HEALTH CARE RESEARCH COLLABORATIVE



Resilient Flooring & Chemical Hazards

A Comparative Analysis of Vinyl and Other Alternatives for Health Care

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Health Care Without Harm has initiated a research collaborative coordinated by faculty of the University of Illinois at Chicago School of Public Health, with support from the Pioneer Portfolio of the Robert Wood Johnson Foundation aimed at stimulating collaborative research around health and safety improvements in health care. This collaborative is designed to increase the evidence base concerning the human health and environmental impacts of materials, products and practices within health care. In partnership with the Global Health and Safety Initiative (GHSI), the Research Collaborative is engaged in research directed at the intersection of environmental, patient, and worker safety issues related to building and operating health care institutions.

This paper is part of series in which the Collaborative will provide research and analysis of the health and environmental impacts of select groups of this new generation of materials and facilitate sharing of experiences on installation, maintenance and performance.

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EXECUTIVE SUMMARY

With the rapid growth of interest in green building, innovative building products are entering the health care marketplace on a continuing basis. As health care facilities evaluate these materials for installation in new and renovated health care facilities, they are searching for better information about the real impact these materials have on health and the environment.

In an effort to help address this need, Health Care Without Harm (HCWH) has initiated a Research Collaborative coordinated by faculty of the University of Illinois at Chicago School of Public Health, with support from the Pioneer Portfolio of the Robert Wood Johnson Foundation. This collaborative is designed to increase the evidence base concerning the human health and environmental impacts of materials, products and practices within health care. In partnership with the Global Health and Safety Initiative (GHSI), the Research Collaborative is particularly interested in research directed at the intersection of environmental, patient, and worker safety issues related to building and operating health care institutions.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care is the first in a series of papers in which the Collaborative will provide research and analysis of the health and environmental impacts of select groups of this new generation of materials and facilitate sharing of experiences on installation, maintenance and performance.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care addresses resilient flooring, evaluating potential health impacts of vinyl flooring and the leading alternatives – synthetic rubber, polyolefin and linoleum — currently in the health care marketplace. The study inventories chemicals incorporated as contents in each of the four material types or involved in their life cycle as feedstocks, intermediary chemicals, or emissions. It then characterizes those chemicals using a chemical hazard-based framework that addresses:

- persistence & bioaccumulation;
- human toxicity; and
- human exposure.

The framework utilizes authoritative chemical hazard lists to rank chemicals based upon the types of hazards that they present and the confidence levels of the science behind the assessments, with priority focus on persistent bioaccumulative toxicants (PBTs) and carcinogens, mutagens or reproductive toxicants (CMRs). The authoritative hazard list approach in some cases is supplemented by reference to emerging science that has not yet been reflected in the lists. This paper also reviews the state of the use of recycled or biobased materials in resilient flooring products and their design for recycling or composting at the end of their useful life and how that could reduce – or exacerbate – chemical hazards.

Patient and staff safety issues affected by performance of the products, such as slip-fall safety, are beyond the scope of this study but will be addressed in future studies in this series.

All three of the petrochemical plastic-based materials studied (vinyl, synthetic rubber & polyolefin) have a common heritage of problems with PBTs and CMRs that are released from drilling and refining operations. The analysis in this paper focuses on the issues that distinguish them in manufacturing and beyond once the petroleum has been extracted and refined.

- **Vinyl** flooring (both sheet and VCT) made from polyvinyl chloride (PVC) has the most pervasive presence of unavoidable persistent bioaccumulative toxicants (PBTs) in its life cycle of the four examined materials. It earns worst in class status due to its dioxin by-products and several other PBTs of concern. Vinyl also has significant user and manufacturing exposure issues associated with chemical additives used in manufacture, including phthalates, heavy metals, and other carcinogens and reproductive and developmental toxicants that are required for its performance characteristics.
- **Synthetic rubber** flooring is an improvement over PVC but still heavily laden with hazards. Like PVC, its manufacture includes a substantial amount of PBTs, but there is more potential to remove PBTs through reformulation than is achievable with PVC.

Still, the primary compound used in synthetic rubber – styrene butadiene – is dependent upon two carcinogen feedstocks, leaving it also with unavoidable serious High Hazard chemicals in its life cycle. Rubber flooring materials trigger concerns with toxic contaminants in the manufacturing process, as well as in the final product, including the use of hazardous flame retardants. Use of recycled rubber flooring may also raise concern because of its potentially high toxic content.

- **Polyolefins** appear to be a more significant improvement over PVC in relative hazard. The specific product we studied has only one with one known PBT problem with a potential decomposition product (other than those associated with petroleum refining). The only known user exposure issues were low level VOC issues (shared by the other materials.) An important caveat to the analysis, however, is that research into the polyolefin material was somewhat hampered by the lack of emissions release data normally available in the U.S. Analysis of available information about manufacturing processes uncovered only one carcinogen (formaldehyde), which may be eliminated through reformulation. The most significant integral hazard identified in association with polyolefins, is the possibility that ethylene – a major feedstock for all of the petroleum based flooring types – may be metabolized into a carcinogen and reproductive toxicant.
- **Linoleum**, the only material reviewed containing biobased content, receives relatively good marks for both current hazard and potential for further improvement. The linoleum life cycle has potential PBT problems from the pesticides used in growing the flax feedstock. Some manufacturers are already working to eliminate these by encouraging organic farming techniques. Linoleum has had some significant user exposure problems with VOCs, but manufacturers are learning to manage those challenges through product redesign. Some linoleum feedstock materials are manufactured with High Concern process chemicals. However, none of these are integral to linoleum's performance and there appear to be reformulation or redesign options that permit elimination of each problematic chemical. Because most of the linoleum used in the U.S. is manufactured overseas, limited information was available on manufacturing process emissions.

It is important to note that in each category, manufacturers produce products which meet the most stringent current indoor air quality standards, but still present some potential user exposure problems. This is because the standards do not cover many of the compounds discussed here and the VOCs they do measure may be individually present in levels below the standard thresholds but still may be problematic in combination.

There are significant differences in the recycled content used in products with the materials studied, but virtually none of the products contain significant quantities of post-consumer content. Furthermore, the products with the most recycled or biobased content today still have significant toxic issues associated with those processes. There is plenty of need for specifiers and purchasers to encourage manufacturers to increase use of renewable materials that are free of PBTs and CMRs and to design for end of life recycling or composting. None of the resilient flooring manufacturers utilizing the materials reviewed are close to closing the loop of material flow through recycling or composting for a significant percentage of their production. In this area there are however, also significant differences between the materials, both in current practice and future potential.

All of the material types have demonstrated the potential to be recycled (or in the case of linoleum, composted), but all face similar challenges in dealing with the adhesives used for securing the product to the floor and in collecting and transporting product at the end of its life back to the manufacturing facilities. All of the petrochemical materials also have the inherent limitation that, due to wide variation in chemical composition of additives, they cannot be mixed for recycling with other materials even of the same plastic type, except for downcycling into lower grade products. Linoleum may have the highest potential here since it can be composted with other materials if the adhesive issue can be resolved.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care indicates that, as currently produced, no resilient flooring option commonly used in health care is perfectly hazard free. The material types vary considerably in the amount, extent, and exposure to PBTs and other chemicals of concern that are involved in each material's life cycle and in the potential for future improvement.

There are many opportunities for specifiers and purchasers to encourage manufacturers to reduce or eliminate the use and production of PBTs and chemicals of High Concern, primarily in the linoleum and polyolefin alternatives. With encouragement from the marketplace, some resilient flooring manufacturers can readily reformulate their products to virtually eliminate the PBTs and CMRs from manufacture, use and disposal. Specifiers and purchasers can also call for greater use of renewable feedstock materials and recycling or improved end of life management.

While no ideal "green" material currently exists for health care flooring options, *Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care* illustrates the existence of a range of alternative materials which are preferable to sheet and tile products made with PVC – posing fewer chemical hazards in their current formulations and having more potential for further improvement. Yet, hundreds of health care organizations continue to source PVC-based products for their facilities. Lack of information about performance, lack of experience in cleaning and maintenance, and the slow pace of change in the health care industry all contribute to slowing the transformation of the industry to source safer alternatives.

Future papers are anticipated in this series to address resilient flooring product cost, durability and performance issues, acoustics, installation and maintenance chemicals (adhesives, sealants, other post-installation finishes, and cleaning chemicals) and other patient/staff health and safety issues affected by physical performance, rather than by chemical content, such as glare, fatigue, traction and slip-fall injuries. Likewise, this analysis will be extended to other flooring product types, including more newly developed synthetic polyethylene-based materials and other traditional materials such as terrazzo and cork.

Many health care systems, including those profiled in this study, are effectively specifying and using the alternative materials in new and renovated health care facilities. Capturing and reporting on the experiences facilities have with these new materials and broadly sharing this information may assist in both wider adoption and product innovation.

With greater awareness of the health issues associated with the materials in resilient flooring products and the products required to install and maintain them, health care organizations and designers can make more informed decisions and collectively help move the market by their specifications and purchasing power. In turn this can reduce the hazardous chemicals introduced into interior environments by the building materials and promote a healthier healing environment.

I. INTRODUCTION

Resilient flooring is a popular choice for floor covering in health care facilities, due to durability, ease of cleaning and routine maintenance, low cost, comfort, and the broad range of available designs. Resilient flooring manufacturers use a range of feedstock materials to make their products: from synthetic petrochemical-based polymers including vinyl, rubber and polyolefin, to natural materials such as natural rubber and linoleum. The products come in roll, tile and plank forms. Until the 1950s, resilient flooring was primarily made from linoleum (typically comprised of wood flour, linseed oil, and rosin). Technological improvements, coupled with falling petrochemical prices, drove the rapid adoption of vinyl floors in the 1960s, replacing linoleum as the predominant resilient floor covering in health care applications. As petrochemical products gained market prevalence, more durable wax coatings were developed to improve wearability and appearance in high traffic areas. By 1970, vinyl sheet and tile flooring products, maintained through rigorous wax and strip protocols, were unchallenged in health care interiors. Moreover, vinyl was marketed and positioned as a "modern material," an appropriate choice for the emerging technologically sophisticated hospital building.

Two important design trends have coalesced to open up new markets for alternative resilient materials: an interest in products and materials that connect building occupants to nature in health care settings, and concerns over potential negative health impacts linked to the polyvinyl chloride (PVC) in vinyl sheet and vinyl composite tile (VCT) flooring products. As a result, the market has developed new products and reintroduced older traditional ones. While scientists have scrutinized PVC and continue to identify the health issues associated with the material, researchers have paid much less attention to the presumed "healthier" alternatives.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care defines a chemical hazard-based framework to assess health impacts associated with materials used in building products. It uses the framework to comparatively assess the materials most frequently used in health care flooring products today. The framework addresses chemical hazard based upon three sets of characteristics: persistence & bioaccumulation, human toxicity, and exposure. The paper focuses on the chemical hazards in the life cycle of the flooring materials from production, to user exposure, to end of life (hazards from associated installation and cleaning products will be addressed in a future paper). This study also reviews the state of the use of recycled or biobased materials in these products and their design for recycling or composting at the end of their useful life and how that could reduce – or exacerbate – chemical hazards.

This paper compares three widely used resilient flooring product material types to PVC-based sheet vinyl: rubber (primarily styrene butadiene rubber or SBR), one of the new polyolefins (Amtico's Stratica), and linoleum. In the appendix, it surveys other comparative studies of these flooring types, which have included assessments of health impacts. Finally, it includes case studies from four health care systems that have installed three of the alternative material types.

Future papers are anticipated in this series to address cost and performance issues, installation and maintenance chemicals (adhesives and sealants, post-installation finishes, and cleaning chemicals) and patient/staff health and safety issues affected by performance of the products rather than chemical content, such as glare, fatigue, traction and slip-fall injuries. We also intend to study other flooring product types, including more newly developed synthetic polyethylene-based materials and other traditional materials such as terrazzo, and cork. Although generally not considered appropriate for hospitals, these materials are beginning to be specified in medical office buildings (MOBs) and other health care facilities with less demanding requirements.

II. DESCRIPTION OF THE ANALYSIS

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care addresses environmental health impacts of materials through a hazard-based analysis. In the analysis, we identify chemicals associated with the material throughout its life cycle: those that are used in each stage of manufacturing, those present in the final product, and those emitted during use or at the end of the life of the product.

Principles

The hazard analysis is grounded in a series of related principles:

The ***Hierarchy of Controls*** is a generally recognized set of principles for addressing hazards developed in occupational health studies that places elimination of hazard above management and protection. The hierarchy can be represented as:

- Elimination
- Substitution
- Engineering controls
- Administrative controls
- Personal protective equipment

Elimination and substitution are inherently safer and hence the most effective at reducing hazard, while administrative controls and protective equipment are the least effective and most prone to failure through human error. Additionally, while frequently cheaper in the short run, controls and protective equipment tend to be more expensive over time.[1]

The ***Pollution Prevention*** principle has applied this same hierarchical approach to environmental damage and public health, encouraging exploration of alternatives and substituting hazardous chemicals with safer ones. The U.S. Environmental Protection Agency's (EPA) Pollution Prevention Act of 1990 places pollution prevention – that is, avoiding the processes that create pollution – as a higher priority than efforts to capture and store or treat pollution.[2]

The process of managing hazard is frequently challenged by the lack of complete health and ecological toxicity information on the bulk of chemicals currently in commerce. Furthermore, available information may be conflicting. Scientists address this uncertainty by evaluating the "**Weight of the Evidence**" to seek patterns indicating likely outcomes.

These uncertainties are then addressed in the policy arena by application of the ***Precautionary Principle,*** which encourages "precautionary measures … when an activity raises threats of harm to the environment or human health, even if some cause and effect relationships are not fully established scientifically."[3]

Finally the principle of designing for a ***Closed-Loop System*** – also referred to as a "**cradle-to-cradle**" process – has long been considered important for slowing the depletion of global resources and reducing waste. At the end of life of a product in a closed-loop or cradle-to-cradle process, all of the material used in a product is cycled back – either through reuse, recycling or composting – to provide the material inputs to make the same product or one of equal performance and value.[4] This principle can have significant implications for chemical hazard as well as for waste and resource depletion. Highly toxic, and in some cases persistent bioaccumulative chemicals, are associated with the extraction and refining of petrochemical materials and, for some materials, with their disposal as well. Closing the loop can bypass the extraction and refining stage of the life cycle, as well as the disposal stage, and eliminate substantial chemical releases.

Priority issues for chemical policy

Chemical policy development under these principles has focused in recent decades on prioritizing various chemicals of concern for substitution with safer chemicals. When applied to material assessment, this prioritization focuses on three different groups of characteristics to inform substitution efforts:

- Persistence and bioaccumulation
- Toxicity
- Exposure

Persistence & bioaccumulation

Persistent and bioaccumulative chemicals resist breaking down into more benign substances and tend to accumulate in increasingly higher concentrations as the chemicals get passed up the food chain to humans (see box on "PBTs Creating Global Challenges"). Hazard reduction puts highest priority on elimination of the chemicals that are known to be the most persistent and/or bioaccumulative.

PBTs Creating Global Challenges

Persistent and bioaccumulative toxicants (PBTs) are particularly detrimental to human health and the environment. "Persistent" means that they do not break down rapidly in the environment and can last for months, even years, and sometimes decades.[5] Once emitted, some PBTs can travel long distances from their origins through air and water.[6 7]

In addition to being persistent, PBTs bioaccumulate; their concentrations build up in living organisms and biomagnify as they move up the food chain. Many PBTs are stored in fatty tissue, increasing their concentrations by orders of magnitude as they move up the food chain to humans at the top, becoming most concentrated in mothers' milk.

Lastly, but clearly of great concern to humans, is the fact that PBTs are toxic. They can cause cancer, gene mutations, or impair normal development or reproduction, among other adverse effects.

