provided as an example in Table 2.2.. In addition, concerns exist over the contribution of oxo-degradable plastics to microplastic formation (European Commission et al., 2017). Preferred recycled feedstock should be well characterised and controlled to avoid potential hazardous content.

2.2.1. Key Considerations - base polymer source materials

When choosing the base polymer for a flooring product, product designers and manufacturers should consider how the alternatives compare in terms of volume of hazardous substances used and/or emitted from manufacturing, potential for exposure from manufacturing, the availability of alternative synthesis routes or manufacturing processes that avoid or reduce hazardous substances, and the data gaps that exist. As outlined above, multiple routes of synthesis or chemical inputs exist for PVC and PET, so understanding the impacts of the plastic material used depends on understanding the supply chain for their chemical inputs.

- Design systems holistically and use life-cycle thinking
    - Were project team members trained on alternatives assessments?
    - Is there a process in place to consider, test, develop and encourage innovative base polymer types?
    - Were alternative base polymers considered and compared using impact assessment tools, such as life cycle assessment?
    - Was the chosen base material analysed using impact assessment tools to identify hotspots and find opportunities for improvement?
    - Were different base polymer manufacturing facilities considered and compared by measures implemented to reduce environmental impacts?
- Maximise resource efficiency
    - Were alternative base polymers considered and compared by resource use? For example, are any based on renewable resources or waste-derived materials?
    - Were alternative base polymers considered and compared by ability to be recycled in the region used?
    - For the chosen base polymer, were availability of alternative synthesis routes considered and compared by resource use?
    - For the chosen base polymer, are there procedures in place to track, report, and set goals to reduce resource use?

- Eliminate and minimise hazards and pollution
  - Were alternative base polymers considered and compared by use and release of hazardous substances and resource use?
  - For the chosen base polymer, were availability of alternative synthesis routes considered and compared by use and release of hazardous substances and resource use?
  - Were different base polymer manufacturing facilities considered and compared by measures implemented to measure, disclose and reduce the use and release of chemicals of concern?
  - If hazardous substances cannot be avoided, are they used in a closed system to reduce or avoid exposures?
  - If recycled content is used as a base polymer source, is the source material known? Has it been tested for legacy hazardous substances? And/or is content transparency documentation available and complete for the material? How much control does the manufacturer have over recycled feedstock? Can they reliably obtain feedstock free of toxic residuals?
  - If no base polymers of inherently low hazard source materials (primary chemicals, intermediates, monomers and catalysts) were identified, was a desire for green chemistry solutions expressed to the supply chain?

2.2.2. Example Trade-offs - base polymer materials

When considering the options for base polymer materials against the sustainability goals, there will be trade-offs. For example, using recycled plastic contributes to a sustainable materials management system by keeping materials out of landfills and avoids chemical emissions associated with the production of virgin materials. On the other hand, using recycled plastic requires the infrastructure to collect and process the material. Safe use of recycled content requires an understanding of its origin and potentially hazardous contaminants, through testing or content transparency, and supply chain management.

Data gaps can also present a challenge in comparing materials. Some hazardous substances are used in both PVC and PET production. Data on PVC-related emissions are available on U.S. Toxic Release Inventory and Canada’s National Pollutant Release Inventory but may not be inclusive of all potentially hazardous emissions. Comparable supply chain and chemical emissions data from PET production is necessary to make a complete comparison of the two base polymer materials. Manufacturers should not assume there are no sustainability implications when no data is available, but should strive to fill data gaps when possible. There can also be significant variation in emissions between manufacturing facilities for the same base polymer material. An understanding of the different processes and different emission controls utilised throughout the supply chain can help a product manufacturer choose, within a given base polymer, which suppliers are minimising the use and release of hazardous substances.

Variations on the base polymers considered may offer additional, more sustainable options. For example, other polyesters may reveal alternatives that avoid the use of SIN List ethylene oxide as an intermediate and may also have options for inputs from rapidly renewable resources. Comparing the sustainability criteria of potential alternatives requires additional data collection and analysis of the supply chain.

When choosing the base polymer for a flooring product, one should consider how the alternatives compare in terms of volume of hazardous substances, the availability of alternative synthesis routes or manufacturing processes that avoid or reduce hazardous substances and related emissions, and identify the data gaps that exist, as well as trade-offs with other life cycle stages.

2.3. Product Manufacture Including Use of Additives

Following the production of the base polymer, these materials are combined with a range of additives to manufacture the flooring itself. A factory-applied finish or topcoat is common for all plastic flooring products. These topcoats are typically UV-cured urethane acrylic finishes and may contain chemicals of concern to workers during product manufacturing, such as asthmogenic isocyanates. Because the topcoat is expected to be similar across all products considered, they are not discussed in detail in this case study, but the chemical hazards of topcoats and potential exposures across all life cycle stages should be considered as part of sustainable product design. Tables 2.3. and 2.4. summarise the primary differences in additives used between the product types and likely exposure scenarios during product manufacturing. Further, additives such as pigments are common in flooring products and may introduce additional hazards. Pigment options are expected to be similar in different types of flooring so were not considered in this analysis, but should be reviewed for hazards as part of sustainable plastic product design.

Table 2.3. Chemicals and materials that may be used during product manufacture of Vinyl Sheet/Tile (PVC) and Wood Plastic Composite (WPC) flooring†

	Chemical Name	SVHC‡	SIN List	POP
Plasticisers	Orthophthalates[a]	○*	○*	
	Terephthalates			
	Dibenzoates			
Stabilisers (UV or Heat Stabilisers)	Lead-based[b]	○*	○*	
	Cadmium-based[b]	○*	○*	
	Calcium-zinc			
	Barium-zinc			
Blowing Agents[c] (WPC only)	Azodicarbonamide	●	●	
	Sodium bicarbonate			
Plasticiser in Adhesive (WPC only)	Hydrotreated Heavy Paraffinic Petroleum Distillates (Mineral Oil)		○	
Exposure Scenarios to Consider	• Occupational exposure. During the manufacturing stage, occupational exposure potential is assumed for all plasticisers, stabilisers, blowing agents and hazardous substances in recycled content. • Human and environmental via environmental release during manufacture			

Note:
† This table and subsequent tables in this report include the chemical inputs and possible exposure scenarios. Columns flagging ODSs and high GWP substances are omitted from this table and subsequent tables because no ODSs or high GWP substances were identified.
● The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.
○The chemical is identified on the hazard list indicated. The chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.
‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.
* This SVHC, SIN List or POP association is identified based on a chemical class-based approach. Not every chemical in these groups will appear on the indicated hazard list, but the list does contain multiple CASRNs within the chemical class.
a Several chemicals within the orthophthalate class, typically the low molecular weight orthophthalates, are known to be hazardous. 13 unique CASRNs are SVHCs and 22 unique CASRNs appear on the SIN list. Orthophthalates have been phased out of use in certain markets and regions such as North America and Europe, but are included here because they may still be used in some regions.
b Historically lead- and cadmium- based stabilisers were common in PVC. Industry data suggest that they have mostly been phased out in North America (Vinyl Sustainability Council, no date). These may still be present in post-consumer PVC waste streams, and may also be present in virgin materials manufactured in other regions.
c Used only in WPC flooring.
Source:
Sources for Tables 2.3. and 2.4. (Healthy Building Network and Perkins+Will, 2015; Vallette, 2015a; Healthy Building Network, no date a, no date c)

Table 2.4. Chemicals and materials that may be used during product manufacture of PET flooring

	Chemical Name	SVHC‡	SIN List	POP
Plasticisers	N/A			
Stabilisers (UV or Heat Stabilisers)	Pentaerythritol tetrakis (3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate)[a]			
Blowing Agents	N/A			
Exposure Scenarios to Consider	● Occupational exposure. During the manufacturing stage, occupational exposure potential is assumed for all plasticisers, stabilisers, blowing agents and hazardous substances in recycled content. ● Human and environmental via environmental release during manufacture			

Note:
● The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.
◯The chemical is identified on the hazard list indicated. The chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.
‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.
a Many different stabilisers may be used. This is an example of one chemical that is used in PVC-free resilient flooring generally and can be used with polyesters.

Source: Sources for Tables 2.3. and 2.4. (Healthy Building Network and Perkins+Will, 2015; Vallette, 2015a; Healthy Building Network, no date a, no date c)

2.3.1. PVC intentional additives

The primary additives in vinyl flooring include plasticisers and stabilisers. Some low molecular weight orthophthalate plasticisers and lead- and cadmium-based stabilisers are SVHCs. In many regions certain orthophthalates and lead-based stabilisers have been phased out in favour of chemicals believed to be of lower hazard, but may still be used in some products across the industry (Tarkett, no date). In the EU, high molecular weight orthophthalates (those with 7 or more carbons in their backbone) or terephthalates are replacing low molecular weight orthophthalates identified as SVHCs in PVC, including in flooring products (Vinyl Plus, 2020). When selecting plasticisers for PVC flooring, all should be fully disclosed and fully assessed for hazard, and the inherently safest alternatives should be used. Examples of alternatives assessments that identify safer alternatives to orthophthalates of concern are available (Maag et al., 2010; Lowell Center for Sustainable Production, 2011; ANSES, 2016). Likewise, industry data suggest that lead- and cadmium-based stabilisers have essentially been phased out in North America; safer alternatives such as calcium- and zinc-based stabilisers are available and should be used (Vinyl Sustainability Council, no date).

2.3.2. WPC intentional additives

Plasticisers and stabilisers are also used in multi-layer resilient wood plastic composite (WPC) flooring. WPC also can use more than three times the quantity of PVC as standard vinyl flooring for a given area,[2] amplifying the hazard concerns associated with its production. The overall material use for a given period of time including expected frequency of replacement should also be considered when comparing designs. Both vinyl sheet/tile and WPC vary in terms of life expectancy from about 5-25 years (Novalis, 2018; Aspecta N.A., 2020; Metroflor Corporation, 2020). The above comparison assumes the same life expectancy.

The WPC core also requires a blowing agent. The common blowing agent, azodicarbonamide, is considered an SVHC for respiratory sensitising properties.

2.3.3. PET intentional additives

No SVHCs, SIN list or POP chemicals were identified as common additives in PET resilient flooring. The common types of additives that may represent SVHCs or SIN List chemicals in vinyl flooring – plasticisers, heat stabilisers, and blowing agents (for WPC) – are not necessary in PET flooring.

PET flooring reports a life expectancy of 25 years, on the upper end of the life expectancy reported for vinyl sheet/tile and WPC, and uses a similar weight of polymer per area of flooring as vinyl tile and sheet (about 0.8-1.0 kg/m2) (Armstrong Flooring, 2019, p. 10).

2.3.4. Key considerations - product manufacture

- Design systems holistically and use life-cycle thinking
  - Were project team members trained on hazard assessments and materials disclosure programs?
  - Is there a process in place to consider, test, develop and encourage innovative technologies to achieve sustainability?
  - Are measures in place to track and report key sustainability measures?
- Maximise resource efficiency
  - Were different manufacturing processes considered and compared by resource use? For example, were they compared based on ability to minimise energy consumption, material use and waste production?
  - Are current facilities tracking resource use such as energy, water, and material use? Have they set goals to reduce the use of these resources?
- Eliminate and minimise hazards and pollution
  - Were different manufacturing processes considered and compared based on ability to minimise use and release of hazardous substances and pollution?
  - Are current manufacturing facilities tracking the use and release of hazardous substances and pollution? Are they reporting the results? Have they set goals to reduce the use and release of hazardous substances?
  - Were inherently low hazard additives identified? If no alternatives of inherently low hazard were identified, is the function of that chemical necessary for product performance or can it be removed? If it cannot be removed, was a desire for green chemistry solutions expressed to the supply chain?

2.3.5. Example Trade-offs - product manufacture

There may be trade-offs for different material choices within product manufacture or trade-offs associated with other life cycle stages based on product manufacture choices. Several challenges related to data gaps may arise. For example, a product manufacturer choosing a particular functional additive (such as a UV stabiliser) may not have complete transparency from their suppliers as to the contents of the additive options. They may have to choose between a known hazardous option and an undisclosed chemical. Even if chemical contents are known, most chemicals do not currently have full hazard assessments, meaning data gaps exist in one or more hazard endpoints. A design team may have to choose between a chemical that is known to be hazardous and a chemical that is not known to be hazardous but has gaps in hazard data.

In the product comparison outlined above, vinyl sheet/tile and PET flooring have options for additives that are not SVHCs, SIN List and POP chemicals. To move further toward inherently low hazard chemicals, a design team can iterate the hazard comparison to consider additional hazards and/or full hazard assessments.

WPC flooring can be installed without adhesives (or with less adhesive), but includes a blowing agent that is an SVHC. PET and vinyl sheet/tile do not use a blowing agent, but the adhesives used to install them may introduce hazardous substances during the installation phase. Alternative blowing agents or alternative designs that do not require the use of a blowing agent could be considered. Alternative blowing agents may require adjustment in the designed manufacturing process.

2.4. Use

2.4.1. Installation

Vinyl sheet and tile and PET flooring are typically installed with an adhesive. WPC does not use adhesive, rather it relies on a tongue-and-groove click tile installation. Some common hazardous substances found in typical flooring adhesives are summarised in Table 2.5. below. For vinyl sheet/tile or PET, installers using site-applied adhesives (acrylic, epoxy and polyurethane) may have more potential for exposure than factory-applied adhesives (peel and stick). WPC has the potential to avoid these hazards during the installation phase by significantly reducing or eliminating the use of an adhesive, but, as discussed above, there are trade-offs at other phases of the life cycle.

Table 2.5. Chemicals that may be used in flooring adhesives identified on selected hazard lists

Type of Adhesive	Chemical Name	Function	SVHC‡	SIN List	POP
Acrylic (Peel and Stick)	Triphenyl Phosphate	Stabiliser in PET film of release liner		○	
	Octamethylcyclotetrasiloxane (D4)	Residual monomer in release liner	○	○	
Acrylic	Distillates (Petroleum), Hydrotreated (Mild) Heavy Naphthenic (9CI)	Defoamer		○	
Epoxy	4-Nonylphenol	Catalyst	●	●	
	Bisphenol A	Monomer	●	●	
Polyurethane	C13-C15 Alkane	Solvent		●	
	Dibutyltin Dilaurate	Catalyst		●	
Exposure considerations	• Occupational exposures during product installation • Human exposure during product use • Environmental and human exposure from disposal of release liner of the peel and stick adhesive				
Qualitative exposure assessment	See the methodology used in the Key Concepts and Definitions section. • D4 is expected to be present at ~0.5% in the release liner, contributing <0.01% to the acrylic peel and stick adhesive as a whole. This chemical may be considered negligible exposure during product use, but could lead to exposures during installation, manufacturing and end-of-life. • None of the other chemicals above met the screening criteria for negligible exposure.				

Notes:
● The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.

◯The chemical is identified on the hazard list indicated. The chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.
‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.

2.4.2. Use as Installed

Additives, stabilisers and topcoats can migrate from flooring and collect in dust. This can lead to exposure for building occupants. Consequently, eliminating hazards in these chemicals and components should be prioritised. Of particular concern is the impact of these chemicals on young children, who have behaviours that increase exposure to dust, such as crawling on floors and placing their hands in their mouths (Mitro et al., 2016). Moreover, children are also physiologically different from adults in ways that can make them more vulnerable to environmental toxicants (Landrigan Philip J et al., 2004). Studies show that flooring can contribute to higher levels of certain orthophthalates in dust and to higher levels of certain orthophthalates in children (Bornehag et al., 2005). Tables 2.6. and 2.7. list chemicals expected to be present in the final product. These include chemicals that could lead to exposures during product use. As noted above, because topcoats are expected to be similar in the three example products, chemicals present in topcoats were not included in this analysis.

Table 2.6. Chemicals that may be present in vinyl sheet/tile and WPC flooring as used and appearing on selected hazard lists

	Chemical Name	SVHC‡	SIN List	POP
Plasticisers and impurities in post-consumer recycled content	Orthophthalate Plasticisers[a]	◯*	◯*	
Stabilisers and impurities in post-consumer recycled content	Lead- and Cadmium-based stabilisers[a]	◯*	◯*	
Impurities in Post-consumer content	PCBs[b]			◯*
Plasticiser in Adhesive (WPC only)	Hydrotreated Heavy Paraffinic Petroleum Distillates (Mineral Oil)		◯	
Exposure Considerations	Human exposure during product use			
Qualitative exposure assessment	See the methodology used in the Key Concepts and Definitions section. • PCBs, if present, would most likely be present below 0.01% and therefore meets the criteria for negligible potential for exposure during the use phase. Exposure potential may exist at other life cycle stages. • None of the other chemicals above met the screening criteria for negligible exposure.			