Because PBTs are often released into the environment and take long to degrade, significant concentrations of these toxicants are often found in wildlife and humans for prolonged periods of time. For example, PCBs have not been manufactured in the United States since the 1970s, yet detectable levels of PCBs still remain in humans more than 30 years later.[8] Twelve PBTs have been targeted for elimination by international treaty[9] and more are subject to action by national and international bodies,[10] the U.S. government[11], and in segments of the health care industry.[12] The highest priority PBTs are those referred to as Persistent Organic Pollutants (POPs), identified in the global Stockholm treaty.[13]

Halogenated organic compounds (containing a halogen such as chlorine, bromine or fluorine attached to carbon) are frequently targeted for special examination and elimination because, members of this class are often persistent, bioaccumulative, biologically available and can frequently lead to formation of high priority halogenated PBTs when manufactured or burned.

Toxicity

Along with PBTs, government[14] and health care policy makers[15] have prioritized avoidance of chemicals that are known **carcinogens**, **mutagens** or **developmental** or **reproductive** toxicants (known as CMRs), including **developmental neurotoxicants** (which affect the development of the brain or nervous system). **Endocrine disruptors** (which disturb the functioning of the body's endocrine system) are sometimes included in this top priority category because of their potential for disrupting normal development with lifelong consequences. Chemicals that cause other chronic or acute health effects, such as asthma, or are toxic to wildlife, often get next priority. Table 1 on the next page summarizes these chemical hazard criteria and the ranking that is utilized in this paper.

A wide range of governmental and non-governmental organizations publish authoritative chemical hazard lists. The assorted lists identify the types of hazards that various chemicals present and the confidence levels of the scientific data behind the assessments. Examples of these include: the Stockholm Convention on Persistent Organic Pollutants (POPs); the U.S. EPA National Waste Minimization Program, Priority Chemicals; the State of California's Proposition 65 list of Chemicals Known to the State to Cause Cancer or Reproductive Toxicity; and the U.S. National Toxicology Program's Report on Carcinogens. The Healthy Building Network (HBN) and Clean Production Action (CPA) have collaborated together to develop a hazard-based ranking of chemicals based upon these authoritative lists and the criteria discussed above. The ranking is designed to facilitate scoring of materials and prioritization of chemicals for substitution with safer alternatives. Appendix B: Chemical Hazard Lists, identifies and references key authoritative lists and categories used in this analysis and characterizes them on a ranking from moderate concern to very high concern.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care inventories chemicals that are used or created in the life cycle of the four materials commonly used in resilient flooring. It then screens those inventoried chemicals against the authoritative chemical hazard lists in Appendix B in order to identify which chemicals have been categorized as persistent bioaccumulative toxicants, carcinogens, mutagens, reproductive toxicants, developmental toxicants, neurotoxicants and aquatic toxicants from these lists. Appendix B includes Table 4, a listing of chemicals discussed in this analysis and cross referenced to the Appendix B authoritative lists upon which Table 4 is based. This list-based analysis is supplemented in some cases by reference to emerging science that has not yet been reflected in the lists.

The screening and ranking shares elements of the Green Screen for Safer Chemicals (Green Screen) analytic framework developed by CPA. The Green Screen utilizes an authoritative list screening and ranking procedure similar to that used in this paper. To the quick scan list-based chemical assessment, the Green Screen adds more detailed quantitative threshold-based assessments of toxicity to create a hierarchy of preferences for chemicals based upon their hazardous properties.[16] It then looks at where the chemical is located in the product life cycle and the resulting potential population exposures to determine preference. The Green Screen not only provides a system for avoidance of hazardous chemicals, but also provides an approach to identifying safer chemicals.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care focuses on the hazard end of the spectrum of preferable chemicals – identifying chemicals with known or suspected hazardous characteristics. As more chemicals are assessed against the Green Screen and tools like it, it will be possible to focus more on the preferable end of the spectrum, identifying truly safer chemicals that can be placed in the green Low Concern category, as identified in Table 1.

Table 1: Criteria for prioritizing chemicals based on persistence, bioaccumulation, health endpoints and confidence in the science

Very High Concern	**Persistent Organic Pollutants** (POPs) targeted in the Stockholm POPs treaty and other **Persistent Bioaccumulative Toxicants (PBTs)***	Highest priority to eliminate
High Concern	Known or likely **carcinogens, mutagens, reproductive** toxicants, **developmental** toxicants or **endocrine** disruptors.	
Moderate Concern	Significant possibility of above hazards but lower confidence *or* known or likely **neurotoxicants, respiratory** sensitizers or leading to **other chronic human or ecotoxicity** endpoints.	
Caution	Moderate concern for any of the above health endpoints *or* preliminary indications of higher concern but with inadequate test data or acute human health concern	Use with caution. Avoid where possible
Low Concern	Tested with low concern for any of the above endpoints**	Prefer

See Appendix B for explanation of criteria and how various chemical lists are ranked by these criteria.
* includes chemicals which are very persistent and bioaccumulative but toxicity is unknown.
** This paper reports on the chemicals that fall in the Moderate to Very High categories, not Caution or Low. Few authoritative lists yet identify chemicals for "Low" categorization.

Exposure

The ultimate goal of this analysis is to encourage the development of products made from materials that utilize chemicals lowest on the hazard spectrum considering usage and exposures at all stages of the product life cycle:

- ***Persistent exposures***: Materials that result in the release of PBTs to the environment from anywhere in the product life cycle – from the raw material extraction and refining, to the factory, to use, to the landfill – rank as "Very High Concern" in this framework because these PBT chemicals persist for long periods of time and so may continue to expose people in the vicinity long after their release. In some cases they can spread to affect people and wildlife over large distances, sometimes even globally.
- ***User exposures:*** Materials that contain toxic chemicals in their contents are of major concern because they expose installers and the occupants of the buildings in which they are installed to the chemicals' hazards associated with them. Products such as resilient flooring, which line the interiors of buildings, are of particular concern because of the large surface areas to which occupants are continuously exposed.
- Manufacturing exposures – worker and community: Every product has feedstocks and intermediaries – the chemicals used in the manufacturing process to make the final product contents – that do not appear on a product content list and may not directly affect users of the product, but may be High Concern chemicals and can pose serious hazards to workers and plant neighbors. Government and advocates have made great strides to improve occupational safety in the U.S. and companies have instituted more technological and administrative control systems, but workers are still exposed to many highly toxic chemicals that could be eliminated through substitution of safer chemicals. Likewise, despite grassroots community efforts to push manufacturers to reduce releases, millions of tons of toxic chemicals are still released every year into neighboring communities[17] – often minority communities already suffering health disparities without the added effects of unnecessary toxic releases into their yards, water, and air.[18]

  Some of the process chemicals that are supposed to be contained or completely transformed or eliminated in the manufacturing process (such as monomers, catalysts or cleaning agents) can instead unintentionally remain in the final product. The chemicals are residual and can result in exposures for users of the final product as well. Some of these chemicals may "off-gas" during or following installation as volatile organic compounds (VOCs). Most major manufacturers of flooring materials for the health care industry provide products that have passed any one of a number of independent indoor air quality (IAQ) certifications to validate that they have addressed IAQ impacts by designing the product for reduced VOC emissions (see box on "VOC Testing: Only Part of the User Exposure Story").

- ***Raw material extraction & refining:*** All three of the petrochemical plastic-based materials studied in this paper (PVC, SBR & polyolefin) have a common heritage of problems with PBTs that are released from drilling and refining operations. Drilling for the oil and gas from which plastics are made releases heavy metals, including cadmium and mercury, and a host of other high hazard chemicals such as furans, xylene, arsenic, chlorophenols, and polycyclic aromatic hydrocarbons into the environment. The hazardous releases continue at petroleum refineries, which emit lead, naphthalene, benzo(a) pyrene, and other toxic chemicals. This analysis does not address that stage of the life cycle of petrochemical plastics, as it is common to all of the plastics studied and so is not a distinguishing factor. Instead, the paper focuses on the issues that distinguish the petrochemical plastics in manufacturing and beyond. As biobased products are credited with positive value by avoiding the toxic releases of the petrochemical extraction stage, however, the study does note the potential for chemical releases in the production of biobased raw materials.

In assessing alternative materials for health care applications, it may be helpful to think about some of the key exposure issues that are relevant to decision making, including the list below. Given the wide variety of health care settings and applications of resilient flooring, it is important to recognize the distinctive and relevant characteristics:

- Will patients and/or staff be exposed to the chemicals released from the product during use? Are staff or patients potentially exposed to the chemicals during installation of the product? Can the risk of exposure be mitigated or eliminated?
- Will patients and/or staff be exposed to hazardous chemicals during routine maintenance and cleaning of the product?
- Have biomonitoring studies shown that the hazardous chemicals associated with the product are in our breast milk, blood, or urine? Have OSHA or other regulatory bodies set threshold limits or warnings for occupational exposure to chemicals involved in the manufacturing of the product?
- Are the manufacturing facilities releasing toxic chemicals into surrounding communities through air or water?

These are only a few of the questions that may be considered when evaluating and weighing exposure concerns.

Closing the Loop

Most of the resilient flooring products reviewed here use materials manufactured from petrochemicals, installed in a building for a single use, and then finally disposed of in an incinerator or landfill at the end of the product's useful life. Extracting fossil fuels from the ground is a process that results in release of a wide range of toxic materials, including PBTs, as noted above. The refining process common to all petrochemical materials is also burdened with a wide range of toxic chemicals. Then if the flooring product is incinerated, it may release more toxic chemicals as gaseous emissions in the burning process and as toxic waste in the fly ash that remains after the burn. Depositing the product in a landfill is also problematic, as chemicals from the product can leach into groundwater or materials may burn in highly polluting and relatively common landfill fires.

Manufacturers reduce the hazards in a product's life cycle by "closing the loop" – designing for manufacture from recycled materials and disposal through recycling back into new feedstock at the end of its life. This turns the one-way path of extraction, manufacture, use and disposal, into a continuous loop of reuse. Using recycled materials in a product can bypasses the toxic (and energy consuming) extraction and refining process needed to make new materials from virgin ores or fossil fuels. Recycling the product at the end of its life avoids generating waste and eliminates the toxic chemical releases at the incinerator or dump.

VOC Testing: Only Part of the User Exposure Story

Several certification programs address the indoor air quality (IAQ) impacts of resilient flooring products, including FloorScore,[19] GreenGuard[20] and the Collaborative for High Performance Schools (CHPS).[21] Each of these addresses the emissions of volatile organic compounds (VOCs) from flooring products and/or assemblies.

VOCs are chemicals that can evaporate into a gas at room temperature, such as toluene, acetaldehyde and formaldehyde. Many VOCs are toxic chemicals, some of which are listed on the chemical hazard lists used in this paper. For example toluene is a listed developmental toxicant.[22] Researchers have implicated them in sick building syndrome cases.[23] The certification programs noted above operate under a protocol that the State of California developed, often referred to as Section 01350.[24] The protocol describes a methodology for measuring the emissions from a sample of an interior finish product and then using modeling to predict the concentrations of the detected chemicals that would accumulate in a typical room or building using that product. To pass these tests, the modeled concentration needs to be less than half of reference levels the State of California has set for 80 of these VOC chemicals. Most of the major manufacturers of flooring products for the health care industry provide products that have passed one of the Section 01350-based certifications to validate that VOC emissions are at or below the State reference levels.

These programs provide important information about indoor air quality and user exposure, but they also have several limitations. It is important to note that the particular test used in these certification programs is not a comprehensive test of all potential exposure issues. Several important issues about the full effects of user exposure to these products are not addressed by any VOC emission program to date:

- The State of California has only established reference levels for 80 VOCs. Hundreds more VOCs are not addressed;
- The reference levels the State of California established only address non-cancer issues and do not necessarily provide protection against carcinogenic effects of these chemical emissions;
- The reference levels do not address the effects of two chemicals in combination, which may have synergistic effects far beyond the additive ones of the two VOCs individually;
- The tests do not measure the effects of sunlight, ozone or other chemicals that may increase or change the nature of emissions;[25]
- The tests only measure emissions of VOCs, not SVOCs (semi-volatile organic compounds) such as phthalates, perfluorinated compounds, and halogenated flame retardants, or heavy metals, like lead, that can migrate from the product by direct user contact or by attaching to dust and transporting into the breathing space; and
- Much of the science behind the setting of these standards is aimed at occupational exposures on middle-aged healthy workers. Newborns, children, elderly and otherwise vulnerable populations are not necessarily protected.

Results from these certification programs should be accompanied by additional screening for hazard chemical content as outlined in this paper to be fully protective of human health and to reduce or eliminate exposures.

It is important to note, however, that closed-loop recycling processes are no guarantee of a lower hazard result and must be approached with caution and scrutiny as toxic chemicals are sometimes used or released in the process of recycling. Another way material manufacturers can close the loop is by utilizing biobased materials and/or designing products to be composted back into nutrients for the agricultural cycle at the end of their life.

Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care addresses both ends of the product life cycle:

- **Renewable content:** Most of the leading manufacturers of the resilient flooring products reviewed claim to have developed processes to recycle their own production waste back into their manufacturing process. A smaller number have developed systems for using other manufacturers' waste material – what is called post-industrial recycling. Waste material from manufacturing processes is important to utilize to improve the efficiency of the use of raw materials, but it does not close the loop. It does not eliminate the waste that comes from the final disposal of the product nor does it end the need to extract more virgin ores and fossil fuels for raw materials. Only by using post-consumer recycled material – material derived from products at the end of their useful life – is the loop closed and extraction replaced. Therefore, post-consumer content is valued more highly in this analysis.

  Biobased material can also potentially reduce fossil fuel consumption, waste, and toxic chemical use and release. However, given the high dependence of modern agriculture on toxic chemicals and fossil fuels, the use of biobased materials does not necessarily reduce chemical hazards, unless steps are taken to improve the agricultural practices through which the feedstock is grown – i.e., by eliminating toxic pesticides, reducing fossil fuel energy use, and using soil conservation practices.

- **End of life:** To close the loop, a product must be designed so that it is capable of being recycled back into materials that can be used for similar grade products. Most current resilient flooring recycling does not meet this standard. Instead most materials are "downcycled" – recycled for use in a less demanding product. For example many carpet and resilient flooring recycling programs recycle the used material into things like traffic cones or, at best, into new carpet backing components. They continue to use virgin materials to make new resilient flooring products.

III. ASSESSING INDIVIDUAL MATERIALS

In the next sections, each material is assessed individually – vinyl, rubber, polyolefins and linoleum.

The investigation employs the analysis framework described above. The evaluation process includes the following steps: inventory the chemicals involved in the material's life cycle, identify the hazards the associated chemicals pose, assess the exposure pathways, identify opportunities to close the loop, and compare each of the alternatives to PVC. Table 2, on page 34, compiles the hazard assessment of the inventoried chemicals graphically by flooring material type. Table 3 on page 35 summarizes the chemical hazard strengths, weaknesses and potentials of each flooring material type by life cycle stage.

The analysis is primarily based upon literature studies of the content, process and health impacts associated with these flooring types generically – with only very limited data gathered from specific manufacturers. An exception is made in the case of the polyolefins, where the investigation focuses on one particular product as explained in that section. Individual manufacturers of each of these materials may use some chemical components that vary from the generic standards described here. Future work may focus on individual, manufacturer specific, product characteristics.

The analysis also focuses on the materials that make up the main body of the flooring product and does not address the polyurethane and polyacrylate coatings now being increasingly used to reduce maintenance and emissions in a variety of flooring products. Nor does it address the adhesives used to secure these products, which can have toxic properties as well. Future work under the Pharos Project[26] will study these same issues at a manufacturer and product specific level, providing opportunity to evaluate more individual product specific variations – such as coatings and adhesives – and to differentiate manufacturers who are exceeding (or not) the industry norms.

A. Vinyl flooring

Polyvinyl chloride (PVC, often called vinyl*) is the primary component of vinyl sheet goods and is the primary synthetic plastic ingredient in vinyl composition tile (VCT). The single largest component of VCT (often 80% or more of total content) is limestone filler.

First discovered in the 19th century, efforts to commercialize PVC began in the early 20th century but were initially stymied by its inherently rigid and brittle nature. The development in 1926 of plasticizers to make PVC more flexible opened the door to widespread applications across a broad spectrum of products and uses, from shock absorber seals and insulated wire to raincoat and shower curtain coatings.[27] The development of vinyl flooring from PVC followed quickly in 1933, but commercialization had to wait until after World War II when the production and use of PVC rapidly accelerated—gradually supplanting linoleum until the last U.S. linoleum plant closed in 1975.[28]

PVC is made by reacting ethylene (also called ethene and derived from petroleum or natural gas) with chlorine gas (made from the electrolysis of salt brine) to make ethylene dichloride (EDC). At high temperature and pressure, the EDC then is decomposed to make vinyl chloride monomer (VCM), which is then polymerized into long chains of molecules to make

* Not all compounds called "vinyl" are actually PVC. In chemistry, the term "vinyl" actually has a broader meaning, encompassing a range of different thermoplastic chemical compounds derived from ethylene. In addition to PVC, "vinyls" in building materials also can include: ethylene vinyl acetate (EVA, CAS #24937-78-8): a copolymer of ethylene and vinyl acetate, used in films, wire coating, carpet backing, and adhesives; polyethylene vinyl acetate (PEVA): EVA or a blend of polyethylene and EVA used in shower curtains and body bags; polyvinyl acetate (PVA or PVAc, CAS #93196-02-2): a polymer made from vinyl acetate monomer (VAM) used in paints and adhesives, such as white glue; and polyvinyl butyral (PVB, CAS #63148-65-2): used in safety glass films and recycled into carpet backing. For more, see PharosWiki article on vinyl at http://www.pharosproject.net/wiki/index.php?title=Vinyl.

PVC resin.[29] Many additional chemicals beyond those covered in this paper are used to facilitate the chemical reactions that go into the production of PVC, including catalysts to trigger chemical reactions, polymerization accelerants and stoppers, solvents, emulsifiers, antioxidants, surfactants, coupling agents, initiator agents, and modifiers, plus a wide range of additives that are used to give PVC resins different performance characteristics.

Vinyl sheet flooring is made by mixing PVC resins, plasticizers and stabilizers together with an azo compound that decomposes into nitrogen bubbles, making a foaming vinyl mixture. The foam is spread on a backing of felt, wood pulp or other plastics. A pattern is printed and then a second wear layer of PVC and plasticizer is layered over the foam base. Sometimes a polyurethane coating is applied on top to improve durability and reduce the need for waxing.

VCT is created by mixing calcium carbonate filler, vinyl resin binders (sometimes PVC is combined with a small amount of vinyl acetate), plasticizers, stabilizers and pigments into a dough-like mixture, pressing the mixture through rollers, and cutting it into tiles. In vinyl sheet goods, PVC resin is the single largest component, making up as much as 55% of the product, whereas in VCT, PVC may make up as little as 11% of the total product.[30]

Persistent exposures

PVC is referred to as a chlorinated plastic or a halogenated organic compound because it contains chlorine – one of the halogen elements – and carbon. Because of the chlorine/carbon combination, PVC's life cycle unavoidably produces dioxins, furans and other hazardous halogenated compounds.

PVC manufacturing creates dioxins. So, too, does the accidental or intentional burning of chlorinated plastic products. According to the U.S. EPA, the manufacture of PVC is one of the largest sources of dioxin and landfill fires are likely one of the largest sources of dioxin formation from any human activity. PVC and other chlorinated plastics are the leading contributors to dioxin releases from landfill fires (see Appendix C: PVC and Dioxin).

Dioxins are a family of PBT chemicals (including certain polychlorinated dibenzo dioxins (PCDDs),

polychlorinated dibenzo furans (PCDFs) and polychlorinated biphenyls (PCBs)) that are known potent carcinogens, reproductive/developmental toxicants, and endocrine disruptors.[31] Because of their extraordinary potency, they are one of the few chemical groups targeted by a global treaty – the Stockholm Convention on Persistent Organic Pollutants (POPs)[32] – and rank in the Very High Concern category of our framework. The need to reduce dioxin formation in health care was one of the drivers behind a landmark Memorandum of Understanding (MOU) between the American Hospital Association (AHA) and the U.S. EPA to coordinate efforts to minimize the production of PBT pollutants.[33] Health care's recognition of PVC's considerable role in dioxin generation due to its chlorine content has been an important factor in driving substitution efforts.[34]

PVC is, by far, the most widely sourced plastic polymer that uses chlorine in the United States, with 14 billion pounds per year produced in the U.S. alone.[35] The construction industry is responsible for more than 60% of worldwide PVC use.[36, *]

The chlorine content also gives PVC significant fire resistance, yet the plasticizers required to make it flexible significantly reduce its fire retarding properties. Thus many PVC products still contain flame retardants to meet fire safety standards.[37] Manufacturers use chlorinated paraffins as fire-retarding plasticizers for PVC flooring and wire sheathing.[38] The paraffins – as well as some of the other flame retardants used in PVC – are PBTs, aquatic toxicants and known carcinogens[39] (see box on "Flame Retardants: Saving & Risking Lives").

* Other chlorinated plastics used in building materials include: chlorinated polyethylene (CPE), chlorinated polyvinyl chloride (CPVC), chlorosulfonated polyethylene (CSPE), polychloroprene (CR or chloroprene rubber, also brand name Neoprene).

Flame Retardants: Saving & Risking Lives[40]

The high flammability of petrochemical plastics and other synthetic materials has led to the addition of chemical treatments to resilient flooring and other interior finishes to meet fire safety standards.

Halogenated flame retardants (HFRs), are often the chemical treatment of choice, including polybrominated diphenyl ethers (PBDEs) and chlorinated paraffins. Recent research, however, has raised concerns about the persistence and toxicity of many of these flame retardant chemicals.[41] Some flame retardants are now ubiquitous in the environment, including in remote areas such as the Arctic[42] and deep in the oceans.[43] Rapidly increasing levels have been measured in sediments, marine animals and humans indicating a significant potential for damage to ecological and human health. Halogenated flame retardants have been linked to thyroid disruption, reproductive and neurodevelopmental problems, immune suppression, and in some cases, cancer in animal studies.[44]

Scientists continue to investigate HFR exposure pathways in humans. What is known is that HFRs are released inadvertently during manufacture, emitted during use into household dust,[45] released in burning, or released in landfill at end of life, making their way into air, soil, food, waterways, wildlife, and humans. Biomonitoring shows that breast milk and other bodily fluids,[46] and our rivers, lakes and streams, contain high levels of some HFRs.[47]

Alternatives to HFRs need to be screened carefully as well. Both PVC and SBR frequently contain antimony trioxide as an alternative fire retardant. Antimony trioxide is a known carcinogen.[48]

The PVC manufacturing processes also generate a large number of highly toxic PBTs,[49] including polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB). PCBs and HCB are known carcinogens, endocrine disruptors and developmental toxicants targeted for elimination by the Stockholm convention.[50]

PVC production is a significant source of PBT heavy metals. Chlor-alkali plants that produce the chlorine gas for PVC production have been major sources of mercury emissions. Mercury is a potent developmental neurotoxicant, endocrine disruptor and aquatic toxicant.[51] In 2000, U.S. plants released 14 tons of mercury and were unable to account for another 65 tons of that year's consumption, making them one of the largest sources of mercury exposure in the environment.[52] More U.S. plants have converted to safer technologies in recent years, but six chlor-alkali plants in the U.S. still use mercury cell technology and a much larger number of similar plants still operate in Europe and the rest of the world.[53]

Other heavy metals are still used as additives in PVC products, including lead, cadmium and organotins, such as tributyltin. Lead is a carcinogen, endocrine disruptor and reproductive and neurodevelopmental toxicant.[54] Cadmium is a carcinogen, a developmental and reproductive toxicant and an aquatic toxicant.[55] Tributyltin is an endocrine disruptor.[56] While manufacturers claim to be replacing these compounds with safer alternatives, emissions continue (see below under manufacturing exposures). Finally, polycyclic aromatic compounds (PACs – known carcinogens[57]) also are byproducts of burning PVC.[58]

User exposures

To make PVC flexible and versatile, the plastics industry blends it with a wide range of additives. In addition to the PBT metals listed above, there are a variety of other High Concern chemicals used to provide PVC with its unique properties – most notably the phthalate plasticizers required to make it flexible. Many of these added chemicals do not permanently bind to PVC and will migrate out of PVC products into the air, soil, dust, water, and be inhaled or ingested by humans.[59] Plasticizers are not VOCs, so will not be evaluated by current standard indoor air quality tests (see box on "VOC Testing: Only Part of the User Exposure Story"), but are increasingly being detected in both dust studies[60] and biomonitoring of humans.[61]

Flooring manufacturers add a variety of phthalate plasticizers to PVC to give it flexibility. The most commonly used phthalates in vinyl flooring[62] include three that are endocrine disruptors and reproductive or developmental toxicants:[63] butyl benzyl phthalate (BBP or BzBP),[64] di(2-ethylhexyl) phthalate (DEHP),[65] and di-n-hexyl phthalate (DnHP).[66] Emerging evidence also links phthalates in PVC interior materials to respiratory problems such as rhinitis and asthma,[67, 68, 69, 70] obesity, and insulin resistance.[71] Phthalate plasticizers typically comprise four percent of the total mass of vinyl composition tiles[72] and 20% or more of the mass of vinyl sheet flooring.[73]

PVC production uses the vast majority of phthalates in the United States.[74] The health concerns with phthalate plasticizers have helped accelerate the health care industry's efforts to eliminate PVC from medical products, such as IV bags and tubing, and have informed the broader building movement's effort to avoid PVC in building materials.

Manufacturers also add a variety of pigments in all of the floorings studied in this analysis, some of which can be highly toxic (see box on "Pigments Can Be Toxic").

Pigments Can Be Toxic

All of the flooring materials studied — vinyl, rubber, polyolefins, and linoleum — share common problems associated with certain pigments added for coloration. For example, carbon black and titanium dioxide are used as flooring pigments and to add other physical properties to the materials. Carbon black is a possible carcinogen[75] when inhaled as dust. Likewise, titanium dioxide is a possible carcinogen[76] through inhalation of fine dust. Toxic pigments such as carbon black and titanium dioxide will be of most concern for user exposure if they are in the surface layer of the flooring product and more prone to being worn off by abrasion and released into dust.

The wax and strip maintenance cycle necessary to keep vinyl sheet and tile good surfaces durable and shiny has long been a source of health concern due to the toxic VOCs such as formaldehyde (a known carcinogen) used in the maintenance products and particulates generated in the process.[77] A life cycle study of flooring installation and maintenance found that the amount of VOCs emitted from a single waxing of a floor may be comparable to the amount of VOCs emitted from the flooring itself over its entire life.[78] Several PVC manufacturers have formulated "no wax" finishes for some of their flooring products, but the issue remains a strong driver toward alternative flooring material.

Manufacturing exposures

PVC manufacturing utilizes many highly toxic chemicals as primary ingredients.

Ethylene is a likely neurotoxicant[79] and there are preliminary indications that it may be metabolized into ethylene oxide, a known carcinogen and reproductive toxicant.[80]

The chlorine gas that is used to react with ethylene is an aquatic toxicant and highly acute toxic gas[81] and a terrorist attack concern.[82] But of even higher concern are the chemicals at the next steps in production: ethylene dichloride (EDC) is a likely carcinogen[83] and vinyl chloride monomer (VCM) is a known carcinogen as well as a neurotoxicant.[84]

The PBTs and additives listed above are potentially problematic in the manufacturing facilities for workers and for residents in neighboring communities. In addition to the PBTs described above that are released in the production of PVC itself, vinyl flooring manufacturers recently reported releases of airborne phthalates, 1,1,1-trichloroethane (likely neurotoxicant and ozone depletor[85]), zinc and acrylic acid (both aquatic toxicants[86]), vinyl acetate (a suspected carcinogen[87]), and a variety of other VOCs and solvents. Vinyl flooring manufacturers claim that lead compounds are no longer used as stabilizers in their products, but significant releases of these carcinogens and neurotoxicants[88] continue from several plants – over 1,000 pounds from one plant alone in the year 2006.[89]

Renewable content

Most vinyl resilient flooring for health care applications uses no or only a very small amount (<5%) of recycled content, which is almost entirely post-industrial material content used as filler, rather than as a replacement for the PVC. While there are a few products claiming higher recycled content, it is almost entirely post-industrial waste that is being recycled.[90] When a new PVC floor comes to market, the majority of the product is made from virgin PVC. Recycling of post-consumer material is challenging for PVC – as it is for some of the other polymers reviewed here – because of the many different additive blends that change performance characteristics in vinyl products. This review found no biobased content incorporated into any vinyl flooring products nor any potential for replacing any significant part of vinyl chemistry directly with biobased materials.

End of life

The vinyl industry has aggressively marketed its efforts to recycle PVC, but has accomplished only limited recycling of post-industrial content – primarily its own production scraps. While PVC is technically recyclable, the multitude of additives used in different combinations in each product required to make PVC useful have made large scale post-consumer recycling nearly impossible for most products. Of an estimated 2.9 billion pounds of PVC discarded in the U.S. in 1999,[91] only 18 million pounds – just over 1/2 of one percent – was recycled.[92] Furthermore, the presence of PVC can interfere with the recycling of other plastics. The Association of Post-Consumer Plastics Recyclers declared efforts to recycle PVC a failure and labeled it a contaminant in 1998.[93]

B. Rubber flooring

Natural rubber from the sap of plants was a material of choice for hundreds of years for many products requiring durability, resilience and elasticity. In fact, the first resilient flooring was made from natural rubber sometime in the 12^{th} or 13^{th} century.[94] Supply problems during World Wars I and II led to the development of synthetic replacements for natural rubber.[95] Styrene butadiene rubber, known as SBR, was the first mass produced synthetic rubber, developed by chemists at I.G. Farbendustrie AG of Germany in 1929.[96] Synthetic rubber now meets more than 70% of global rubber demand.[97]

SBR is manufactured from styrene and 1,3-butadiene. 1,3-butadiene is a gas derived from petroleum, produced as a byproduct of ethylene production and extracted using solvents such as acrylonitrile or dimethylformamide. Styrene is made from ethylbenzene, which is in turn made from ethylene and benzene, also a petroleum product. As with PVC, a wide range of chemicals are involved as intermediates and additives in the manufacture of SBR including catalysts, polymerization accelerants and stoppers, solvents, emulsifiers, antioxidants, surfactants, coupling agents, initiator agents, and modifiers.

CASE STUDY

Brigham & Women and Nora Rubber

As early as 2000 when Rick Bass, Director of Environmental Services, began working at Brigham and Women's Hospital (BWH), he identified issues with vinyl flooring, in particular the high costs and health effects associated with care and maintenance of VCT. The frequent stripping and waxing of VCT floors, not to mention the toxic properties of the chemicals to undertake the activity, had led him to investigate alternatives that would perform equal to, if not better, than VCT without the accompanying negative aspects. Nursing staff exposed to the odors associated with the VCT cleaning products, even the low VOC products in use, identified health issues associated with the chemicals. Moreover, as a hospital with a normal occupancy approaching 100%, BWH was finding it challenging to maintain the VCT, which required vacating entire units, erecting plastic barriers, and increasing filtration during the VCT refinishing regimen.

Brigham and Women's Hospital - Surgery Center; Nora Rubber Flooring; Photo by: Tyrone Turner; Courtesy of: Robert Wood Johnson Foundation

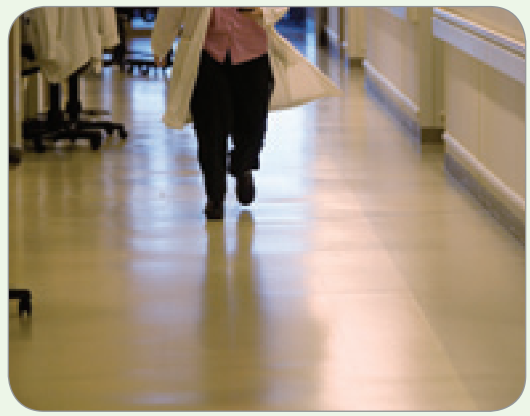
Noting that most hospitals install rubber flooring in their stairwells in order to avoid the need for waxing or buffing while maintaining required slip resistance, he thought the product might warrant investigation as to its application in other areas of the hospital. The opportunity to look at rubber flooring for broader application arose when BWH was renovating an entire floor of its main tower in 2004. The floor included an Intensive Care Unit (ICU), which would benefit from no wax, no buff floors, particularly due to the sensitivities of ICU patients as well as the needs of staff. Bass knew that some Operating Rooms in BWH were using rubber or linoleum floors, so he looked to the experience with those units to evaluate the potential for using rubber flooring in the ICU. Based on his evaluation, as well as manufacturer presentations, BWH installed Nora rubber flooring on one complete floor of its main hospital tower (approximately 18,000 sq. ft.).