Notes:
● The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.
◯The chemical is identified on the hazard list indicated. The chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.
‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.
* This SVHC, SIN List or POP association is identified based on a chemical class-based approach. Not every chemical in these groups will appear on the indicated hazard list, but the list does contain multiple CASRNs within the chemical class.
a These have largely been phased out as intentional content in new products in North American and European markets but may still be present in virgin materials in other regions.
b Residual antimony trioxide is known to be present in PET water bottles, and may be present in PET flooring as well.
Source:
Sources for Tables 2.6. and 2.7. (Filella, 2020; Healthy Building Network, no date a)

Table 2.7. Chemicals that may be present in PET flooring as used and appearing on selected hazard lists

	Chemical Name	SVHC‡	SIN List	POP
Residual Catalyst	Antimony Trioxide[a]		◯	
Exposure Considerations	Human exposure during product use.			
Qualitative exposure assessment	See the methodology used in the Key Concepts and Definitions section. • None of the chemicals above met the screening criteria for negligible exposure. Antimony has been detected in PET samples at levels of up to 0.03% PET resin (de Jesus et al., 2016). Antimony has also been shown to leach out of the resin using a simple water extraction (Filella, 2020).			

Notes:
⬤ The chemical is identified on the hazard list indicated. No alternatives were identified for this chemical function.
◯The chemical is identified on the hazard list indicated. The chemical is not used in all regions, being phased-out, and/or alternative chemicals are available for this process.
‡ The chemicals flagged in this column are identified as Substances of Very High Concern (SVHC) for REACH, either banned unless authorised, candidate list, or prioritised for listing.
* This SVHC, SIN List or POP association is identified based on a chemical class-based approach. Not every chemical in these groups will appear on the indicated hazard list, but the list does contain multiple CASRNs within the chemical class.
a Residual antimony trioxide is known to be present in PET water bottles, and may be present in PET flooring as well.
Source:
Sources for Tables 2.6. and 2.7. (Filella, 2020; Healthy Building Network, no date a)

Vinyl sheet/tile and WPC

The biggest use-phase exposure concerns for vinyl flooring come from plasticisers and stabilisers required for this type of plastic. Residual vinyl chloride monomer may also be present, though this is not common. Flooring manufacturers should fully disclose their product composition, and choose plasticisers and stabilisers that have full hazard assessments and are the lowest hazard options available.

PET

Because PET flooring does not require plasticisers and stabilisers, there is minimal concern with respect to hazardous substance exposures during the use phase. Residual monomers and catalysts (such as antimony trioxide) may be present in polymer resins, typically at less than 1000 ppm and 100 ppm by weight, respectively (Rossi and Blake, 2014).

2.4.3. Non-standard use-phase conditions

Additional use-phase considerations include impacts during disaster scenarios, such as fires, where residents and firefighters can be exposed to hazardous combustion products. Consideration of materials that can minimise hazardous exposures for first responders and residents during fires should be part of the design considerations for sustainable plastics where possible.

2.4.4. Key considerations - product use

- Design systems holistically and use life-cycle thinking
    - Is there an engagement plan to educate workers and customers on different installation options and the impact trade-offs of each option?

- Is there a process in place to consider, test, develop and encourage innovative installation technologies or products as a service approaches?
- Are measures in place to track and report key sustainability measures? For example, survey installation workers on injuries and health concerns, or measure how long before flooring is replaced and why it was replaced.

- Maximise resource efficiency.
  - Were different product designs and installation methods considered and compared by resource use? For example, consider installation methods that reduce waste during installation or tiles that can be replaced when damaged instead of having to replace the whole floor.
  - Are current installers measuring and reporting product waste during installation? Are there goals to reduce product waste during installation?
  - Are products tracked to understand product performance, measure how long before a product is replaced, and track why it was replaced?

- Eliminate and minimise hazards and pollution
  - Were different product designs, installation methods and adhesives considered and compared based on ability to minimise hazardous substance use and pollution?

2.4.5. Example Trade-offs - product use

For vinyl sheet/tile or PET flooring, adhesives can introduce additional hazardous substances into buildings during installation. Site-applied adhesives (acrylic, epoxy and polyurethane) may have more potential for installer exposure than factory-applied adhesives (peel and stick). WPC has the potential to avoid these hazards during the installation phase by significantly reducing or eliminating the use of an adhesive, but it uses an SVHC blowing agent as identified in the product manufacture section. Alternative blowing agents of inherently low or lower hazard may be available. In addition, flooring manufacturers may manufacture or sell their own recommended flooring adhesives to go with specific flooring products. These adhesives can be designed to reduce the use of hazardous substances as well, and the flooring can be designed to work with inherently low hazard adhesives.

Products that are more complex, like WPC with its vinyl floor layer, rigid core, cork underlayment, and adhesive between layers, may be more difficult to recycle. The trade-off for avoiding adhesives during installation may be a more complex commercial afterlife, where different types of materials must be separated and recycled in different ways. Products installed with an adhesive will have their own commercial afterlife considerations in terms of whether the adhesive impacts its recyclability or the recycling process. A floor designed to be recyclable with the adhesive simplifies the commercial afterlife.

While eliminating hazards altogether is the most effective means of avoiding exposures (NIOSH, 2015), that may not always be possible. Within adhesives, hazardous chemicals that are volatile would have the greatest potential for exposure during installation and over a shorter period of time after that, while less volatile chemicals may be released over longer periods of time, presenting prolonged exposure to building occupants.

2.5. End-of-Life

The European Union’s Waste Framework Directive is an example of a framework that can be used to design products that meet the sustainable plastics goals by maximising resource efficiency. It defines a waste hierarchy that prioritises how waste should be dealt with at the end-of-life to minimise its impact on the environment. In order of decreasing priority, the hierarchy includes prevention, reuse, recycling, other recovery (e.g. energy recovery), and disposal (Directive 2008/98/EC, 2018).

Flooring products can be landfilled, incinerated or recycled at their end-of-life. Plastic flooring is not typically reused or recycled today (Armstrong Flooring, 2019; Resilient Floor Covering Institute, 2019a, 2019c, 2019b). Some manufacturers do have take-back programs for both PVC and PVC-free flooring; a small but increasing amount of plastic flooring is being recycled (Armstrong Flooring, 2016; Vinyl Plus, 2020; Tarkett, no date; Vinyl Sustainability Council, no date). It is not clear how much collected material is recycled back into new flooring.

2.5.1. Landfill

Landfill is the most common end-of-life for flooring. In the United Kingdom, for example, over 90% of flooring goes to landfill (Thomas and Blofeld, 2010). Fires in landfills or leaching can lead to chemical releases. When PVC burns in uncontrolled fires such as landfill fires, it releases chlorine gas that can contribute to the formation of dioxins (Zhang et al., 2015).

2.5.2. Incineration

Waste-to-energy processes are examples of controlled burning, but there is still potential to form dioxins, furans and corrosive acids, chemicals known to have reproductive toxicity and high acute toxicity. These chemicals are formed particularly when the incinerators are not operating at ideal conditions, such as during start up and shut down (NITE, no date). Studies have demonstrated that dioxin formation is highly dependent on combustion conditions, and measures can be taken to minimise dioxin formation in incinerators (Avakian Maureen D et al., 2002). Incineration of PET does not generate dioxins but can still generate polyaromatic hydrocarbons (PAHs) and other volatile organic compounds (VOCs) in non-ideal conditions (Sovová et al., 2008).

2.5.3. Recycling

Recycling of plastics is an important end-of-life pathway to support a circular economy. Plastics can be recycled through either a chemical or a mechanical process. Chemical recycling allows separation of additives and returns polymers to their original monomer form. Mechanical recycling is the less expensive option, but it does not allow for the separation of additives.

Vinyl sheet/tile

In North America, over 1 billion pounds of vinyl is recycled annually, and 146 million pounds of this comes from post-consumer content (Vinyl Institute, no date). In 2019, 1.7 billion pounds of vinyl was recycled in Europe's VinylPlus framework, among which approximately 375 million pounds was flexible PVC (Vinyl Plus, 2020). Flooring is one of the top end markets for recycled vinyl as post-consumer vinyl can be used in the bottom layer of vinyl products (Helm, 2009; Krock and Tarnell, 2015).