At approximately the same time, the BWH Planning and Construction team set out to specify materials for the new Carl J. and Ruth Shapiro Cardiovascular Center (Shapiro). They built upon the positive experience with the ICU pilot to specify resilient flooring for Shapiro. The team was led by a commitment from BWH leadership to achieve LEED silver certification. As a hospital running 24/7, BWH found accomplishing LEED Silver challenging, with very few energy reduction credits available due to the building's intensive energy usage. To achieve LEED silver requirements, the team looked to innovative credits within the LEED rating system, and focused on attaining as many of the other points available as possible – including the reusable materials points.

Bass informed senior management that if VCT was specified for Shapiro, as many as 5 additional full-time equivalent employees would be required for VCT maintenance. Moreover, the BWH Department of Environmental Affairs expressed concerns regarding storing additional chemicals for VCT maintenance, chemicals that raised concerns relative to indoor air quality in the hospital. With 350,000 square feet of flooring to be specified – approximately 250,000 square feet of it resilient flooring — and the opportunity to put down a no wax, no buff, rubber floor, "the decision really made itself," said Joe O'Farrell, Senior Project Manager at BWH.

In 2008, the team installed approximately 250,000 square feet of Norament rubber flooring in Shapiro. The team has found that the rubber floors perform far better than VCT. They knew that rubber flooring would be easier to maintain—added benefits include fewer color aberrations and no shrinkage. The challenge for them with the rubber flooring was the labor costs associated with installation. The rubber flooring requires more smooth subflooring and precise adhesion in addition to longer cure time, so the floor prep was quite labor intensive. They initially had some problems with bubbling, but those issues have been mitigated as the installers have gained expertise in installing the flooring.

BWH has received feedback from clinicians and others associated with the hospital that the floors are more comfortable, reduce noise, and release "no smell." Some patients and staff miss the "shine" associated with VCT, commenting that the dull luster of rubber makes it appear less clean than VCT. BWH's response has been to educate staff to the differences between appearance and maintenance of the two products, and those perceptions are lessening. While it's only been in place at Shapiro since July 2008, the experience with Nora floors has led BWH to consider rubber flooring as the hospital resilient flooring standard for all major projects going forward.



Brigham and Women's Hospital - Surgery Center; Nora Rubber Flooring; Photo by: Tyrone Turner; Courtesy of: Robert Wood Johnson Foundation

About Brigham and Women's Hospital: Brigham and Women's Hospital is a 777 bed nonprofit teaching affiliate of Harvard Medical School and a founding member of Partners HealthCare. The Carl J. and Ruth Shapiro Cardiovascular Center is a 136-bed facility that is anticipating LEED silver certification by spring 2009 and is one of the most advanced cardiovascular care facilities in the world for patients and their families.

SBR has now been joined by more than 20 other synthetic rubber formulations including polybutadiene, ethylene propylene (EPDM), acrylonitrile-butadiene (NBR, also called nitrile rubber), polychloroprene (also called neoprene), synthetic (rather than natural) polyisoprene, silicone, and ethylene vinyl acetate (EVA). Natural rubber is still used as a component in some health care flooring products, but generally comprises only a small fraction of the total content of rubber flooring materials. SBR is far and away the most prevalent of the rubber materials now in use for resilient flooring,[98] with annual global production of over 13 million metric tons, growing at 5-7% per year[99] and is the focus of this analysis.

Persistent exposures

With no chlorine content, SBR is not a significant source of dioxins.* SBR plants do, however, release significant amounts of other PBTs,[100] including lead,[101] mercury,[102] benzo(g,h,I)perylene[103] and other polycyclic aromatic compounds (PACs) which are carcinogens.[104] Additionally, chlorinated paraffins, decaBDE and other flame retardants used as additives in SBR and other rubber products may include PBTs, known carcinogens, endocrine disruptors and aquatic toxicants[105] (see box on "Flame Retardants: Saving & Risking Lives").

User exposures

The flame retardants referred to above remain in the final product, creating a significant user exposure concern with rubber flooring.

Some testing has indicated residuals of styrene (possible carcinogen and likely neurotoxicant and endocrine disruptor[106]) from manufacturing in rubber flooring products. Several SBR flooring products that health care organizations use have passed emissions testing, but concerns remain about the aggregate effects of the range of VOCs that are emitted by these floors despite the fact that each chemical individually tests below VOC threshold standards. In some instances, the industry has not yet established threshold standards for some of the chemicals (see box on "Indoor Air Quality Problems with Recycled Rubber Floors").

* Unlike SBR, neoprene rubber (polychloroprene), another synthetic rubber, is a chlorinated plastic and is a potential source of dioxin when burned.

CASE STUDY

St. Joseph and Mondo and Nora Rubber, Stratica Polyolefin and Forbo Linoleum

Approximately four years ago, St. Joseph Health System (SJHS) decided to move to PVC-free interior finishes. This was decided as part of their goal to provide healing environments with improved air quality standards for their patients.

Unlike other large health systems that hire architect and design firms to specify their materials, SJHS specifies all its interior finishes through their corporate office, coordinated by the Director of Interior Design and Space Planning, Dawn Fredrick-Seibert. Ms. Fredrick-Seibert is committed to specifying products that are safe for patients, staff, and the environment and engaged an interior design consultant to research healthier materials to find replacements for PVC.

As part of their PVC-free commitment, SJHS searched for alternatives to the vinyl sheet goods and VCT flooring they used throughout their many hospitals. SJHS had already been using rubber flooring in the Operating Room environment in order to meet the code requirements. In their Operating Room experiences they found that the rubber flooring did not require wax or any other surface finish, which both improved air quality and decreased maintenance costs.

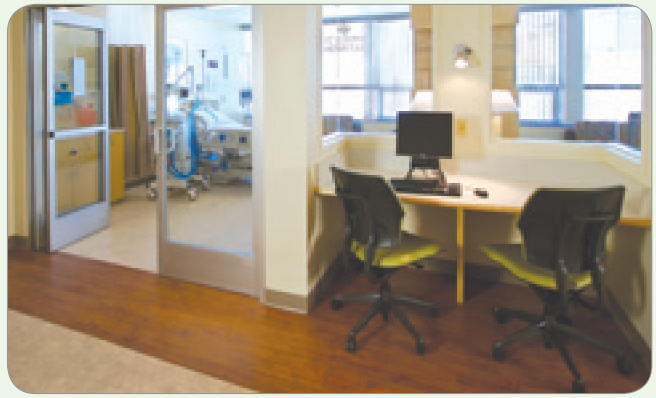
Queen of the Valley Medical Center - Surgery Center; Mondo Rubber Flooring; Photo by: Solar Eye Communications

St. Joseph's Hospital in Orange County, California undertook renovation projects to test rubber flooring in other contexts. The design team and user groups evaluated the rubber products in use at St Joseph's and found that they met the clean air, care and maintenance requirements.

Based on the results of that test, SJHS made the decision to stop sourcing vinyl and VCT and have not installed a single project using PVC since. For major renovations, the system will take the opportunity to go into a facility and strip out the VCT and replace it with healthier alternatives whenever the budget allows. For new construction, the additional capital cost associated with non-vinyl flooring is built into a project from the very beginning.

St. Joseph Hospital; Patient Care Center - Operating Room; Nora Rubber Flooring; Photo by: Solar Eye Communications

Each of the alternative materials discussed in this paper are now used in different situations in SJHS hospitals, including Nora Rubber and Mondo Rubber. SJHS Queen of the Valley Hospital in Napa Valley chose Mondo rubber sheet goods for use in its operating rooms and Stratica and Forbo Marmoleum linoleum in other areas of the hospital. System users are satisfied with the flooring products, the strongest attribute being a wax and finish free flooring system. The room turn over rate has vastly improved.



St. Joseph Hospital; Patient Care Center - ICU Patient Room; Nora Rubber, Stratica, and Forbo Linoleum

About St. Joseph Health System:
Founded in 1982, St. Joseph Health System is a not-for-profit Catholic health care system with facilities in Northern and Southern California, as well as West Texas and Eastern New Mexico. St. Joseph operates 14 hospitals, 3 home health agencies, and multiple physician groups. For fiscal year 2007, St. Joseph had net revenues of $3.69 billion.

Some SBR manufacturers have historically used mercury as a catalyst to trigger chemical reactions in the manufacturing process. In fact, regulators have measured mercury emissions from some older rubber floors.[107] The extent of current mercury catalyst use in the industry and residuals in newer products is not known, but at least two SBR manufacturers are continuing to release mercury from their manufacturing processes, as indicated by 2006 Toxic Release Inventory (TRI) emissions reports.[108]

Some flooring users have raised concern about latex allergies associated with rubber floors. Most rubber flooring is not, however, expected to trigger latex allergies simply because there is so little natural rubber in the products. The primary component of rubber flooring is synthetic rubber, made from different compounds than the proteins in natural latex rubber that trigger allergies. Manufacturers assert that the allergenic latex proteins in natural rubbers are totally destroyed in the vulcanization process, though no independent testing sources were identified to confirm this.

Manufacturing exposures

SBR plants in the U.S. report major releases of other highly toxic chemicals from their processes, in addition to the PBT releases referred to above.[109] Combined TRI reports for the seven U.S. SBR manufacturing plants show releases of almost 2,000 tons of TRI chemicals annually from those plants.[110]

Over 1.4 million pounds of 1,3-butadiene are released annually to the atmosphere from petroleum refineries and manufacturers of 1,3-butadiene, plastic resins, and synthetic rubber.[111] 1,3-butadiene is a carcinogen and reproductive & developmental toxicant.[112] Studies associate considerable risks with 1,3-butadiene exposures in synthetic rubber factories. Research published in 2007 found an association between leukemia rates for synthetic rubber workers and 1,3-butadiene exposures, independent of other chemical exposures.[113] Earlier studies correlated 1,3-butadiene workplace exposures to increased mortality from arteriosclerotic heart disease.[114]

In 2006, SBR manufacturers reported releases of 778,000 pounds of styrene[115] (a carcinogen and neurotoxicant[116]). Other chemicals in the TRI releases include polycyclic aromatic compounds, lead, mercury, acrylonitrile (carcinogen and neurotoxicant[117]), ethylbenzene (carcinogen[118]), benzene (carcinogen developmental toxicant and mutagen[119]), and a variety of acute toxicants.[120]

Additional workplace hazards (though not appearing in TRI reports) are dithiocarbamates used as polymerization accelerants and stoppers that are endocrine disruptors and neurotoxicants[121] and dimethylformamide, used as a solvent to extract 1,3-butadiene from petroleum[122] that is a likely developmental and reproductive toxicant[123] and ethylene (see box on "Ethylene's Problematic Ethylene Oxide Connection").

Renewable content

Select rubber flooring products contain high post-consumer recycled content, some as high as 100%.[124] The post-consumer recycled content, however, is primarily sourced from tires and may contain toxic materials that make their use in interior environments questionable. (See box on "Indoor Air Quality Problems with Recycled Rubber Floors").

Indoor Air Quality Problems with Recycled Rubber Floors

Many rubber flooring products contain recycled rubber content. Much of the recycled content is post-industrial synthetic rubber from the companies' own operations.[125] A variety of resilient flooring products – both sports floors and floors intended for regular commercial interior use – contain high amounts of post-consumer rubber recycled content. These are generally made from vehicle tires.[126] Scrap tires pose a large disposal problem, so the search has been on for beneficial reuse opportunities. The introduction of scrap tire materials inside buildings potentially can introduce significant chemicals of concern into the indoor environment. Products made from recycled tires can contain high levels of VOCs, which can be carcinogens or reproductive toxicants, including naphthalene, toluene, and aniline.[127]

Although some of the high recycled content rubber floors have passed VOC emissions testing sufficient to be listed on the CHPS Low Emitting Material table,[128] health care designers have been reluctant to specify them and it is not clear if these products are yet finding significant use in health care applications. A State of California report found that 4 of 11 rubber flooring products made with high recycled content did not pass VOC emissions criteria.[129] Furthermore, all 11 emitted a wide range of chemicals at levels high enough to lead California and others to recommend against the use of tire-derived rubber-based products in most indoor environments. The test results also led the State of California to begin work to establish reference levels for chemicals in order to address emissions from tire-derived recycled rubber products.[130]

Some health care flooring products contain natural rubber, harvested from rubber trees. But when used, these renewable materials generally comprise a small fraction (15% or less*) of the total content. Manufacturers blend natural rubber with higher percentages of SBR; therefore, the flooring products still have all the toxic chemical problems of SBR. There are flooring products made entirely from natural rubber,[131] but to our knowledge, those products are not used in the health care sector and are not reviewed here. Note also that although natural rubber is a biobased renewable, it has other significant production issues beyond the scope of this analysis – most notably that workers on rubber plantations in Africa and East Asia are reportedly working in near-slave conditions with much exploitation of child labor.[132]

End of Life

A few rubber flooring manufacturers offer to take their SBR products back at the end of life,[133] though the fate of the returned product is not clear. Given that most SBR products are actually complex composites of SBR and other materials that are difficult, if not impossible, to disaggregate, recycling of rubber flooring on a large scale is not easily achievable.

Virtually all SBR flooring ends up in landfills or incinerators. While various industrial facilities burn tire-derived fuel (TDF), including cement kilns, pulp and paper mill boilers, electric utility boilers and other industrial boilers,[134] there is no infrastructure in place to collect used SBR floor for TDF burning. We have identified no studies that characterize the by-products of burning SBR flooring. Comparable TDF facilities burning scrap tires, however, emit many carcinogens and neurotoxicants (including developmental neurotoxicants),[135] such as benzene, chloroform,[136] 1-2-dichloroethane (DCE), methylene chloride,[137] lead, and mercury.

* Mondo products in North America for example use 3-13% natural rubber while SBR comprises 30-50% of the product (e-mail communication from Erika Marcoux, Technical Department Supervisor, Mondo America, Inc. February 10, 2009). Nora Rubber's Noraplan has 10% natural rubber, 20% SBR, 55% clay filler, 5% pigments and 10% post industrial recycled content. Norament contains no natural rubber and is 45% SBR, 45% clay, 5% pigments and 5% other post industrial recycled content (Nora product literature www.norarubber.com).

C. Polyolefin flooring

A variety of new polyolefin-based materials have been introduced into the flooring market in recent years. These materials generally consist of blends or laminates of different polymer blends – largely ethylene-based – usually with some calcium carbonate (limestone) filler. They all claim high durability and no wax maintenance. The term polyolefins covers a wide range of different blends, many proprietary in nature, making it difficult to generalize about polyolefin flooring. This analysis is focused on a single example product – Stratica by Amtico. Stratica is selected because it is the polyolefin resilient flooring product that has been longest on the market (over 10 years) and is the most widely used of the polyolefin flooring options in health care today, with the most information available on its make up and use. Polyolefin is a very generic term and this analysis of the Stratica product is not necessarily representative of other polyolefin-type products. This selection also should not be read as an endorsement of Stratica over other polyolefin products.

Stratica comes in both tile and plank styles, but is too rigid for larger sheet goods. Manufacturer marketing emphasizes the resilience of the top layer of Surlyn – an ethylene/methacrylic acid (E/MAA) copolymer with zinc – the same material that is used on golf balls. E/MAA is made from isobutylene and tert-butanol, oxidized into methacrolein and then to MAA and then polymerized with ethylene into E/MAA. Behind the Surlyn, Stratica is made from layers of ethylene/methyl acrylate and trimethylolpropane trimethacrylate (TMPTMA) backing. Finally there are binders of ethylene/maleic anhydride terpolymer or ethylene vinyl acetate and fillers of common minerals (calcium carbonate, kaolin or hydrated aluminum oxide). See Appendix D: Composition of Stratica for a full discussion of the contents of Stratica

Persistent exposures

Amtico literature asserts that Stratica contains no chlorine[138] and our research did not uncover any evidence that halogenated compounds or other PBT chemicals are used or emitted in the life cycle of the product (see box "Lack of Emissions Availability Outside of the U.S.").

Lack of Emissions Availability Outside of the U.S.

For PVC and SBR, this analysis review utilizes emissions data from the U.S. EPA's Toxic Release Inventory (TRI) to inform assessment of chemicals involved in the manufacturing process and released to the environment. We have not found this type of data for either linoleum or Stratica-related facilities. Most of the manufacturing of both materials is located in European countries with less detailed reporting requirements for manufacturing facilities than the U.S.[139] The analysis is, therefore, restricted to analyzing both materials based only on what we have learned about their contents and what we can project from contents and process about possible emissions.

The only indication of potential PBT activity is the presence of 2-propenoic acid in the Lotryl ethylene/methacrylate copolymer.[140] The chemical is under investigation by the Stockholm Convention as a possible chemical that may degrade to Perfluorooctane Sulfonate (PFOS), a PBT.[141]

User exposures

There is very little indication of potential significant user exposure issues associated with Stratica, based on the materials used to make the flooring product. Like all of the other flooring materials in this review, Stratica passes the current indoor emissions certifications but does have a significant number of VOC emissions that are either below threshold or have no established threshold (see box on "VOC Testing: Only Part of the User Exposure Story"). Stratica contains carbon black and titanium dioxide compounds in the last 2 of the 6 layers, not in the surface wear layers, therefore these chemicals are unlikely to be released as dust (see box on "Pigments Can Be Toxic"). The zinc in Stratica is an aquatic toxicant.[142] Because zinc is in the surface layer, it could wear off and be washed down drains into sewage systems. The levels possible are probably insignificant in comparison to zinc handled by sewage systems from other sources.

CASE STUDY

Kaiser Permanente and Stratica Polyolefin

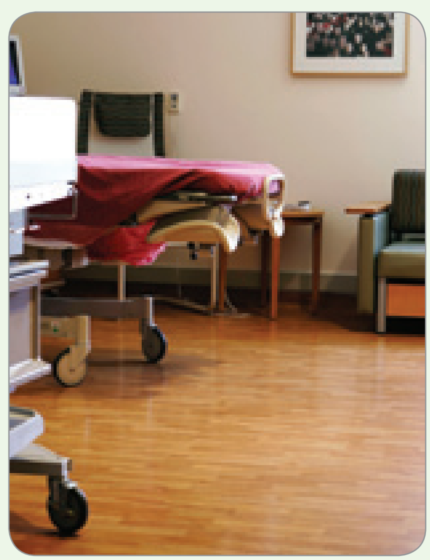
Kaiser Permanente's (KP) annual spending for purchased products and services is approximately $13 billion. The system leases or owns more than 65 million square feet of real estate and has a ten-year capital plan of more than $30 billion. Despite this leverage, KP has experienced limitations in achieving its goal of using products and materials that are environmentally sustainable.

Kaiser Permanente, as both a building owner and operator, has always had to look beyond first costs (the cost of installing a product) to recognize that there are additional costs of using a product over its life. As a not-for-profit, pre-paid health system, KP focuses on preventive medicine both in care delivery and in understanding the connection between environmental risks and public health outcomes. KP's organizational model and culture has made KP open to addressing environmental issues, in that it understands that reducing environmental exposures to staff, patients, and the community at large is part of "total health."

KP's Environmental Stewardship Council guides the health system's environmental work. Its vision statement reads: "We aspire to provide health care services in a manner that protects and enhances the environment and the health of communities now and for future generations." In its commitment to environment and health, KP has developed its own chemicals disclosure document that is required for all large national purchasing contracts. The disclosure asks for information on the categories of: persistent bioaccumulative toxic compounds and carcinogens, mutagens and reproductive toxins in addition to specific existing and emerging chemicals of concern such as mercury, polyvinyl chloride (PVC), phthalates, bisphenol-A and halogenated flame retardants.

In its efforts to remove hazardous chemicals by purchasing safer products, almost eight years ago, KP's Tom Cooper, National Manager, Sustainable Building Design and Research, spearheaded the health care system's efforts to look at replacing PVC building materials with alternatives. Many of the medical centers and office buildings had been using vinyl sheet goods and/or VCT (made from PVC) as resilient flooring options. As part of the effort to ensure the use of environmentally sustainable products, KP's green building committee undertook a research project evaluating resilient flooring alternatives to vinyl and VCT.

Resilient flooring alternative products had a higher first cost than the VCT that KP was using. They learned, however, that the alternatives might actually be less expensive than VCT, when evaluating the full costs of the flooring over the life of the product. They noted a Florida hospital study of different flooring types and costs associated with health care, including carpet, rubber, linoleum, and VCT. The Florida study showed that the total cost of VCT was higher across its lifespan than any other material.



Kaiser Permanente Medical Center, Santa Teresa-San Jose; Stratica; Photo courtesy of Kaiser Permanente

KP's facilities teams identified that there was ongoing disruption in operations every time they had to strip and wax a vinyl floor, especially in inpatient facilities. Some staff complained about headaches and there was some documented work loss associated with this process. Based on the desire to reduce PVC in KP facilities and information that VCT might actually cost the system more over time, Cooper and colleagues undertook a multi-tiered strategy to test and evaluate no-wax flooring alternatives.

They looked at products that had already been used in the U.S. market and focused on products that were used in high traffic areas, like health care. KP created a research team of internal staff and consultants to coordinate the effort. They sought a product that would be no wax, in order to prevent the maintenance disruptions associated with VCT and reduce the lifecycle cost. They reviewed product market data, traveled to sites where products had already been installed to see them in person, got references from the manufacturers, did a preliminary cost analysis based on each manufacturer's cleaning protocols, and then installed four different products in KP facilities as a pilot project. One such product was Amtico's Stratica (a polyolefin-based product).

Kaiser Permanente Medical Center, Santa Teresa-San Jose; Stratica; Photo courtesy of Kaiser Permanente

KP's National Environmental Health and Safety (NEH&S) team evaluated the Stratica in the pilot site for emissions: they collected data as to aesthetics, comfort, cleanability, stain removal, and chemical testing. KP maintenance staff were specially trained by Amtico on cleaning protocols. The final outcome after extensive evaluation of Stratica was that it was a product KP would be interested in specifying: it required no finish, was aesthetically pleasing, withstood stain testing, had little to no off-gassing, had improved coefficient of friction over a waxed floor, had better acoustic properties, and was PVC-free. KP had enough information to put together a business case identifying the benefits and potential problems with Stratica and to recommend a combination of Stratica flooring and Nora rubber flooring (which underwent a similar pilot testing process) as their national design standard for resilient flooring for large renovations and new buildings.

Kaiser Permanente Medical Center, Santa Teresa-San Jose; Stratica; Photo courtesy of Kaiser Permanente

KP has indicated that Stratica is not without its challenges. It only comes in tile and planks, so KP cannot source it for areas of their facilities where sheet flooring is required for infection control purposes. Because the maintenance and cleaning requirements are so different from vinyl, it cannot be installed where it will be surrounded by vinyl because it will not be properly maintained. The installation process requires no point load on the floor for 48 hours, requiring careful planning in terms of construction time and creative strategies (such as covering new floors with protective sheeting) in existing facilities to avoid significant disruption in services. Finally, despite lots of education and training, some facilities still wax Stratica to get the shiny look that folks have become accustomed to in hospitals. Where the proper cleaning protocol is followed, KP is seeing a 50% to 80% reduction in maintenance costs over time. These maintenance savings haven't paid back the higher first cost of the flooring yet, but good indicators are emerging. Feedback from patients and staff is that Stratica has improved acoustics, comfort, and aesthetics. Importantly, injuries appear to be reduced on the new flooring and KP is optimistic that it will be able to quantify reductions in costs for slips, trips and falls, absenteeism, and other metrics over time and understand the complete business case for this material.

About Kaiser Permanente: Founded in 1945, Kaiser Permanente is the nation's largest nonprofit health plan, serving 8.6 million members in nine states and the District of Columbia. Kaiser Permanente operates 1,020 medical and administrative buildings including 500 ambulatory care facilities and 35 acute care hospitals. KP includes 65 million square feet of facilities and 14 million square feet of parking. There are 164,000 employees and 14,000 physicians. Total operating revenue for fiscal-year 2008 was $40.3 billion.

Manufacturing exposures

One potential metabolic decomposition product of ethylene is a carcinogen (See box on "Ethylene's Problematic Ethylene Oxide Connection"), and the formaldehyde used in the synthesis of the trimethylolpropane binder is also a carcinogen.[143] As with the other three flooring material types, the pigments may include carcinogens (see box on "Pigments Can Be Toxic") and require care in usage industrially. The rest of the materials used in manufacture include serious irritants and corrosives that also require significant industrial protection measures for occupational safety from acute hazards, but do not pose any known chronic cancer, mutagenic, developmental or reproductive hazards.[144]

Ethylene's Problematic Ethylene Oxide Connection

Ethylene is the building block of many of the layers of Stratica and other polyolefins and also the styrene and butadiene of SBR. It has been evaluated for cancer potential repeatedly and determined not classifiable.[145] However, preliminary studies indicate that in nature and in humans, a small fraction of inhaled ethylene can metabolize to ethylene oxide,[146] a carcinogen, mutagen, neurotoxicant and reproductive toxicant.[147] A study in Sweden found that ethylene metabolized to ethylene oxide in plastic industry workers, although at a very low conversion rate.[148] Ethylene is also a neurotoxicant at high levels of exposure.[149]

Renewable content

Amtico claims a 100% recovery rate for Stratica's post-industrial waste, but the product itself has no post-consumer recycled content, no known post-industrial content other than Amtico's own, and no biobased content.

End of life

Post-consumer Stratica waste theoretically can be recycled into backing for more Stratica flooring; however, the removal of adhesives is a challenge and the company has not yet developed facilities for this process.[150] "Down-cycling" Stratica into backing would be an improvement over current completely virgin production, but would not constitute a true completely closed-loop system, since the use of the recycled polyolefin would be limited to backing – replacing some or all of the filler – yet the face layers would still require new fossil fuel-based polymer production.

D. Linoleum flooring

Linoleum, invented in 1860 by Englishman Frederick Walton, brought resilient flooring to the masses. Until the late 19th century, most floors were bare wood or dirt, with only the wealthy able to afford carpets or rubber floors. Linoleum and similar coverings were the dominant flooring option until the 1960s when synthetic materials began to replace linoleum.

The name linoleum comes from the Latin word, linum, which means flax, and oleum, which means oil, named after the primary ingredient – linseed oil extracted from the flax plant. The basic formula to produce linoleum has remained the same for almost a century. Linseed oil is oxidized to thicken it and give it a rubber-like quality. The oxidized linseed oil mixture is mixed with resins from pine trees, wood flour, cork and limestone fillers (and some pigments) and pressed onto a backing to make sheet linoleum.

Today, the linoleum manufacturing process is quite similar to the process hundreds of years ago. The most significant change has been the use of tall oil to replace some of the linseed oil. Tall oil is a by-product of the Kraft process used in pulp and paper manufacturing.

Modern linoleum is often coated with UV-cured polyurethane or polyacrylates to reduce VOC emissions from the oxidation process of the linseed oil and to improve resilience and reduce maintenance. Many sheet linoleum products are still backed with the traditional woven jute, while tile products utilize other backings made from polyester or glass fibers to provide greater rigidity.[151]

CASE STUDY

Maimonides Medical Center and Forbo Linoleum

Maimonides Medical Center, Brooklyn, New York, has a long history working with Guenther 5 Architects (now part of Perkins+Will). "We understood early on the link between environmental health and the materials we specified for health care projects," said Jason Harper, Associate Principal from Perkins+Will. "We recommend products that contribute to improved indoor air quality. Any material that can reduce VOCs and be maintained with greener cleaning protocols is our preference. We try to avoid specifying flooring products that require wax and strip procedures, for example."

When Maimonides partnered with the firm to undertake renovations throughout the medical center, and later with the design and construction of a major addition, the commitment to sustainability drove the project partnership. Maimonides began piloting alternatives for vinyl flooring. The design team first recommended linoleum for small renovation projects (such as an 800 square foot family lounge), then in corridors for larger renovation projects, including a large full floor renovation that created an entire new 30 bed patient unit (using linoleum in the corridors and Stratica in the patient rooms). Through these pilots, Maimonides became comfortable with both performance and maintenance.

With the initial projects, the facilities staff noted positive reactions from staff, patients, and visitors. Linoleum reinforced the natural look that the design strived to achieve and provided other aesthetic benefits –it was colorful and provided patterning capabilities for areas of the hospital like the pediatric wing, where design could play an important role in the comfort of patients. It was softer and quieter. Moreover, the reduced maintenance costs in human power and absence of chemical cleaning agents—the material requires no waxing or stripping—meant that staff and patients with allergies and other health issues were protected.

Maimonides Health Center; Forbo Linoleum; Photo by: Frank Oudeman

At the same time, Maimonides faced challenges throughout its pilot projects with regard to maintenance of the floors. While the medical center chose linoleum in part for its no wax attributes, when it was installed in areas adjacent to existing vinyl floors that needing to be stripped and waxed, staff often waxed the new linoleum floors as part of their normal maintenance practices. As Environmental Services staff became more comfortable with the reduced maintenance requirements of linoleum, the additional benefits associated with reduction in chemical use and labor required to wax and strip began to be realized.

Maimonides Health Center; Forbo Linoleum; Photo by: Paul Rivera

With a variety of pilot projects using linoleum, Maimonides was prepared and committed to specifying linoleum throughout a 9-story, 100,000 sq. ft. addition and 50,000 sq. ft. of related renovations, including a NICU, Surgery, Obstetrics, and Critical Care. "The President was very much committed to greening the hospital," said Derek Goins, Senior VP of Facilities and Support Services. "We felt sustainability was the right thing to do for the institution. You need a commitment from the beginning and going forward. And, you can't do it half way."

The design team was able to demonstrate potential life cycle cost savings to Maimonides if it were to specify non-vinyl alternatives (the project includes linoleum, Stratica, and rubber). While there might be a higher "first cost" for the installation of linoleum, they calculated significant savings throughout the life of the product – an estimated 3-5 year payback when projecting the reduced costs associated with maintenance of a linoleum floor. Mr. Goins said, "You believe there may be a savings, but it's really hard to quantify. You just have to have the commitment to sustainability."

Maimonides is satisfied with their new linoleum and they continue to source it for many of their new projects. It is not without its installation challenges. The adhesives require 48 hours with no traffic on the floors after installation, which now is built into the construction time line. And, the subfloor preparation protocol for installing linoleum to ensure a smooth, flat surface to avoid buckling and bubbling comes with higher first costs as well, both in new construction as well as renovation. Goins confirms that the hospital hasn't experienced chronic ongoing performance issues with the linoleum—the materials are performing acceptably.

Maimonides Health Center; Forbo Linoleum; Photo by: Paul Rivera

About Maimonides Medical Center:
Founded in 1911, Maimonides Medical Center is one of the largest independent teaching hospitals in the nation, with more than 700 patient beds, over 90,000 emergency room visits, 230,000 ambulatory care visits, and 7,200 births each year.

Persistent exposures

We know of no PBTs used or released in the manufacture of linoleum or elsewhere in its life, with the notable exception of in the farming of the flax used as a feedstock. At least one of the pesticides approved for use on flax – Trifluran,[152] is a PBT as well as a carcinogen, endocrine disruptor and aquatic toxicant.[153] This analysis is constrained by the lack of emissions data to confirm our analysis of the manufacturing process (see box "Lack of Emissions Availability Outside of the US").

User exposures

Linoleum has odor issues associated with the material, much more than most synthetic flooring materials, due to the oxidation products of linseed oil. Some products made from linseed oil have not qualified for the Danish Indoor Climate Label due to their persistent odors.[154]

Two linoleum products failed product VOC emissions testing in a State of California study[155] due to emissions of acetaldehyde (a respiratory irritant and carcinogen[156]). Manufacturers have begun to successfully address the odor and VOC problems associated with linoleum – through use of less odorous oil varieties[157] and by reformulating surface coatings to reduce emissions.[158] Linoleum flooring products from many of the major manufacturers now are certified by FloorScore, GreenGuard, or otherwise meet the most stringent emissions standards (see box on "VOC Testing: Only Part of the User Exposure Story").