Mechanical recycling of PVC can lead to the incorporation of hazardous legacy chemicals into new products. Full materials disclosure, manufacturer take-back programs, source separation and testing are key in the recycling process to avoid contamination from flooring or other types of feedstocks with hazardous legacy chemicals or contaminants (Vallette, 2015a).

Box 2.1. Manufacturer take-back programs

Some flooring manufacturers have already developed take-back programs that extend to vinyl products. These programs allow for post-consumer PVC flooring to be incorporated into new products through closed-loop processes that screen for hazardous content. Armstrong's ON&ON™ program and Tarkett's ReStart® program both accept post-consumer luxury vinyl tile (LVT) and vinyl composition tile (VCT) (Armstrong Flooring, 2016; Tarkett, 2020). The manufacturers place guidelines on which products are acceptable in order to prevent contamination of the recycled content. Armstrong does not accept flooring containing asbestos, floors from buildings constructed prior to 1990, burnt tiles, or wet, mouldy or weathered tiles. The content must also meet Armstrong's internal limitations on levels of heavy metals and diethylhexyl phthalate (DEHP). Tarkett's program has also historically been driven by getting the total orthophthalate product content to below 0.1% and by preventing contaminants found in recycled PVC scrap from being incorporated into their products (Dr. F. Bezati, 2015a, 2015b).

The potential for contamination underscores the urgency to continue to develop closed-loop recycling processes for PVC flooring products that ensure new PVC flooring formulations do not get contaminated by feedstocks containing old PVC flooring formulations and other sources of PVC that may contain hazardous legacy chemicals.

Where the complexities of recycling mixed PVC feedstock, including non-flooring products, make mechanical recycling too difficult, chemical recycling is possible (European Council of Vinyl Manufacturers, no date). Chemical recycling of PVC can help avoid legacy contamination. If a pyrolysis chemical recycling process is used, formation of dioxins is possible (Achilias et al., 2012). It also may not be economically feasible to remove legacy chemicals to acceptable levels, as was the case when EU REACH Regulations on orthophthalates led to the closure of the VinyLoop plant in 2018, with removal of the contaminants proving too costly (Hann and Connock, 2020).

WPC

While WPC flooring has similar composition to traditional vinyl flooring, the two closed-loop recycling processes highlighted in Box 2.1 made no mention of take back programs for WPC flooring. It is possible that the additional layers that must be separated prior to recycling may make it more difficult to recycle. However, one source suggested that closed-loop recycling of WPC flooring may be possible (Petchwattana, Covavisaruch and Sanetuntikul, 2012). Otherwise, similar recycling impacts to those seen in vinyl sheet/tile would be expected in WPC.

PET

Chemical recycling of PET can occur through a variety of mechanisms. One of the most common mechanisms is glycolysis, which relies on reagents with known and potential human health effects like ethylene glycol and propylene glycol (though neither is an SVHC or SIN List chemical) (Scheirs and Long, 2005; Healthy Building Network, no date b). It may also employ organometallic catalysts based on toxic heavy metals (Sangalang, Seok and Kim, 2016). The outputs are the monomer bis(2-hydroxyethyl) terephthalate and ethylene glycol (Hann and Connock, 2020). In the mechanical recycling process, PET is ground up and reprocessed through a melt extrusion into granules that can be used for a variety of purposes, including aggregates in concrete mixes (Raheem et al., 2019).

Table 2.8. End-of-Life Considerations

	Vinyl Sheet/tile	WPC	PET
Reuse possible		✓	
Chemical recycling available	✓	✓	✓
Mechanical recycling available	✓	✓	✓
Closed-loop process available & in place	✓		
Legacy chemical concerns to consider in recycling operations[a]	Certain Orthophthalates, lead- and cadmium-based stabilisers, PCBs	Certain Orthophthalates[b]	Antimony trioxide
Incineration	✓	✓	✓
Landfilled	✓	✓	✓
Chemical concerns from leaching and burning to address[a]	Dioxins, furans, corrosive acids	Dioxins, furans, corrosive acids	PAHs, VOCs

Note:
a These chemical groups are included because they contain numerous CASRNs identified as SVHCs, that are present on the SIN List, or that are identified as POPs under the Stockholm Convention.
b Because WPC products are newer to the market, most are not likely to contain orthophthalates and lead- and cadmium-based stabilisers. At least one product surveyed, however, did contain an orthophthalate plasticiser (Wellmade Floors, 2015).

2.5.4. Key considerations - end-of-life

- Design systems holistically and use life-cycle thinking
    - Are manufacturer take-back programs in place? Has a study been completed to understand regional gaps and opportunities in infrastructure to support manufacturer take-back programs?
    - Is there a process in place to consider, test, develop and encourage innovative end-of-life solutions?
    - Are measures in place to track the end-of-life of plastic flooring options? Are there goals to increase reuse and recycling and reduce incineration, landfill and uncontrolled end-of-life practices?
- Maximise resource efficiency
    - Have different product designs been considered and compared by end-of-life options that reduce waste? For example, those that facilitate product reuse, disassembly, and recycling.
    - Are the current product's end-of-life options known for each region? Are there regionally specific programs in place to increase reuse and recycling and reduce incineration, landfill and leakage?
- Eliminate and minimise hazards and pollution
    - Were different product end-of-life options considered and compared based on ability to minimise release of hazardous substances and pollution?

- o Are there regional specific programs in place to minimise release of hazardous substances and pollution at the end of the product's life?

2.5.5. Example Trade-offs - end-of-life

Landfilling and incineration are not consistent with a sustainable materials management system and should not be considered options for future sustainable plastic product development. Mechanical or chemical recycling of flooring offers an opportunity for sustainability, but it comes with many challenges and trade-offs and is not currently widely adopted for flooring products. If hazardous additives are present in products, recycling workers can be exposed and chemicals released into the broader environment when materials are mechanically recycled. Where chemical additives are known and of low hazard, mechanical recycling is typically the most economically feasible option and is possible for both PVC and PET. Potential impacts of contamination of flooring products from the use phase (such as adhesives), during removal from buildings, and during transportation of the materials must be considered. Transporting materials long distances for recycling can lead to additional life cycle impacts that would need to be considered when reviewing trade-offs of mechanical recycling. In the design process, using inherently low hazard additives and mechanically recyclable plastics, along with programs to develop the necessary infrastructure, can foster a closed-loop system.

Chemical recycling can help maximise resource efficiency by keeping materials out of landfills and has the potential to generate pure monomer feedstocks. It can minimise hazard and pollution by avoiding chemical emissions associated with the production of virgin materials and can remove legacy hazardous substances that may otherwise enter the environment if the product were to be landfilled. There are trade-offs in terms of energy required for transportation of the materials and for the chemical recycling process (Hann and Connock, 2020). Some chemical recycling processes also utilise hazardous process chemicals as noted above with respect to PET. There is current chemical recycling infrastructure for PET, but no resilient flooring is known to be recycled this way (Hann and Connock, 2020). Chemical recycling of vinyl flooring has previously not been found to be economically feasible. There are many unknowns with respect to most chemical recycling processes. As noted in a December 2020 report on the current state of chemical recycling published by CHEM Trust, "...the overriding finding is that there is a general lack of transparency or clear evidence base that can be used to back up claims or generate firm conclusions around the viability of many technologies. This is due, in part, to the sheer number of smaller, lab scale examples that demonstrate possibility rather than viability. At the commercial scale (or close to it), the competition to be first to market is strong and this appears to limit publicly available evidence. This also means that caution must be exercised as a lack of evidence can mean either a knowledge gap or that the answer is less favourable" (Hann and Connock, 2020).

Notes

[1]An estimated 79% of the world's chlor-alkali capacity is based on PFAS membranes or diaphragms, 18% on asbestos diaphragms, and 3% on mercury cells. Production by asbestos technology is heavily concentrated in the United States. As of 2018, in North and South America 8 of the 12 largest plants in operation (an estimated 41% of chlor-alkali capacity) still used asbestos diaphragm technology and 8 plants (an estimated 4% of chlor-alkali capacity) used mercury cells. In Europe, these two technologies are less common due to phase-out of these technologies, but Germany has one large plant that still uses asbestos diaphragms and two plants that use mercury cells. In Asia, an estimated 94% of chlorine is produced using PFAS-coated membranes, although several still operate using asbestos diaphragms. No major chlorine producers in Africa use mercury cell or asbestos diaphragm technology.