Like the other resilient floor materials analyzed above, linoleum may also include carbon black and/or titanium dioxide as pigments (see box on "Pigments Can Be Toxic"). Another issue associated with old linoleum flooring is that some products made before 1979 contained asbestos (carcinogen[159]) in the backing. While asbestos is no longer used in today's linoleum products, proper testing and remediation should be done for any disturbance or removal of linoleum (or other) flooring tile products from pre-1979 installations.[160]

Manufacturing exposures

Exposure to chemicals during the manufacturing process for linoleum depends upon the choice of modes for growing the flax and for processing the tall oil. Linoleum can be manufactured without creating health exposures; flax can be successfully grown organically without any toxic chemicals. But in practice, a range of toxic pesticides and fungicides are approved for use on flax, [161] including the PBT trifluran (carcinogen, endocrine disruptor and aquatic toxicant[162]), mancozeb[163] (carcinogen and endocrine disruptor[164]), bromoxynil (developmental toxicant[165]) and trichlorfon,[166] (neurotoxicant).

Another aspect of linoleum manufacturing that raises potential concerns is the processing of tall oil. Tall oil is usually esterified, first with polyhydric alcohols and sometimes with the use of maleic anhydride (MA), dimerized fatty acids, or pentaerythritol. MA is traditionally produced by oxidizing benzene (a carcinogen and developmental toxicant[167]). Over the last two decades, the MA industry, however, has begun to use n-butane rather than benzene, in order to eliminate potential benzene exposure.[168] The pentaerythritol process is also problematic as this chemical is made from acetaldehyde and formaldehyde,[169] both carcinogens.[170]

Some linoleum processes prepare the tall oil with the use of glycerol polyethers obtained by heating a polyhydric phenol with epichlorohydrin[171] (a probable carcinogen and reproductive toxicant[172]). It is not known how widespread the use of the epichlorohydrin-based process is.

Other than these potential material problems, linoleum workplace problems appear to be primarily dust related bronchial and dermal irritation.

Renewable content

Linoleum sheet goods generally contain about 80% renewable content – linseed oil, wood flour, cork, tall oil, rosin and jute. Some of the renewable content is also post-industrial recycled material, with the wood flour coming from lumber mill waste and the tall oil from paper production.

The one significant downside of the renewable content of linoleum is that current modern agriculture practices lead to significant eutrophication (see box on "Eutrophication Explained"). Eutrophication is one of the few significant negatives found in life cycle assessment studies of linoleum (see Appendix A: Review of Other Comparative Studies). The agricultural runoff problem that triggers this impact is a solvable problem with better farming practices. At least one linoleum manufacturer has been working with the Flax Council of Canada to develop programs to train and encourage flax farmers in more sustainable farming techniques.[173] These programs are aimed both at reducing toxic chemical usage and improving field practices to reduce the runoff responsible for eutrophication impacts.

Eutrophication Explained

Eutrophication is a term for what happens when a lake or other body of water is overloaded with nutrients. This can happen from sewage laden with phosphate detergents, industrial outfalls, agricultural field runoff laden with fertilizers, or any other manmade source of nitrogen and phosphorus. This essentially fertilizes the body of water and can lead to heavy growth of algae and other plants in the water, upsetting ecological balances. The growth spurt can in turn use up the dissolved oxygen supply in the water, killing fish, making the lake uninhabitable, and degrading water quality. Good farming practices such as decreased fertilizer usage and soil conservation techniques that diminish both the amount of runoff and the fertilizer content of the runoff can reduce or eliminate this problem.

End of life

Starting in 2007, one linoleum manufacturer set up a pilot composting program in the Mid-Atlantic region. The program collects and composts outdated samples, installation job site scraps, roll ends and trimmings from the distribution facility. The program is diverting nearly 20 tons of solid waste per month from landfills and has reduced the amount of solid waste from the distribution facility by 85%.[174] Expansion to all of North America is planned in the coming year. As with the other flooring products and their recycling challenges, adhesive removal continues to be a significant obstacle to the composting of linoleum at the end of its life.

IV. SUMMARY: COMPARISONS AND RECOMMENDATIONS ON CHEMICAL HAZARD AND CLOSED-LOOP CHARACTERISTICS

This section reviews and compares the chemicals of concern associated with each of the four flooring material types and where the potential exposures occur in the life cycle of the materials. This is followed by a review and comparison of their current and potential renewable material content and end of life strategies. In each case, issues that are integral to the materials used are differentiated from issues that have the potential to be improved with reformulation or different process decisions by manufacturers. Together, the analysis forms the basis not only for preferable product selection, but also for potential actions that designers and specifiers can undertake to urge suppliers and manufacturers to move toward desirable improvements in the life cycle profile of their products.

PBT Production

Many building products such as resilient flooring are made with materials that result in the release of very high priority PBTs at one or more points in the life cycle (see box on "PBTs Creating Global Challenges"). International treaties have prioritized reducing or eliminating sources of PBTs.

All three of the petrochemical plastic-based materials studied here (vinyl, synthetic rubber and polyolefin) have a common heritage of problems with PBTs that are released from drilling and refining operations. This analysis focuses on the issues that distinguish them in manufacturing and beyond once the petroleum has been extracted and refined.

Polyolefin flooring, specifically Stratica, appears to have relatively minimal problems in its life cycle with only one potentially problematic decomposition product identified, albeit limited by lack of access to manufacturing release data because manufacturing facilities do not currently exist in the U.S..

Linoleum flooring also revealed only one PBT problem, albeit also limited by the lack of access to manufacturing release data because manufacturing facilities do not currently exist in the U.S. At least one of the pesticides that may be used to grow the flax to make linoleum is a PBT. The problem is not integral to linoleum and can be solved by initiating organic growing techniques that eliminate use of pesticides that are PBTs.

For both linoleum and polyolefins, it would be useful to have access to emissions data from the European factories that make them in order to confirm that there are no PBT emissions from process chemicals that have not yet been identified in this analysis.

Synthetic rubber flooring, specifically SBR, has more PBTs involved in its chemistry and composition. Some of the PBTs in SBR – the halogenated flame retardants specifically – can be replaced with non-PBT alternatives. The other PBTs in SBR – mercury, lead and polycyclic aromatic compounds – are not known components but are reported in manufacturing emissions and hence are likely additional process chemicals. Further analysis is necessary to determine if these chemicals can be eliminated from the SBR processes or are integral to it.

Vinyl flooring has the most significant PBT challenges in its life cycle. In addition to all of the PBTs identified for rubber flooring above, the life cycle of vinyl flooring also results in the generation and/or release of several more PBTs, including dioxins/furans, PCBs and hexachlorobenzene, all of which are highest priority chemicals identified in the Stockholm POPs Treaty. They are also all apparently unavoidable by-products of the PVC manufacturing process itself. It is not possible for PVC flooring manufacturers to eliminate these PBTs.

User exposure

Sick building syndrome has made direct user exposure to chemicals from building materials an important issue in the design of buildings. User exposure to toxic chemicals is a particular concern for interior finish products such as resilient flooring. The large surface area in occupied spaces in health care provides many opportunities to expose occupants to hazardous chemicals in the product, the adhesives, and the ongoing maintenance and cleaning. Most assessments and certifications aimed at evaluating toxics in products to protect users from exposure focus on indoor air quality (IAQ) and specifically on measuring volatile organic compounds (VOCs) during and immediately following installation. Many resilient flooring products made from each of the material types studied here pass current VOC emissions tests, but still may lead to user exposures to chemicals.

Potential emission problems remain for each of the material types. None of them are truly "zero VOC." All flooring types emit multiple problematic VOCs at levels below the established threshold levels for each individual VOC. No studies, however, have fully explored how multiple VOCs interact with one another. Further research is needed to understand the synergies between individual chemical releases, and whether, combined, they will produce health impacts at much lower thresholds than one-at-a-time chemical tests would indicate. Health impacts of VOC emissions from the adhesives and their interactions with the VOCs from the flooring products need to be explored. Related adhesive VOC emissions are not consistently addressed by current VOC emission standards. Furthermore, some of the materials have chemical contents that are High Concern chemicals that are not VOCs, but can expose occupants by contact or migration on dust. All of the flooring types contain pigments such as titanium dioxide and carbon black that are potential carcinogens, although only if ground into fine dust and inhaled.

Linoleum & **polyolefin** flooring products have no known chemical hazard problems for users beyond the common low level VOCs and pigment issues referred to above. Linoleum can have odor problems. Manufacturers are developing ways to minimize this.

Synthetic rubber flooring products can include halogenated flame retardants and at least one of the non-halogenated flame retardant alternatives (antimony trioxide) is a carcinogen. SBR products also have problems with various contaminants used during the manufacturing process, including styrene and heavy metals. The heavy metals may be able to be eliminated from the product. Sample content testing with equipment such as an x-ray fluorescence (XRF) device* might help confirm this. Styrene contamination may be more difficult to eliminate as it is integral to the manufacturing process, although process controls can probably reduce its presence in the final delivered product. It is unknown how much styrene occurs through degradation of the SBR. Synthetic rubber flooring products made from recycled content are particularly problematic because of the large number of toxic additives in the tires from which these products are generally recycled. There is no known way to eliminate exposures. Some synthetic rubber users also report odor issues.

Vinyl flooring shares with rubber the flame retardant issues, using both halogenated flame retardants and antimony trioxide. Like rubber, PVC also has a legacy of heavy metal problems that warrant testing to ensure safety. Additionally, PVC is problematic due to the use of plasticizers that must be added to the polymer to soften it. Many of the plasticizers in common use in vinyl flooring products are High Concern chemicals associated with cancer, reproductive and developmental toxicity, and asthma.

Manufacturing exposures

Manufacturing of materials used to make resilient flooring products frequently includes the use of High and Very High Concern chemicals. Beyond the intended contents of the product, there may be feedstocks, catalysts and other processing aids that are not intended to leave the factory. These chemicals routinely escape from the factory via smokestacks, fugitive emissions, outfall pipes or waste haulers, and may expose neighboring communities to hazardous chemicals. Even when they don't impact the surrounding community, these releases may pose a hazard to workers in the factory. Workers in all four industries face hazards from chemicals that are acute toxicants as well as the chronic health impact issues focused on in this analysis, but acute exposures are not the focus here.

* X-ray fluorescence (XRF) testing involves using a device that uses x-ray fluorescence to determine the presence and concentration of a variety of chemicals, including many of the heavy metals.

None of the flooring materials studied can claim a completely clean process that is certain to be safe for workers or for surrounding communities. Each of them also may contain and expose users to hazardous chemicals. They do vary, however, in how necessarily integral those compounds are to the process.

Linoleum flooring manufacturing may utilize any of a number of High Concern carcinogens, including benzene, formaldehyde and epichlorohydrin. However, none of these appear to be integral to the process of making linoleum, meaning that manufacturers presumably could design processes that do not use or produce any of the identified High Concern chemicals that are currently used. Linoleum does have the extra burden of some High and Very High Concern agricultural chemicals involved in the agricultural production of flax for linseed oil. These also are not integral to linoleum as flax can be grown by organic methods that do not rely upon any high hazard chemicals. Some manufacturers are working to improve field techniques and move away from Very High Hazard chemicals in flax agriculture.

Polyolefin flooring manufacture is only known to use one High Concern carcinogenic chemical – formaldehyde – and given the wide range of formulas for polyolefins, polyolefins may be redesigned to eliminate formaldehyde exposures. There is an additional potentially significant but poorly understood cancer risk from the potential ability of ethylene – which is integral to all three petroleum based materials – polyolefins, synthetic rubber and vinyl – to be metabolized into a carcinogen (ethylene oxide).

Synthetic rubber flooring made from SBR has several High Concern chemicals that are integral feedstocks to the polymer. Therefore, while some of the High Concern chemicals used in manufacture could be removed through better design of the process, synthetic rubber flooring manufacture will only become free of high hazard toxicants by development of new rubber polymers not based upon styrene and 1,3-butadiene chemistry.

Vinyl flooring also has several High Concern feedstocks that are integral feedstocks to the polymer (ethylene dichloride, chlorine and vinyl chloride monomer), plus the Very High Concern PBTs referenced earlier. As with SBR, PVC has inherent problems with the chemistry of the polymer that make it impossible to create PVC that is free of high hazard toxicants, made worse by the addition of PBTs.

Renewable content

Using recycled or other renewable content can bring benefits not only by reducing consumption of fossil fuels and minerals but also can help avoid the toxic chemicals involved in the manufacture of products from virgin raw materials. The highest value is from using post-consumer recycled materials – those captured at the end of use of the product. Most of the recycled content used in flooring materials today, however, is post-industrial, not post-consumer content.

Linoleum is the only flooring that uses biobased content and the only one in which all of the products have a significant amount of renewable content of any sort. The biobased content is currently tarnished by the toxic chemical usage in and eutrophication from the agricultural system. This can, however, be changed. At least one linoleum manufacturer is working with the flax industry to improve agricultural practices to reduce these impacts. Linoleum products all have a significant amount of recycled content, although it is post-industrial.

Polyolefin, synthetic rubber and vinyl floorings generally use little to no post-consumer recycled content. Most of the recycled content used in PVC, SBR, and Stratica-type polyolefin products is post-industrial, mostly waste scraps from their own production processes. Only a few SBR flooring products have significant quantities of post-consumer recycled content. The content comes from vehicle tires that contain a wide variety of toxicants.

End of life

It is important to “close the loop” at the end of the life of a flooring product to bring it back as a recycled material or compost it back into the agricultural system. All of the materials studied are theoretically recyclable. Linoleum is theoretically compostable. But additives, adhesives, infrastructure and economics are major impediments to closing the loop for all of them. A few pilot projects are underway with vinyl, rubber and linoleum recycling, but the projects involve very small volumes. They take primarily job site waste, not end of life waste, and are mostly presumed to be downcycled (recycled into lesser uses). One linoleum manufacturer is piloting a composting program for its products. The market has far to go to improve the end of life for flooring products and none of the products has a significant advantage on this count at this time.

Table 2. Chemicals of highest concern by exposure

	Chemicals	PVC	SBR	Stratica	Linoleum	Hazards
Persistent PBT s*	Dioxins					POP, PBT, carcinogen, endocrine
	Polychlorinated biphenyls (PCBs)					POP, PBT, carcinogen, developmental neuro, endocrine & aquatic
	Hexachlorobenzene (HCB)					POP, PBT, carcinogen, neurotoxicant, developmental & aquatic
	Cadmium					PBT, carcinogen, developmental & reproductive & aquatic
	Mercury	Opt	Opt			PBT, developmental neuro & endocrine
	Lead	Opt	Opt			PBT, carcinogen, reproductive, developmental neuro & endocrine
	Chlorinated paraffins & decaBDE	Opt	Opt			PBT, carcinogen & endocrine
	Polycyclic aromatic compounds	Intl	Opt			POP, PBT, carcinogen
	Trifluran & other PBT pesticides					PBT, carcinogen
Contents- User exposures	Lead, cadmium, paraffins & decaBDE					see Persistent exposures
	Butyl benzyl phthalate (BBP or BzBP)	Opt				Developmental & reproductive, endocrine & aquatic
	Di(2-ethylhexyl phthalate (DEHP)	Opt				Developmental, reproductive & endocrine
	Di-n-hexyl phthalate (DnHP)	Opt				Reproductive
	Tributyltin	Opt				endocrine
	Antimony trioxide	Opt	Opt			Carcinogen
	Styrene		Int			Carcinogen (possible), endocrine, neuro
	Toluene, acetaldehyde and other VOCs	Opt+	Opt	Opt	Opt	Carcinogens, developmental & neuro
	Pigments (titanium dioxide & carbon black)	Opt	Opt	Opt	Opt	Carcinogen through inhalation
-Feedstocks & intermediary chemicals or emissions Additional manufacturing exposures**	Ethylene dichloride (EDC)	Intl				Carcinogen
	Vinyl chlorine monomer (VCM)	Intl				Carcinogen & neuro
	Chlorine gas	Intl				Aquatic & acute
	1,1,1-trichloroethane	Int				neurotoxicant and ozone depletor
	Acrylic acid	?				acute
	Vinyl acetate	Opt		Opt		Carcinogen (suspected)
	Mercury	Opt	Opt			PBT, developmental & neuro
	Ethylene	Int	Int	Int		Neuro & may metabolize to ethylene oxide (carcinogen & reproductive)
	1,3, butadiene		Int			Carcinogen, reproductive & developmental
	Acrylonitrile		Opt			Carcinogen & neuro
	Dimethylformamide		Opt			Reproductive & developmental
	Dithiocarbamates		Opt			Endocrine, neuro
	Ethylbenzene		Int			Carcinogen
	Benzene		Int		Opt	Carcinogen, developmental & mutagen
	Formaldehyde			Opt	Opt	Carcinogen
	Epichlorohydrin				Opt	Carcinogen, reproductive, mutagen
	Bromoxynil, Trichlorfon, Mancozeb & other pesticides				Opt	Carcinogens, developmental toxicants, neuros & endocrines

Fill colors in the table reflect the concern level in Table 1

Black = Very High Concern | **Red** = High Concern | **Orange** = Moderate Concern

* In addition to the chemicals listed, all three of the petrochemical plastics (PVC, SBR & polyolefin) share common PBT releases from the extraction and refining process of the petrochemical raw materials

** Manufacturing exposures also include all of the exposures from the persistent PBT & user exposure categories

Int =integral – fundamental unavoidable part of the base material, not likely to be designed out of the chemical process without significant redesign.