[2] Vinyl tile/sheet and WPC products can vary in terms of the overall thickness, density, percentage of polymer within the product. Based on HBN's Common Product Research, vinyl tile and sheet contain about 0.7-2.0 kg of PVC per square meter of flooring. WPC flooring contains 2.0 to 4.0 kg of PVC per square meter of flooring. PVC-free resilient flooring contains 0.6 to 0.7 kg of polymer per square meter of flooring.

Chapter 3. **Policy Considerations**

This case study has used plastic flooring as an example to identify opportunities for improvement toward sustainable plastics from a chemicals perspective. In the introduction, design principles are used to generate key considerations needed to work towards sustainable plastics goals (see Figure 2.2). In this section, those same sustainable plastic goals are used to define policy instruments that can encourage and reward work towards sustainability outcomes.

3.1. Broad Regulations on Chemical Content

Regulations restricting chemical content in a finished product not only can eliminate hazards at all phases of production, but also have potential to give a product a commercial afterlife. In order for these regulations to be effective at promoting the development and use of sustainable plastics, however, they must have a wide reach both in product type coverage and, when appropriate, chemical class coverage.

To illustrate the need for wide product type coverage, consider how in 2005 regulations in the EU began limiting the use of certain orthophthalates in children's toys (ChemSafetyPRO, no date). The same chemicals banned in children’s products, however, were still being used in consumer and commercial flooring products, continuing potential exposure for children and adults. Fifteen years later, in July 2020, restrictions under the EU’s REACH legislation went into effect, restricting the use of four specific orthophthalates of concern in consumer products, including flooring (ECHA, 2017, 2018). The absence of orthophthalate plasticisers of concern means that these products can be more easily recycled, barring the use of other hazardous chemicals in their formulations.

The class-based approach, described in the key concepts section above, is designed to ensure protective regulations and avoid regrettable substitutions. A class-based approach recommends that if known hazards are sufficient to justify restrictions associated with one member of a family or class of chemicals, then the entire class should be considered for restrictions unless proven otherwise. The burden of proof for such chemicals should be placed on proving low hazard and safety of the exceptions, rather than proving hazard and potential harm. Existing examples of the class-based approach in policy include the U.S. EPA ban on polychlorinated biphenyls (PCBs) and the European Union directive limiting total perfluoroalkyl substances (PFAS) in drinking water (US EPA, 1979; Directive (EU) 2020/2184, 2020).

3.2. Emissions Inventories and Regulations

Emissions inventories can be useful in identifying major sources of pollution and can be helpful in setting targets for reducing environmental emissions of hazardous substances. The Batumi Action for Cleaner Air (BACA) initiative was established to help policymakers implement decisions to improve air quality in 27 countries (UNECE, 2016, 2018). One goal of the initiative is the establishment of systematic, comparable and transparent monitoring activities and emissions inventories. One approach to reducing these emissions is the development of engineering controls that mitigate the release of hazardous substances into the environment. The development of manufacturing processes that minimise the use of hazardous chemical inputs, intermediates, products, and byproducts (i.e. those that use fewer hazardous chemicals at all stages of production) can further help reduce the release of these chemicals into the environment. For example, when manufacturers in the U.S. transitioned away from the use of formaldehyde-based binders in fiberglass batt insulation, the U.S. EPA Toxics Release Inventory data revealed a sharp decline in environmental releases of formaldehyde from these facilities in the decade that followed (Vallette, 2015b). In this regard, emissions inventories can be a means to track progress in the reduction of environmental emissions achieved by using chemical processes that are inherently low hazard.

3.3. Material Disclosure Incentives/Requirements

Policies requiring or incentivising material disclosure can also have widespread effects. Like regulations on chemical content, they can incentivise the creation of products that are inherently low hazard and can also support a commercial afterlife for products. Material disclosure, like that found in the database on Substances of Concern In articles as such or in complex objects (Products) (SCIP) in the EU enables SVHCs to be identified in products at various stages of their lifecycle (ECHA, no date b). This level of transparency not only can help product designers eliminate hazardous substances from products, but also can give waste operators the ability to segregate products based on the presence or absence of SVHCs and identify potentially problematic waste streams. For instance, current vinyl flooring formulations that have removed orthophthalate plasticisers and cadmium- and lead-based stabilisers could be separated from post-consumer PVC waste streams containing orthophthalates, making recycling more feasible.

Policies requiring full product content disclosure standardise materials transparency across an industry. For example, in the cleaning product sector, California now requires cleaning products to disclose all ingredients on their labels (S.B. 258, 2017). Most product content disclosure today has been driven by either cost savings or market advantage. Data from the electronics sector have demonstrated that full material disclosure incurred more up-front costs, but over time led to net cost savings as changing regulations or client specifications could be confirmed immediately with fewer compliance requests needed from suppliers (Wu, 2018). In the building product sector, green building standards such as LEED sparked materials disclosure by adding a building materials disclosure and optimisation credit to LEED V4.0 (USGBC, no date). Now product disclosure is driven, in part, by firm-wide policies. As of 2020, approximately 100 architecture and design firms have signed a letter to building product manufacturers stating they will prefer, select and specify products with content disclosure (Materials Pledge Signatories, 2020).

Regardless of the driving forces, extending the materials disclosure principle to full product content disclosures such as Health Product Declarations and Declare Labels, as described in the key concepts section above, has the added benefit of both identifying known hazardous substances as well as those not identified as hazardous, which may not yet be fully studied. Such disclosure has clear benefits from a circularity perspective. Whether or not the content has known hazards at the time of manufacture, product content disclosures enable proper handling at the end-of-life when additional hazard information may be available. Thus, transparency creates greater opportunity for reuse or recycling. Furthermore, this disclosure can also help provide a broader understanding of the chemicals most often used in products and identify priorities for full chemical hazard assessments.

3.4. End-of-Life Policies

Creating a plastic with inherently low hazards and a commercial afterlife does not guarantee that it will be reused or recycled. The proliferation of plastics use and often poor end-of-life waste management have helped to generate widespread plastic pollution. Strong end-of-life policies can help ensure that materials that can be recycled are recycled. They can also limit the generation of waste, and ensure that waste-derived materials without hazardous content are incorporated into new products. Thus, financing efficient collection and management schemes should be prioritised.

The new plastic waste amendments to the Basel Convention could potentially drive the development of policies that aim to separate plastic waste contaminated with legacy chemicals from waste that is not. (UNEP, 2019a, 2020a). Because the Basel Convention is aimed at reducing the movement and disposal of hazardous waste across international boundaries, domestic policies aimed at reducing hazardous waste should reflect the priorities outlined in the Convention as well.

Policies to promote recycling in the flooring sector must address the lack of efficient collection and management schemes and related economic barriers. In order to reduce the amount of flooring going to landfills, end markets for flooring waste need to be identified, infrastructure and economic barriers to recycling like transportation costs and environmental impacts need to be addressed, and information on recycling opportunities and activities needs to be disseminated effectively (Thomas and Blofeld, 2010).

An efficient recycling infrastructure would ideally be coupled with policies promoting and rewarding aggressive collection and management schemes that are essential to ensure plastic that can be recycled is recycled. In the building materials sector, government policies that promote construction and demolition debris recovery can help nations and communities move toward zero waste and promote the use of sustainable plastics. For instance, the U.S. city of San Francisco has an ordinance requiring all construction and demolition debris to be reused or recycled (SF Environment, 2011). Specific to flooring, the European Union is funding a research and innovation program to support the development of new products from waste PVC flooring and recycling processes that will safely remove plasticisers from flooring waste (‘Circular Flooring’, no date). Such programs and policies do not ensure that new materials are inherently low hazard. In order for them to be effective from a sustainable plastics perspective, they must be combined with strong policies limiting hazardous content and promoting product content disclosure. Sweden, for example, has taken steps in this direction by requiring inventories of hazardous wastes in buildings; these hazardous wastes must then be separated from other waste and collected before demolition. Likewise, other Nordic countries have regulations requiring inventories and reporting of hazardous wastes prior to demolition to varying degrees (Wahlström et al., 2019). While the benefit of combining aggressive collection and management schemes with policies limiting hazardous content and those requiring product content disclosure may not be felt immediately, combining them should be a long-term goal of sustainable materials management.

Effective waste management policies are also key in efforts to generate zero waste. Closed-loop recycling programs aim both to give products a commercial afterlife and to generate no waste, but also must ensure that toxic chemicals are not passed on as post-consumer content is incorporated into new materials. In order for closed-loop recycling efforts to be seen as economical, governments may need to work with industry to determine whether or not subsidies are necessary. For example, the state of California has made chemical recycling efforts for carpet more cost effective, increasing recycling rates and creating post-consumer markets for recycled nylon 6 (Peoples, 2019).

An additional pathway to reduce waste is extended producer responsibility (EPR). OECD defines EPR as “a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products” (OECD, no date b). EPR programs, such as those implemented in Korea, Japan, and parts of Europe, have been shown to increase recycling and reduce waste; these programs may also help promote the development of products that are designed for takeback, disassembly, and reuse or recycling (OECD, 2006). In 2020, France put in place the legal framework for a new EPR scheme for building and construction products and materials, including flooring. This scheme will be implemented in 2022 (Ministry of the Ecological Transition, 2020). The Basel Convention offers a number of resources related to the environmentally sound management of plastic waste geared towards helping parties to the convention comply with the plastic waste amendment adopted in2019 (UNEP, no date a). These guidelines include a manual providing stakeholders with guidance on the implementation of EPR that includes key elements to be considered and strategies to formulate policies, along with practical examples of EPR programs (UNEP, 2019b).

3.5. Using the Full Diversity of Policy Instruments

Table 3.1. summarises the policy considerations outlined above, and suggests which sustainable plastics goals each is likely to impact. While many of the actions described here will be familiar to policymakers, no one policy is likely to address every element required to create more sustainable plastics. In order to fully support the development of sustainable plastics, a diverse set of policy instruments should be adopted and tested to ensure that they align to produce the desired results. By vetting policies against the sustainable plastics goals, policymakers can begin to identify where existing policies need to be supplemented. Careful analysis should be conducted to determine whether or not policies are influencing design considerations that help achieve these goals. Furthermore, policymakers should work to actively identify roadblocks that exist to accomplishing these intended goals.

Sometimes these roadblocks are other policies. The OECD recently held a workshop where case studies on real-world examples of conflicting policies hindering progress on chemicals and waste management and possible solutions. For example, regulations in Colombia limiting the transport of hazardous substances to another company for reuse leads to more hazardous substances being landfilled. Solutions include alignment of legislation that promotes a circular economy and policies that regulate hazardous substances (OECD, 2020).

A vital element of implementing an array of policies focused on these sustainable plastics goals is information sharing. The Basel Convention Partnership on Plastic Waste has identified a number of activities that aim to address plastic waste prevention and minimisation, plastic waste collection, recycling, and other recovery including financing and related markets, transboundary movements of plastic waste, outreach, education, and awareness- raising (UNEP, 2020b). Aggressive plans to collect and analyse information on the degree to which chemical regulations, product content disclosure and end-of-life financing schemes like EPR contribute to the development of sustainable materials over time can support their efforts. These efforts, in turn, have potential to support the further development of sustainable plastics.

Table 3.1. Policy Considerations to Support Sustainable Plastics

	Sustainable Plastics Goals			
Examples of Policy Instruments	Inherently low hazard	Commercial afterlife	Generate no waste	Rapidly renewable resources or waste-derived materials
Chemical Regulations				
Broad regulations on chemical content	✓	✓		
Material Disclosure Incentives/Requirements				
Emissions inventories and regulations	✓		✓	
Material disclosure incentives/ requirements (e.g. SCIP database)	✓	✓		
End-of-Life Policies				
Subsidisation of recycling programs and infrastructure		✓	✓	
Construction and demolition waste collection programs[a]	✓	✓	✓	
Extended producer responsibility (EPR)	✓	✓	✓	
Closed-loop recycling programs		✓	✓	✓
Controlling movement/disposal of hazardous wastes (e.g. Basel Convention)				✓

Note:
a Subsidisation of recycling programs and infrastructure can help ensure materials are inherently low in hazard when used in combination with pre-demolition audits requiring materials containing hazardous substances to be identified and separated from other waste prior to demolition (European Commission, 2018; Wahlström et al., 2019).

Chapter 4. Sustainable Plastic Flooring Criteria

Using the Sustainable Plastic Goals outlined above and informed by the data collected on the example plastic flooring products, vinyl sheet/tile, WPC, and PET, a set of criteria was developed to use to benchmark and compare material alternatives. Below is a summary of important criteria to consider when designing or selecting plastic resilient flooring to reduce the impacts on human health and the environment at each life cycle stage of the product.

Sustainable plastics enhance human and environmental health and safety across the entire product life cycle. They:

Are inherently low hazard:

- Hazardous substances, especially those with potential for exposure to workers, community, users and environmental receptors, are eliminated at all life cycle stages including
    - Base polymer and source materials:
        - The base polymer chosen uses the least hazardous chemicals in the manufacturing and produces the least hazardous production emissions.
        - Within that base polymer, the manufacturing route chosen uses the least hazardous chemicals.
        - The base polymer chosen minimises the need for additives, simplifying the makeup of the final product.
        - Recycled feedstocks are used and are from known sources and tested for common hazardous content to avoid introducing hazardous content into new products.
    - Product manufacturing including additives/additive life cycle:
        - The product uses the fewest number of additives/components possible.
        - Additives that are used are fully assessed for hazards and are the least hazardous available.
        - The product is designed with circularity in mind, considering potential future regulations and emerging chemicals of concern that could impact the recyclability/reusability of the product at the end-of-life.
    - During installation and use:
        - The installation process avoids the use of hazardous adhesives.

  - If adhesives or other accessories are needed for installation or during use, they have been fully disclosed, fully assessed for hazards, and the least hazardous option is used.
  - If needed, additives are chosen that stay in the product and do not migrate into living spaces or the environment.
- End-of-life:
  - Additional hazardous substances are not required for processing at end-of-life.
  - Hazardous substances are not produced at end-of-life (e.g. combustion by-products).
  - Legacy hazardous substances are not perpetuated in the supply chain as part of recycling processes.

- Transparency in terms of content and emissions exists at every step of the supply chain.
  - Third-party verified Health Product Declarations with all contents characterised, screened, and identified to 100 ppm are available for all products used in the manufacturing of the product.
  - Supply chain material flows for chemical inputs are identified.
  - Emissions data is publicly reported for all stages of chemical and product manufacture, and hazardous emissions are eliminated.

- Full hazard assessments are available.
  - Full chemical hazard assessments are available on all chemicals used in a product and used to make the product.
  - Alternatives to chemicals of concern are fully disclosed, fully assessed alternatives of low concern.

Sustainable plastics are managed within a sustainable materials management system. They:

Have a commercial afterlife:

- Products are designed for durability, reclamation, reuse, and recycling
  - The product can be reclaimed and reused if removed before the end of its useful life.
  - The material is recyclable at the end-oflife into products with equal or greater value than the original product, and suitable recycling infrastructure exists.

- Content transparency exists to support reuse and recycling
  - Products have public content transparency to aid in understanding of product content at this stage and potential impacts on recycling. Third-party verified Health Product Declarations with all contents characterised, screened, and identified to 100 ppm are available.

- Infrastructure exists to support reclamation, reuse, and recycling
  - Suitable reclamation and recycling infrastructure exists.

- Partnerships and initiatives are in place to expand and improve reclamation and recycling infrastructure as part of the product development process.
- Reclamation and recycling of materials when a building is constructed, renovated, or demolished is all part of an extended manufacturer responsibility program.

- Materials are able to undergo multiple cycles of recycling

Generate no waste:

- Manufacturing waste is eliminated at every step of the production process.
- Scrap from installation is eliminated or recycled.

Use rapidly renewable resources or waste-derived materials:

- Use rapidly renewable resources that do not compete with "higher" uses.
  - Bio-based feedstocks are used when they do not compete with "higher" uses (e.g. food production) and when they have lower impacts than virgin materials.
- Use waste-derived materials without hazardous content.
  - Waste feedstocks are used and are from known sources and tested for common hazardous content to avoid introducing hazardous content into new products.