Opt=Optional variation on additives or manufacture process that is relatively more possible to avoid by selection or redesign.

+ Note that materials engineering can reduce, but not likely totally eliminate VOC emissions from any of these flooring types.

Table 3. Life Cycle Comparison of Flooring Material Types

	Issues	PVC/Vinyl Reference	Synthetic Rubber (SBR)		Polyolefin (Stratica)		Linoleum	
Raw material	Biobased content	None	=	None	=	None	+	High, but ag practices need improvement
	Post consumer recycled content	Virtually none	?	Some have but may be toxic	=	None	=	No PC, highest PI (post industrial)
	POPs, other PBTs, CMRs	Many in petroleum extraction & refining	=	Many – petroleum extraction & refining	=	Many – petroleum extraction & refining	+	Few – pesticides can be eliminated
Manufacturing	POPs	Many, major dioxin source	+	None identified	+	None identified	+	None
	Other PBTs	Many but may be able to be designed out	=	Many but may be able to be designed out	+	None identified	++	None
	CMRs	Many integral	=	Many integral	+	Few – all optional, ex ethylene	++	Many but may be able to eliminate all
Use	Heavy metals & flame retardants	Many but may be able to be designed out	=	Many but may be able to be designed out	++	None	++	None
	Phthalates	Many but may be able to be designed out	++	None	++	None	++	None
	VOC	Many. May reduce but not eliminate	=	Many. May reduce but not eliminate	=	Many. May reduce but not eliminate	=	Many. May reduce but not eliminate
End of Life	Recycling or composting	Small experimental recycling	–	None	–	None	=	Small experimental composting
	POPs	Major dioxin source	+	None identified	+	None identified	+	None identified

Key: Comparison to vinyl

? Unclear	– Worse	= Similar	+ Better	++ Best

V. CONCLUSION AND FUTURE RESEARCH

Not one of the materials reviewed is hazard free as currently produced. The product types do, however, vary considerably in the amount and extent and exposure of Very High Concern PBTs and High Concern chemicals that are currently involved in the product life cycle. There are also distinct differences between the materials reviewed here with regard to the potential for manufacturers to further reduce the hazards.

For some products, there are a range of opportunities for specifiers and purchasers to encourage manufacturers to reduce or eliminate the use and production of PBTs and other High Concern chemicals. With encouragement from the marketplace, some resilient flooring manufacturers could reformulate their flooring products to virtually eliminate the PBTs and CMRs from manufacture, use and disposal, so as not to expose workers or users to PBTs, carcinogens, mutagens or reproductive toxicants. All of the fossil fuel-based products, however, have a common burden of PBTs and other toxics from the extraction and refining process of the fossil fuels.

Linoleum has strong prospects for minimizing its already lower chemical hazard. Opportunities exist both in agricultural production and the manufacturing processes. It should be technically possible to produce a product free of PBTs and CMRs, making this the most preferable product from a chemical hazard perspective, both in current practice and in likely potential. Manufacturing emissions data is needed to verify the assessment. Furthermore it should be noted that manufacturing truly free of PBTs and CMRs can only be accomplished when the process is powered by renewable energy sources (an issue common to all of the examined products).

Polyolefins are the next preferable material – the most preferable of the purely petrochemical-based products. While they share the toxics of the refining process with the other petrochemical-based products, they appear to be otherwise largely PBT-free. Problems with ethylene's metabolites warrant further study and could limit the ability to get to a completely CMR-free manufacturing process. This review is based on just one product (Stratica) within the polyolefin family and without the benefit of manufacturing emissions data. It will also be necessary to obtain manufacturing emissions data for Stratica and assess other polyolefin products to confirm the more preferable assessment of polyolefins.

Synthetic rubber products have much room for improvement, but more significant inherent limitations than polyolefins, making them less preferable on a chemical hazard basis. With several High Concern carcinogens playing key roles in synthetic rubber material chemistry, they may be able to eliminate the PBTs from manufacturing and end of life, but can never become CMR-free.

Vinyl products have some room for improvement, but are even more handicapped than SBR. With High Concern carcinogens and PBTs inherent in their manufacture and life cycle chemistry, PVC-based products can not, by definition eliminate the hazard of PBTs and CMRs from any part of the life cycle and are hence the least preferable of all the materials assessed.

Closing the Loop: Flooring products have a long way to go on closing the material loop. While there are big differences in the recycled content available between the products studied, virtually none of them use significant quantities of post-consumer content. Furthermore, the products with the most recycled or biobased content today still have significant toxic issues associated with those processes. There is plenty of need for specifiers and purchasers to encourage manufacturers to increase use of renewable materials that are free of PBTs and CMRs and to design for end of life recycling or composting. None of the resilient flooring manufacturers utilizing the materials reviewed are close to closing the loop of material flow through recycling or composting for a significant percentage of their production. In this area there are however, also significant differences between the materials, both in current practice and future potential.

All of the product types have demonstrated the potential to recycle (or in the case of linoleum, to compost) the product, but all face similar challenges in dealing with the adhesives used for securing the products to the floor and in gathering product at the end of its life and transporting it back to the factory for recycling. All of the petrochemical products also have the inherent limitation that, due to wide variation in chemical composition of additives, they can't be mixed for recycling even with other products of the same plastic type, except for downcycling into lower grade products. Linoleum may have the highest potential here since it can be composted with other materials if the adhesive issue can be solved.

Energy and other environmental issues: This analysis focuses on chemical hazard-based human health issues. There are many other issues that could be included in a full environmental analysis of resilient flooring. Embodied energy, carbon footprint and corporate social responsibility are just examples of other important areas that warrant assessment but that are beyond the scope of this paper. The Healthy Building Network's Pharos Project will be developing analyses of these and other building products across a broader set of parameters, expanding to incorporate more categories of issues such as these.

Next Steps: While no ideal "green" material currently exists for health care flooring options, *Resilient Flooring & Chemical Hazards: A Comparative Analysis of Vinyl and Other Alternatives for Health Care* illustrates the range of alternative materials which are preferable to sheet and tile products made with PVC – posing fewer chemical hazards in their current formulations and having more potential for further improvement. Yet, hundreds of health care organizations continue to source PVC-based products for their facilities. Lack of information about performance, lack of experience in cleaning and maintenance, and the slow pace of change in the health care industry all contribute to slowing the transformation of the industry to safer alternatives.

Many health care systems, including those profiled in this paper, are effectively specifying and using the alternative materials in new and renovated health care facilities. Capturing and reporting on the experience facilities have with these new materials and broadly sharing this information may assist in both wider adoption and product innovation.

The Research Collaborative intends to follow this paper with a project to assess the installation and performance challenges and benefits of the different materials profiled here. Interviewing hospital staff, the study will explore a number of attributes of the alternative materials, including:

- Durability;
- Safety – traction and effect on slips, trips and falls;
- Glare;
- Comfort, fatigue and strain;
- Acoustics;
- Installation, including analysis of both installation processes and toxic properties of adhesives and sealants recommended for use with the materials;
- Time constraints; and
- Cleaning and maintenance.

Many health care organizations are committed to eliminating products from their buildings that contain chemicals that can harm patients, staff, and the environment. With greater awareness of the health issues associated with resilient flooring and the products required to install and maintain them, health care organizations and designers can make more informed decisions and collectively help move the market by their specifications and purchasing power. In turn this can reduce the hazardous chemicals introduced into interior environments by the building materials and promote a healthier healing environment.

APPENDIX A: REVIEW OF OTHER COMPARATIVE STUDIES

This appendix reviews a series of other studies that have compared health and other environmental impacts of some of the flooring materials assessed in this paper. A number of organizations have undertaken life cycle assessments (LCA) of the flooring material types evaluated in this paper. As opposed to the hazard-based approach, LCA studies work on a material flow approach. LCAs attempt to quantify all of the flows of materials, energy and emissions that go into and out of the production, use and disposal of a product over its life cycle. They then assign weights to the impacts of each of the material flows to try to make them comparable. A full assessment of the strengths and weaknesses of the LCA approach is beyond the scope of this review.[175] This review also includes one emission-based study.

TURI Five Chemicals Alternatives Assessment Study: The Toxic Use Reduction Institute (TURI) at the University of Massachusetts Lowell conducted a study to assess safer alternatives for five chemicals (lead, formaldehyde, perchloroethylene (PCE), hexavalent chromium and di(2-ethylhexyl)phthalate (DEHP). It applied an alternatives assessment methodology to evaluate alternatives in selected applications. The study includes a section on resilient flooring which addressed PVC plasticized with DEHP and a variety of alternatives, including linoleum, cork and polyolefin (studying the same single polyolefin studied in this paper). Product types are compared across a wide range of factors of health, environment and performance. The three alternatives are similar or better than PVC in almost every issue category.

U.S. Green Building Council TSAC LCA & Risk Assessment: The U.S. Green Building Council (USGBC) Technical Science Advisory Committee (TSAC) carried out a comparative assessment of PVC and a variety of alternative materials used in building materials, including vinyl and linoleum flooring (but not SBR or polyolefins).[176] Using a combination of LCA and risk assessment, the study concluded that vinyl (both VCT and vinyl sheet) flooring performed worse than linoleum on its measures of cancer and total human health. The impact of dioxin emissions from disposal was a particularly important factor distinguishing health impacts of PVC from linoleum. Sheet vinyl performed worst overall on all other environmental impact categories as well, except eutrophication.

NIST BEES LCA: The U.S. National Institute of Standards and Technology (NIST) has created a software package called BEES (Building for Environmental and Economic Sustainability) that allows comparative LCA analyses of a variety of building materials including linoleum and VCT.[177] BEES creates LCA scores for a range of environmental and human health impacts, and then combines them into a total score. At the individual impact level BEES 3.0 ranked VCT equal or worse than linoleum in every category except eutrophication, with VCT scoring anywhere from 1.4 to 8 times worse than linoleum. Linoleum even outperformed VCT on fossil fuel depletion, despite the fact that linoleum is imported from Europe, while VCT is manufactured in the US. Nonetheless, BEES 3.0 calculated that linoleum's eutrophication score outweighed all of the others and gave it a worse overall score.

Studies of the BEES protocol revealed numerous issues with that assessment. A Healthy Building Network (HBN) analysis of the BEES database revealed that the BEES analysis did not account for dioxin releases from manufacturing or end of life combustion. This omission biased the BEES analysis by leaving out the most important impact of the PVC life cycle.[178] Industry representatives asserted that the eutrophication calculation was one or more orders of magnitude too high as well. The most current release of the BEES software (BEES 4.0e) using new databases does now account for substantial dioxin flows from PVC manufacture. It still does not, however, account for end of life dioxin releases. Nonetheless in the new analysis, linoleum now comes out with far less environmental impact overall than VCT, primarily driven by a better human health score.

Fraunhofer LCA: The *Environmental Building News* has reported that a Fraunhofer Institute life cycle comparison commissioned by Amtico compared Stratica and vinyl flooring and concluded that the manufacture of

Stratica requires 30% less energy and 29% less water, resulting in 33% less contribution to global warming and 54% less acidification.[179] The authors attempted to obtain a copy of this study; however, the manufacturer informed us that it is unavailable in the United States.

Gunther European manufacturer LCA: Fourteen European producers of resilient floor coverings collaborated on an LCA study authored by Gunther in 1997 that compared floorings made with PVC, polyolefins, linoleum and SBR rubber.[180] For most of the measures compared, PVC performed either worst or second worst amongst floor covering types. For chemical waste, PVC was responsible for more than four times the waste than from rubber and more than ten times the waste than from polyolefin or linoleum. PVC also required the most non-renewable energy per unit of flooring. All of the products were roughly comparable for water demand and municipal waste generated. Synthetic rubber performed worst in one category – acidification potential due to sulfur emissions during vulcanization. PVC performed second worst in acidification with about half the potential of rubber. Polyolefin and linoleum produced about half the acidification potential of PVC.

Linoleum performed worst in this study in one category – global warming potential, with PVC second worst again. The study assumes that 100% of the linoleum would be disposed of in a landfill and anaerobically digested, creating methane. The calculation, however, fails to consider that a significant percentage of disposed linoleum is burned in a waste incinerator instead of landfilling, replacing the highly potent methane global warming emissions with far less potent carbon dioxide emissions. It is also unclear whether the European study accounted for the CO2 sequestered by the plants used as feedstock for the linoleum manufacture. Composting linoleum—a practice just now beginning to be undertaken—would also replace the methane emissions with carbon dioxide emissions.

Hodgson LBL emissions study: A team from the Lawrence Berkeley Laboratory at the University of California, Berkeley did laboratory measurements of VOC emissions from samples of a variety of interior finish products that are frequently used in relocatable classrooms. Products tested included vinyl composition tile (VCT), sheet vinyl, and an unspecified chlorine-free tile resilient flooring alternative.[181] The VOC emissions from the VCT and the chlorine-free tile contained only a few compounds at detectable levels. The emissions from the sheet vinyl flooring, however, contained a relatively large number of aromatic hydrocarbons, many of them higher molecular weight alkyl-substituted benzenes, including phenol. The study only addressed VOCs, not SVOCs, such as phthalates.

Summary

PVC: These comparative studies, with limited exceptions, indicate that the health and environmental performance of vinyl flooring is equal to or worse than the other flooring types in the categories assessed.

Synthetic rubber: Synthetic rubber – specifically SBR – was only evaluated in one of the studies. In the Gunther study it generally performed better than PVC but not as well as linoleum or polyolefins. Synthetic rubber performed worst in one category – acidification potential, due to sulfur emissions during vulcanization.

Polyolefins/Stratica: Stratica and the polyolefins generally performed well in the studies where it was assessed. It should be noted, however, that it was included in only two of the studies and neither was independent. Both were sponsored by manufacturers.

Linoleum: Linoleum generally scored well in these studies, except for the eutrophication category, in which it ranked worst in two studies. The magnitude of these results is a subject of some controversy, but it is a generally acknowledged problem area for linoleum (and any biobased product) and efforts are underway to rectify the problem. The global warming impact associated with linoleum disposal in the Gunther study, described above has not been reflected in other studies.

APPENDIX B: CHEMICAL HAZARD LISTS

All chemical hazard lists screened for the analysis in this paper are listed below with any categories used in the list to differentiate hazard types and confidence levels. The parenthetic abbreviation before the list title is the abbreviation used for reference to this list in Table 4 below which cross-references the chemicals identified in the text to any chemical hazard lists where they have been identified. The square bracketed phrase indicates the level of concern assigned in the analysis framework for this study and the chemical characteristic or health endpoint associated with that list or list category.

Persistent, Bioaccumulative and Toxic (PBT) substances include very Persistent and very Bioaccumulative (vPvB), very Persistent and Toxic (vPT) and very Bioaccumulative and Toxic (vBT).

Note that governmental bodies are still in the process of developing authoritative lists for neurotoxicity and endocrine disruption. Due to the importance of these endpoints, we have incorporated a list for each of these developed with peer review from surveys of the scientific literature.

- (CA Prop65) California Proposition 65 (Safe Drinking Water and Toxic Enforcement Act Of 1986) **Chemicals Known to the State to Cause Cancer or Reproductive Toxicity**
  A. "cancer" *[High concern – carcinogen]*
  B. developmental" *[High concern – development]*
  C. "male" (reproductive) *[High concern – reproductive]*
  D. "female" (reproductive) *[High concern – reproductive]*

  State of California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA) – Source: http://www.oehha.ca.gov/prop65/prop65_list/Newlist.html

- (EC CMR) **Carcinogens, Mutagens, & Toxic for Reproduction** – See consolidated version of Annex I of Directive 76/769 EEC, which includes Annex I of Directive 65/548/EEC (which is to be replaced by Annex XVII of REACH on 1 June 2009) point 29.
  A. Carcinogen Category 1: "known" *[High concern – carcinogen]*
  B. Carcinogen Category 2: "should be considered carcinogenic to humans" *[High concern – carcinogen]*
  C. Mutagen Category 1: "Substances known to be mutagenic to man" *[High concern – mutagen]*
  D. Mutagen Category 2: "Substances with should be regarded as if they are mutagenic to man" *[High concern – mutagen]*
  E. Reproduction category 1: "known" to impair fertility in humans or cause developmental toxicity in humans" *[High concern – reproduction]*
  F. Reproduction category 2: "should be regarded as if" they impair fertility to humans or cause developmental toxicity to humans" *[High concern – reproduction]*

  European Commission, Enterprise and Industry DG
  Source: http://ec.europa.eu/enterprise/chemicals/legislation/markrestr/index_en.htm

- (EC ESIS} **European Chemical Substances Information System (ESIS) PBT list**
  A. Fulfilling PBT criteria *[Very high concern – PBT]*
  B. Fulfilling POP criteria *[Very high concern – PBT]*

C. Fulfilling vPvB criteria *[Very high concern – PBT]*

European Commission, Joint Research Centre, Institute for Health & Consumer Protection
Source: http://ecb.jrc.it/esis/index.php?PGM=pbt

- (EC Risk) **Substances with EU Risk & Safety Phrases** (Commission Directive 67-548-EEC)
  A. R45 "May cause cancer" *[High concern – carcinogen]*
  B. R46 "May cause heritable genetic damage" *[High concern – mutagen]*
  C. R49 "May cause cancer by inhalation" *[High concern – carcinogen]*
  D. R60 "May impair fertility" *[High concern – reproduction]*
  E. R61 "May cause harm to the unborn child" *[High concern – reproduction]*
  F. R63 "Possible risk of harm to the unborn child" [Moderate concern – reproduction]

  Joint Research Centre (DG JRC), Institute for Health and Consumer Protection (IHCP)
  Source: http://ecb.jrc.it/documentation/ (click on: "DOCUMENTS", "CLASSIFICATION-LABELLING", "DIRECTIVE 67-548-EEC", "ANNEX I OF DIRECTIVE 67-548-EEC", and then either of the files listed as: "Annex I of Directive 67548EEC")

- (EPA IRIS} **Integrated Risk Information System database**
  1. 2005 Guidelines:
     A. "Carcinogenic to humans" *[High concern – carcinogen]*
     B. "Likely to be carcinogenic to humans" *[High concern – carcinogen]*
     C. "Suggestive evidence of carcinogenic potential" [Moderate concern – carcinogen]
     D. "Unknown cancer" [Moderate concern]
  2. 1999 Guidelines:
     A. "Carcinogenic to humans" *[High concern – carcinogen]*
     B. "Likely to be carcinogenic to humans" *[High concern – carcinogen]*
     C. "Suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential" [Moderate concern – carcinogen]
     D. "Unknown cancer" [Moderate concern – carcinogen]
  3. 1996 Guidelines:
     A. "Known/likely human carcinogen" *[High concern – carcinogen]*
     B. "Unknown cancer" [Moderate concern – carcinogen]
  4. 1986 Guidelines:
     A. Group A – Human Carcinogen" *[High concern – carcinogen]*
     B. "Group B1 – Probable human carcinogen – based on limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in animals" *[High concern – carcinogen]*
     C. "Group B2 – Probable human carcinogen- based on sufficient evidence of carcinogenicity in animals)" *[High concern – carcinogen]*
     D. Group C – "Possible human carcinogen" [Moderate concern – carcinogen]
     E. Group D – "Not classifiable as to human carcinogenicity" [Moderate concern – carcinogen]

  U.S. Environmental Protection Agency (EPA), USEPA National Center for Environmental Assessment
  Source: http://www.epa.gov/ncea/iris/search_human.htm

- (EPA NWMP) **NWMP PBT Priority Chemicals List.** *[Very high concern – PBT]*

  U.S. Environmental Protection Agency, National Waste Minimization Program
  Source: http://www.epa.gov/epawaste/hazard/wastemin/priority.htm

- (EPA PPT) **Priority PBT Profiles** *[Very high concern – PBT]*

  U.S. Environmental Protection Agency, Pollution Prevention & Toxics, Persistent Bioaccumulative and Toxic Chemical Program – Source: http://www.epa.gov/opptintr/pbt/pubs/cheminfo.htm

- (EPA TRI) **PBT Chemical List**, *[Very high concern – PBT]*

  U.S. Environmental Protection Agency, Toxic Release Inventory Program
  Source: http://www.epa.gov/triinter/trichemicals/pbt%20chemicals/pbt_chem_list.htm

- (IARC) **Agents Reviewed by the IARC Monographs**

  A. Group 1: Agent is carcinogenic to humans *[High concern – carcinogen]*

  B. Group 2A: Agent is probably carcinogenic to humans *[High concern – carcinogen]*

  C. Group 2b: Possibly carcinogenic to humans [Moderate concern – carcinogen]

  International Agency for Research on Cancer – Source: http://monographs.iarc.fr/ENG/Classification/

- (Lancet**) List of 201 Chemicals known to be neurotoxic in man.**

  A. Developmental neurotoxicant – *[High concern – developmental neurotoxicant]*

  B. Neurotoxicant – [Moderate concern – neurotoxicant]

  "Developmental neurotoxicity of industrial chemicals" Grandjean, P & PJ Landrigan. 2006, *The Lancet*, v.368: 2167-2178

  Source: http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(06)69665-7

- (NTP ROC) **Report on Carcinogens**

  C. Known to be Human Carcinogens *[High concern – carcinogen]*

  D. Reasonably Anticipated to be Human Carcinogens *[High concern – carcinogen]*

  U.S. National Institutes of Health, National Institute of Environmental Health Sciences, National Toxicology Program (NTP) – Source: http://ehis.niehs.nih.gov/roc

- (OSF) **Widespread Pollutants with Endocrine-disrupting Effects List** and
- **Background Information on Common Endocrine-Disrupting Compounds [High concern – endocrine disruptor]**

  Our Stolen Future authors Dr. Theo Colburn, Dianne Dumanoski, and Dr. John Peterson Myers
  Source: http://www.ourstolenfuture.org/Basics/chemlist.htm
  http://www.ourstolenfuture.org/Basics/chemuses.htm

- (WA PBT) **Chapter 173-333 WAC Persistent Bioaccumulative Toxins (PBT) List** *[Very high concern – PBT]*

  State of Washington, Department of Ecology – Source: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-333-310

- (UN POP) **List of 12 POPs currently under the Stockholm Convention** – *[Very high concern – PBT]*

  United Nations Environment Programme (UNEP), Stockholm Convention Secretariat
  Stockholm Convention on Persistent Organic Pollutants (POPs)
  Source: http://chm.pops.int/Convention/12POPs/tabid/296/language/en-US/Default.aspx

- (UN POPRC) **Chemicals in the Stockholm Convention POPRC review process** – *[High concern – PBT]*

  United Nations Environment Programme (UNEP), Stockholm Convention Secretariat
  Stockholm Convention on Persistent Organic Pollutants (POPs)
  Source: http://chm.pops.int/Convention/POPsReviewCommittee/tabid/60/language/en-US/Default.aspx

Table 4: Resilient Flooring Chemical Listings on Hazard Databases

Chemicals	CAS No	CA Prop 65	EC CMR	EC ESIS	EC Risk	EPA IRIS	EPA NWMP	EPA PPT	EPA TRI	IARC	Lancet	NTP ROC	OSF	UNPOP	UNPOPRC	WA PBT
1,3, butadiene	106-99-0	X	X		X	X				X		X				
1,1,1-trichloroethane	71-55-6				X						X					
Acetaldehyde	75-07-0	X			X					X		X				
Acrylic acid	79-10-7				X											
Acrylonitrile	107-13-1	X	X		X	X						X				
Antimony trioxide	1309-64-4	X			X					X						
Asbestos	1332-21-4	X				X				X		X				
Benzene	71-43-2	X	X			X				X						
Benzo(g.h.l)perylene	191-24-2						X		X							X
Bromoxynil	1689-84-5	X														
Butyl benzyl phthalate (BBP or BzBP)	85-68-7	X	X		X	X							X			
Cadmium	7440-43-9	X			X	X	X			X						X
Carbon black (pigment)	1333-86-4	X								X						
Chlorinated paraffins	85535-84-8	X		X	X							X			X	X
Chlorine	7782-50-5				X											
decaBDE	1163-19-5			X								X	X			X
Di(2-ethylhexyl phthalate (DEHP)	117-81-7	X	X		X	X						X	X			
Dimethylformamide	68-12-2			X	X											
Di-n-hexyl phthalate (DnHP)	84-75-3	X														
Dioxins	1746-01-6	X					X	X	X	X		X	X	X		X
Dithiocarbamates	Multiple												X			
Epichlorohydrin	106-89-8	X	X			X				X		X				
Ethylbenzene	100-41-4	X								X						
Ethylene	74-85-1										X					
Ethylene dichloride (EDC)	107-06-2	X				X						X				
Ethylene oxide	75-21-8	X	X		X					X	X	X				
Formaldehyde	50-00-0	X				X				X		X				
Hexachlorobenzene (HCB)	118-74-1	X	X	X	X		X	X	X		X	X		X		X
Lead	1-12-8	X				X	X	X	X	X	X	X	X			X
Mercury	7439-97-6	X			X		X	X	X		X		X			
PFOS	29457-72-5														X	
Polychlorinated biphenyls (PCBs)	1336-36-3	X	X	X	X		X	X	X		X	X	X	X		X
Polycyclic aromatic compounds	65996-93-2			X			X			X		X				X
Styrene	100-42-5									X	X		X			
Titanium dioxide	13463-67-7									X						
Toluene	108-88-3	X									X	X				
Tributyltin	688-73-3												X			
Trichlorfon	52-68-6										X					
Trifluran	1582-09-8				X	X	X		X				X			
Vinyl acetate	108-05-4									X						
Vinyl chloride	75-01-4	X	X			X				X	X	X				
Zinc	7440-66				X											

APPENDIX C: PVC AND DIOXIN

Dioxins are created in the manufacture of PVC during ethylene dichloride (EDC)/vinyl chloride monomer (VCM) production, released by on-site incinerators, flares, boilers, waste water treatment systems and even in trace quantities in vinyl resins. EDC/VCM production for PVC is one of the top well-quantified sources of dioxin in U.S. EPA's Inventory of Sources and Releases of Dioxin (number 8 for 2000) and is the largest source of dioxins in the Inventory that is specific to the manufacture of a building material.[182] The EPA Inventory number estimates only the fugitive and stack air emissions and water emissions directly from manufacturing plants. Far more dioxin is generated in the manufacturing process than is identified in the EPA Inventory. The chlorine industry as a whole (of which PVC manufacture is a major portion) reported in its Toxic Release Inventory (TRI) data that it sent 20 times more dioxin (260 g TEQ*) in heavy ends, tars and other hazardous materials to landfills and injection wells in 2000 as it did to the air and water, only 100 g TEQ of which went to hazardous waste landfills.[183] Another 810 g TEQ was transferred to "off site management," some incinerated, some landfilled, some unspecified.[184] Finally a massive 6900 g TEQ are "treated on and off site," most commonly in hazardous waste incinerators.[185]

The EPA's Inventory estimate of the likely magnitude of the emissions from landfill fires is substantial at 1,126 TEQ. This is over twice the size of the next largest source – backyard barrel burning, which is estimated at 498.5 TEQ. Burn barrel sources are frequently identified as "the largest source" of dioxins because of confusion about the organization of the EPA Inventory lists. The listing most frequently referenced is Table 1-12 of the Inventory, a table which lists the EPA's ranking of "well-quantified sources." "Well quantified sources" are those for which EPA has a relatively high level of confidence in its estimate. Landfills fires are not included in this table because the EPA's confidence level in the precision of the estimate is low. The estimate should be used for indicating approximate magnitude, not precise amount. Directly measuring total actual emissions from a diffuse underground fire in a landfill is nearly impossible and requires substantial sampling and modeling to estimate. Nonetheless, the EPA's estimate of the likely magnitude of the emissions from landfill fires is far larger than that from burn barrels. There is significant evidence that PVC is the leading source of dioxin releases from these landfill fires.[186]

The same EPA Inventory also characterizes forest fires as another low confidence, but potentially even larger source of dioxins. Currently used estimates of forest fire emission factors are likely high by an order of magnitude or more due to confounding factors in the studies utilized. There is significant evidence that dioxin emission rates from forest fires are actually not very significant and that much of what emits from them may be due to re-suspension of dioxin from industrial sources that was previously filtered out of the atmosphere by the trees.[187]

* TEQ is "toxic equivalents" – a measure of the toxicity of a mixture of dioxins adjusted for the equivalent weight of the most toxic form of dioxin, 2,3,7,8-TCDD

APPENDIX D: COMPOSITION OF STRATICA

Patents[188] and a Swedish product content declaration[189] filed by Amtico, the manufacturer of Stratica, indicate the flooring contains the following ingredients,[190] roughly in order of quantity:

- mineral fillers make up one third to one half and may be any one or more of the following
  - calcium carbonate (CAS 471-34-1)
  - kaolin (CAS 1332-58-7)
  - hydrated aluminum oxide (CAS 21645-51-2)

- ethylene/methyl acrylate resin (CAS 25103-74-6) – trade name Lotryl 18MA02 also known as ethylene/methacrylate copolymer, propenoic acid, methyl ester, polymer with ethane[191]

- ethylene/methacrylic acid copolymer (E/MAA, trade name Surlyn 9910 CAS 9078-96-0)
  - zinc compounds (CAS 7440-66-6); added to E/MAA as an acid neutralizer
    MAA is made from Isobutylene (CAS 115-11-7) and tert-butanol (CAS 75-65-0, oxidized into methacrolein (CAS 78-85-3) and then into MAA[192]

- Backing of either:
  - Trimethylolpropane trimethacrylate (TMPTMA – CAS 3290-92-4) from Methyl Acrylate (CAS # 96-33-3) or
  - Trimethylolpropane (TMP – CAS 77-99)

- Lotader 4700 (ethylene/acrylic ester/maleic anhydride terpolymer binder resin,

- Polymer binder of either
  - ethylene/maleic anhydride terpolymer (trade name Lotader CAS 41171-14-6 100% by weight, 2-propenoic acid, ethyl ester, polymer with ethane and 2,5-furandione (maleic anhydride CAS 108-31-6).[193]
  - ethylene vinyl acetate (EVA – CAS 24937-78-8).

- Pigments

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TRI ID 70602FRSTNLA108; Firestone, Orange, TX, TRI ID 77630FRSTNFARMR; Goodyear, Beaumont, TX, RI ID 77720THGDYINTER; Goodyear, Houston, TX, TRI ID 73505GDYRT1GOOD; ISP Elastomers, Port Neches, TX, TRI ID 77651SPSYN1615M; Lion Copolymer, Baton Rouge, LA, TRI ID 70821CPLYM5955S.

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