4.1. Application of Criteria to Case Study

No one plastic flooring product will currently meet all of the criteria outlined above. Furthermore, comparing products using these criteria is going to highlight differences, but also trade-offs between different product types. One way to use these criteria is demonstrated in Table 4.1. below. The products are compared side-by-side not only to compare impacts between the product types, but also to identify opportunities for mitigation and promote avoidance of shifting impacts to another life-cycle stage.

As an example where the types of considerations highlighted in this case study have been deliberated, the flooring company Tarkett has been on a journey to more sustainable design of flooring products. Annex B presents a case story of how they have been addressing a number of transparency and sustainability issues regarding chemicals.

Table 4.1. Comparison of PVC, WPC and PET flooring. Impacts and opportunities for mitigation

Criterion	Vinyl Sheet/Tile (PVC)	WPC	Polyester (PET)
Sustainable plastics enhance human and environmental health and safety across the entire product life cycle. They are:			
Inherently low hazard: Base polymer and source materials	**Impacts:** Currently SVHC, SIN, and POPs chemicals are used in chlorine and resin manufacturing **Opportunities for mitigation**: Use recycled PVC from known sources without chemicals of concern instead of virgin polymer. Consider alternative plastic types with lower inherent hazards.	**Impacts**: Same hazards as vinyl sheet/tile. 3 times more PVC needed. **Opportunities for mitigation**: Same as vinyl sheet/tile and redesign to use less PVC resin	**Impacts**: Currently two SIN list chemicals are used in intermediate and resin manufacturing **Opportunities for mitigation**: Develop/utilise safer catalysts. Use recycled PET from known sources without chemicals of concern instead of virgin polymer. Consider alternate polyesters or alternate plastic types with lower inherent hazards.
Inherently low hazard: Product manufacturing including Additives/Additive Life Cycle	**Impacts**: stabilisers and plasticisers can be SVHCs **Opportunities for mitigation**: Use fully disclosed, fully assessed alternatives of low concern.	**Impacts**: same as vinyl sheet/tile plus the use of SVHC blowing agent **Opportunities for mitigation**: same as vinyl sheet/tile	**Impacts**: residual antimony-based catalyst in recycled feedstock. **Opportunities for mitigation**: Use fully disclosed, fully assessed alternatives of low concern.
Inherently low hazard: During installation and use	**Impacts**: adhesives can contain SVHC and SIN List chemicals **Opportunities for mitigation**: Develop or specify safer adhesives to be used with the product. Use fully disclosed, fully assessed alternatives of low concern.	**Impacts**: no adhesives used for installation **Opportunities for mitigation**: Elimination of adhesive eliminates risk from exposure to toxic adhesive chemicals.	**Impacts:** adhesives can contain SVHC and SIN List chemicals **Opportunities for mitigation**: Develop or specify safer adhesives to be used with the product. Use fully disclosed, fully assessed alternatives of low concern.
Inherently low hazard: End-of-life	**Impacts**: Incineration and landfill are currently the most common end-of-life for plastic flooring materials. Both can lead to the release of hazardous substances. Recycling can be energy- and material-intensive and can release hazardous substances present in the product or used in the recycling process. **Opportunities for mitigation**: Incentivise extended producer responsibility programs. Engage with recyclers. Support recycling infrastructure development and reuse innovations.		

Transparent in terms of content and emissions at every step of the supply chain	**Current state**: Disclosure of product content is occurring for resilient flooring. The quality and completeness of this disclosure is inconsistent. **Opportunities for improvement**: Strive to generate third-party verified Health Product Declarations with all contents characterised, screened, and identified to 100 ppm. Implement data collection for supply chain material flows and manufacturing emissions to the environment.		
Fully assessed for hazards	**Current state**: Few of the chemicals used in flooring products are fully assessed for hazards. **Opportunities for improvement**: Strive to generate full chemical hazard assessments on all chemicals used in a flooring product to facilitate informed decision-making.		
Sustainable plastics are managed within a sustainable materials management system. They:			
Have a commercial afterlife	**Impacts**: Currently plastic flooring is most often landfilled or incinerated. Legacy hazardous substances or adhesives may make recycling more difficult or reduce the value of recycled material. **Opportunities for mitigation**: Incentivise extended producer responsibility programs. Engage with recyclers. Innovate mechanical installation options with simplified materials designed for recyclability.	**Impacts**: Same as vinyl sheet/tile. Recycling may be more difficult with multilayer products made of different materials. Click tile design avoids use of adhesives. **Opportunities for mitigation**: Incentivise extended producer responsibility programs. Engage with recyclers.	**Impacts**: Currently plastic flooring is most often landfilled or incinerated. Fewer additives may make PET easier to recycle; adhesives may make recycling more difficult. **Opportunities for mitigation**: Incentivise extended producer responsibility programs. Engage with recyclers.
Generate no waste	**Impacts**: Waste occurs during manufacturing, installation and end-of-life. **Opportunities for mitigation**: Strive towards zero waste at manufacturing sites. Educate installers on ways to reduce and recycle scrap during installation.		
Use rapidly reviewable resources or waste derived materials	**Impacts**: Use of recycled content in new flooring may reintroduce legacy hazards (certain orthophthalates and lead- and cadmium-based stabilisers) from old PVC products. **Opportunities for mitigation**: Use recycled PVC from known sources without chemicals of concern instead of virgin polymer. Consider bio-based alternative plasticisers with lower impacts over virgin materials.	**Impacts**: Same as vinyl sheet/tile **Opportunities for mitigation:** Same as vinyl sheet/tile.	**Impacts**: Use of polyester partially from bio-based content is possible in flooring, but not in many products yet. Similar to virgin PET, recycled PET may contain residual antimony-based catalysts. **Opportunities for mitigation**: Use recycled PET from known sources without chemicals of concern instead of virgin polymer. Consider bio-based alternatives with lower impacts over virgin materials.

Chapter 5. **Conclusion**

The sustainable plastic goals derived at the beginning of this case study informed the generation of key criteria that can be used by product design teams and procurement specialists to benchmark their current practices and identify opportunities for improvement. These opportunities include consideration of different materials, different manufacturing processes, different designs, number and type of data gaps, and range of policy instruments that could reduce product impacts throughout the life cycle. While the criteria were developed with plastic flooring in mind, they are relevant for any durable plastic product.

As stated above, the sustainable plastic goals are lofty. Current products are unlikely to meet all of the criteria. While they may not be immediately achievable, the criteria provide a pathway toward truly sustainable plastic products. This case study focuses on comparing plastic flooring products; however, additional flooring materials such as ceramic tile, carpeting and linoleum should be considered and compared from a sustainability perspective. In product design, innovation may require the consideration of vastly different materials and/or business models for products versus making incremental improvements in chemistry for a particular type of product. With any alternatives, evaluation of impacts at all stages of the product life cycle is important to make an informed decision. Products should be envisioned and designed within sustainable material systems.

For any product design or policy development, teams should decide early on based on their group's values which sustainability goals and criteria are most important to focus on and make decisions based on an understanding of the connection to other sustainability goals and the potential trade-offs. In addition to the comparison table above, various tools are available to help project teams make decisions in the face of multivariable data such as the criteria outlined in this case study (DM, 2010; OECD, 2018b). The sustainable plastic goals can be used in an iterative way, filling data gaps as needed to discern between options and to make informed decisions.

Annex A. Product Composition

A Common Product profile is a type of data record generated by Healthy Building Network and consists of a list of substances that are most commonly present in a product type as delivered to building sites. They are based on numerous sources including specific product literature, transparency documents, trade association data, industry standards and patents. The profiles are not specific to any manufacturer. Although Common Products and the example formulations cited below are specific to product compositions available in North America, for the report above potential regional variations are discussed that may exist outside of this region. This same product information and original source documentation is available in the Common Products section of the Pharos database (Healthy Building Network, no date a). Common Product research methodology is described in detail at https://pharosproject.net/common-products/methodology.

Luxury Vinyl Tile Common Product*

Chemical	CASRN	% Weight Product	Function
Limestone	1317-65-3	63.7%	Filler
Polyvinyl chloride	9002-86-2	22.4%	Resin
Bis(2-ethylhexyl) terephthalate	6422-86-2	9.6%	Plasticiser
Epoxidised soybean oil	8013-07-8	1.4%	Stabiliser, Process Aid, Plasticiser
Quartz	14808-60-7	0.7%	Impurity
Zinc stearate	557-05-1	0.6%	Stabiliser
Magnesium aluminium hydroxide carbonate	11097-59-9	0.5%	Acid Absorber
Zeolites	1318-02-1	0.5%	Acid Absorber
Calcium stearate	1592-23-0	0.2%	Stabiliser
Titanium dioxide^	13463-67-7	0.2%	Pigment
UV cured finish	Various	0.3%	Finish

***** *For a full list of sources used to generate this Common Product see Luxury Vinyl Tile (LVT) (2016) Pharos. Available at: https://pharosproject.net/common-products/2077801 (Accessed: 18 September 2020).*
^ *Many other pigments may be used in specific products.*

Wood Plastic Composite Common Product*

Chemical	CASRN	% Weight Product	Function
Luxury Vinyl Tile	Various (see above)	56.4%	Vinyl base, wear layer, and protective coating
Polyvinyl chloride	9002-86-2	21.3%	Polymer in WPC core
Calcium carbonate	471-34-1	6.8%	Filler in core
Bis(2-ethylhexyl) terephthalate	6422-86-2	1.7%	Plasticiser in core
1,1'-Azobis(formamide)	123-77-3	1.3%	Blowing agent in core
Calcium stearate	1592-23-0	0.4%	Stabiliser in core
Zinc stearate	557-05-1	0.2%	Stabiliser in core
Sodium bicarbonate	144-55-8	0.1%	Blowing agent in core
Quartz	14808-60-7	0.07%	Impurity
Cork	61789-98-8	9.0%	Filler in underlayment
1,2-Ethanediol, polymer with 1,3-diisocyanatomethylbenzene	9072-91-7	1.3%	Binder in underlayment
Petroleum resins	64742-16-1	0.7%	Tackifier in adhesive
Styrene butadiene rubber	9003-55-8	0.5%	Adhesive
Mineral Oil	64742-54-7	0.3%	Plasticiser in adhesive

* For a full list of sources used to generate this Common Product see Multilayer Resilient Flooring (WPC) (2019) Pharos. Available at: https://pharosproject.net/common-products/2203433 (Accessed: 16 September 2020).

PVC-free Resilient Flooring (Homogeneous) Common Product*

Chemical	CASRN	% Weight Product	Function
Limestone	1317-65-3	65.9%	Filler
2-Propenoic acid, 2-methyl-, polymer with ethene, zinc salt#	28516-43-0	15.0%	Binder
Ethylene vinyl acetate copolymer#	24937-78-8	14.4%	Binder
Zinc stearate	557-05-1	1.5%	Lubricant
Titanium dioxide^	13463-67-7	1.1%	Pigment
Quartz	14808-60-7	0.7%	Impurity
Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate)	6683-19-8	0.6%	Antioxidant
UV cured finish	Various	1.0%	Finish

* For a full list of sources used to generate this Common Product see PVC-free Resilient Flooring (homogeneous) (2019) Pharos. Available at: https://pharosproject.net/common-products/2180586#contents-panel (Accessed: 17 September 2020).

Many different base polymers may be used in PVC-free resilient flooring. Because the remainder of the contents was found to be similar (binders, pigments, etc.), they were combined into a single Common Product. Information on polyester flooring specifically includes content disclosure. See: Declare Label - Migrations BBT and Striations BBT with Diamond 10 Technology Coating (no date). Available at: *https://declare.living-future.org/products/migrations-bbt-and-striations-bbt-with-diamond-10-technology-coating* (Accessed: 17 September 2020).

^ Many other pigments may be used in specific products.

Annex B. A Company Case Story

Tarkett Case Story - Responsible Use of PVC in Floorings

(This case story was provided by Tarkett)

More than 10 years ago, Tarkett, a global floor coverings manufacturer, committed to transition towards a circular economy while caring for the people and the planet. To do so, the company chose to follow a holistic perspective based on Cradle to Cradle® principles – assessing and selecting good materials, eco-design products that are recyclable and effectively recycled, being a good steward of resources in operation, shifting to more renewable energy use and considering social equity in the value chain[1].

To overcome confidentiality and transparency concerns in the supply chain, material assessment was made in collaboration with suppliers and a third party assessor, the Environmental Protection and Encouragement Agency (EPEA). It has been Tarkett's approach since then. Risk assessment of materials used in products, down to 0.01% per product weight in formulations, is made according to chemicals regulations and the most relevant toxicology database. The screening and assessment of more than 5000 materials by the end of 2020[2] allowed Tarkett to develop a robust strategy for optimising material composition and substituting hazardous chemicals or groups of chemicals by safer alternatives ahead of regulatory change. Whereas hazardous plasticisers had been phased out in the late 1990s in the flooring industry, plasticisers containing phthalates are still authorised. Since 2010, Tarkett has been progressively replacing the entire phthalate group by alternative plasticizers approved for food contact or use in toys. In 2019, it was fully completed for its Europe Middle East & Africa region, including recycled content. The same material optimisation and substitution was made with heavy metal stabilisers and additives. Tarkett vinyl products do not contain biocides since 2013 and have low VOC emissions. On average today, homogenous floors contain 25% recycled PVC.

In addition, Tarkett transparently discloses the composition and risk assessment of its formulations on their web site in the form of Material Health Statements, third party verified by EPEA[3].

At the same time, Tarkett developed its own closed loop take back and recycling programme ReStart®[4], for post-industrial, post-installation or post-use waste and invested in five vinyl floors recycling plants globally. Moreover, post-use vinyl floors recycling is today made possible by the development of loose lay solution for vinyl rolls or click systems for modular vinyl floors LVT/WPC, avoiding the use of adhesives. A proprietary technology is in place since 2020 for cleaning post-use (glued) flooring backing from concrete and glue residues, allowing recycling of post-use phthalate-free homogenous flooring.

Mechanical recycling of its flooring waste is essential to reducing climate impact. Recycling 1 kg of iQ homogeneous vinyl installation waste saves 3.7 kg of CO_2. Recycling 1m² of iQ homogeneous vinyl post-use waste saves 9.8kg of CO_2[5].

Tackling climate change is a key consideration for eco-designing products and Tarkett is investigating further options for using bio-attributed PVC in its productions. IQ natural with bio-attributed vinyl, using mass balance principles was launched in 2020. It emits 60% less CO_2 eq emissions compared to average vinyl floors using fossil based PVC and plasticizers[6].

This example shows a responsible use of PVC is possible at industrial scale. Addressing material health and transparency is a prerequisite for developing closed loop collection and recycling technologies. PVC value chain has a role to play in climate mitigation, by enhancing the recycled content of PVC floors and the promising use of bio-attributed PVC as a substitute of PVC from fossil oil origin.

Source:

[1] https://media.tarkett-image.com/docs/BR_INT_CRADLE_TO_CRADLE.pdf

[2] CSR Report 2020: https://www.tarkett.com/sites/default/files/2020_CSR_Report_EN.pdf

[3] https://media.tarkett-image.com/docs/EMEA_WP_Material_transparency.pdf

[4] https://media.tarkett-image.com/docs/BR_INT_ReStart.pdf

[5] Based on IVL Methodology Report 2021 U 6450 Avoided greenhouse gas emissions by recycling of flooring materials Data from Tarkett EPD S-P-01346 (https://www.environdec.com/) and ERFMI generic EPD ERF-20180176-CCI1-EN (https://ibu-epd.com/veroeffentlichte-epds/

[6] https://professionals.tarkett.com/en_EU/collection-C000124-iq-natural

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This case study on flooring was developed to provide input to and inform the development of general considerations for design of sustainable plastics from a chemical perspective. Four case studies were developed as concrete examples and included two in the plastic packaging sector (biscuit wrappers and detergent bottles) and two in the construction sector (flooring and insulation). For this purpose, the case studies start from the premise that plastic material will be used and therefore alternative material selection is not considered. They identify the key considerations regarding environmental/health sustainability that should be examined along the product life cycle when chemicals are selected at the design stage, as well as the potential trade-offs between these considerations.

The examples of material selection within the case studies are developed in the context of the information gathered for the case studies to exemplify the sustainable design process and to highlight key considerations. To make actual decisions about material selection other factors would also need to be considered and the analysis could be further informed by elements such as life cycle assessment comparing alternatives and a full review of regulatory restrictions.

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