Post-Consumer Polyvinyl Chloride in Building Products

A Healthy Building Network Evaluation
for StopWaste and the Optimizing Recycling Collaboration

2015

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Acknowledgements: We are grateful to Jeff Gearhart, Mike Belliveau, Feliks Bezati, Amy Costello, Mikhail Davis, Tracey Easthope, Diane Martel, Mike Schade, Tatiana Santos and Bev Thorpe for their information and insights.

Funding for research on post-consumer PVC feedstock was provided by StopWaste and donors to the Healthy Building Network (HBN). It was conducted using an evaluative framework to optimize recycling developed by StopWaste, the San Francisco Department of the Environment, and HBN (the "optimizing recycling collaboration").

The views expressed in this evaluation are those of the authors and do not necessarily reflect the position or policy of StopWaste, the San Francisco Department of the Environment, or donors to HBN.

Originally published April 2015, revised July 2015.
Cover photo left: © Greenpeace
Photo right: Imported cable scrap in China. Photo public domain.

This briefing paper on post-consumer recycled PVC is a prequel to a forthcoming white paper by a new collaboration looking to optimize recycled content feedstocks commonly used in building materials.

The recycling industry and building product manufacturers have made significant strides toward the vision of a closed loop material system, whereby materials produced today become the raw materials for their products in the future. Contamination of feedstocks with chemicals of concern, however, is reducing feedstock value, impeding growth of recycling rates and potentially endangering human health. The white paper assesses the extent of these challenges based on reviews of eleven sample feedstocks. It describes how best practices for monitoring and improving the purity of recycled feedstocks in building materials can improve feedstock value, protect human health and dramatically increase recycling rates in North America.

This first phase of this collaboration, the results of which are summarized in the forthcoming white paper, identifies pathways to optimize the benefits of using post-consumer recycled feedstocks in building products sold in the Bay Area of California and beyond. The most common conditions of post-consumer feedstocks, as consumed in the United States, establish the baseline for assessments found in this report.

A second phase of this report, expected to begin in the summer of 2015, will explore in more depth the products that make use of recycled feedstocks in building materials.

The white paper and subsequent feedstock briefing papers will be found at HBN's website, http://healthybuilding.net/content/optimize-recycling.

Post-Consumer Polyvinyl Chloride (PVC) in Building Products

- **Feedstock Health and Environmental Hazards**
- **Supply Chain Quality Controls / Transparency**
- **Green Jobs & Other Local Economic Impacts**
- **Room to Grow**

Overall

Major retailers[1] and a leading manufacturer[2] this month announced they are rapidly phasing out the use of phthalate plasticizers in resilient floors. As reformulated PVC products enter the recycling stream, this post-consumer material will provide a preferable option to virgin PVC feedstocks in building products.

Pathways for Optimization

Many manufacturers are moving away from lead and cadmium stabilizers and phthalate plasticizers in new products, and those should be preferred because they reduce exposure to toxicants, as well as provide a cleaner feedstock for future materials recycling. Given vinyl's durability, it could take a decade or more before significant volumes of these cleaner products enter the waste stream for reuse. If a project specification requires recycled PVC, seek recycled content that has been screened for contaminants like heavy metals and phthalates. Recycled PVC must be assumed to contain these additives unless manufacturers provide documentation to the contrary. Chemical (rather than mechanical) recycling processes can eliminate additives of concern from current feedstocks and can better protect workers. However the technology is nascent and the most common method can create toxic dioxin emissions, not to mention other potential unintended consequences. Further research is needed to determine best practices for chemical recycling processes.

Many manufacturers are moving away from lead and cadmium stabilizers and phthalate plasticizers in new products, and those should be preferred because they reduce exposure to toxicants, as well as provide a cleaner feedstock for future materials recycling.

1 See HealthyStuff.org for further information.

2 See discussion on Tarkett's limits on post-consumer PVC on page 22.

Recommendations

For Manufacturers

Incorporate post-consumer PVC where the source is known, contaminants are identified, and the incorporation of the feedstock does not elevate contamination levels in the final product above established thresholds of concern. PVC building product manufacturers should demand transparency, and a chain of custody, from suppliers of recycled feedstocks. If sources are unknown or undisclosed, screen for contaminants including lead and cadmium, organotin catalysts, PCBs, and phthalates. For products that may come into contact with end users, the safest course of action is for manufacturers to stop using highly contaminated recycled feedstocks. Not only does this limit exposure, but it also creates the ability to take-back products at end-of-use and the ability to recycle them indefinitely. Manufacturers should also ensure that their recycled feedstock comes from operations that use best practices to protect the health and safety of workers. Manufacturers can also research and develop chemical recycling infrastructure that can optimize PVC recycling.

For Consumers

Seek out manufacturers that have eliminated problematic stabilizers and plasticizers in their products. Additionally, prefer companies that track their sources and have tested the concentration of contaminants in their recycled content. Look for manufacturers that ensure worker and environmental protection during processing stages.

For Government Agencies

Develop regulatory thresholds that are protective of human and environmental health for allowable amounts of high hazard content in recycled feedstocks used in building products. This may impact short-term recyclability, but will increase overall future materials reuse cycles due to higher value and less contaminated products for the industry. In the absence of regulatory action, agencies, consumers, recyclers, industrial hygienists and product manufacturers should collaboratively develop unified voluntary thresholds.

For the Recycling Industry

Encourage or invest in processes that can remove problematic ingredients from global feedstocks, such as depolymerization and other chemical recycling processes. Ensure that as newer PVC formulations enter the recycling stream, they are not commingled with old contaminated feedstocks.

About Post-Consumer Polyvinyl Chloride

Polyvinyl chloride products entering the waste stream may be either rigid (such as window frames and pipes) or flexible (such as flooring, roofing membranes, and wire & cable scrap insulation). Manufacturers add a wide range of functional additives to PVC resins to create different performance characteristics. Many additives such as phthalate plasticizers and lead stabilizers are toxic, and some manufacturers are beginning to reformulate their products to avoid them. But the industry's transformation is in its infancy.

Roofing membrane is one of the more frequently recycled PVC materials.

Recycling processes can be mechanical or chemical, but chemical processes potentially have significant benefits over mechanical. Although frequently referred to as "mechanical recycling," the dominant method of plastics recycling is actually a labor-intensive activity in which workers, who are poorly trained, poorly informed and poorly protected, hand-sort waste streams and glean the plastic in small batches, disassembling products and stripping wires and cables by hand, sometimes burning plastics in open pits in order to extract more precious metals. Though mechanical recycling dominates the industry because of lower cost, chemical recycling technologies can strip additives, like heavy metal stabilizers, from PVC. If done in significant quantities, chemical recycling processes could therefore overcome the toxic additive problem at a faster rate than waiting for "clean PVC" to enter the waste stream. Furthermore, the removal of problematic legacy functional additives via chemical processes can result in higher quality materials for reuse. Chemical recycling labor processes, however, are currently more expensive than mechanical recycling which relies upon cheap, exploited overseas labor. Additionally, similar to virgin PVC production, these chemical processes also have environmental impacts, such as the formation of toxic dioxin emissions.

A variety of PVC types may be commingled in the recycling process, such as those that process both wire and cable insulation and roofing membranes into feedstocks used in new flooring and other building materials. Without proper specifications and screening of the materials streams, the post-consumer PVC used in vinyl flooring is more likely to come from insulation jackets stripped from old cables and wires than from discarded vinyl flooring. These jackets typically contain high levels of heavy metals, problematic plasticizers, and even PCBs.

Plastic scrap traders engage in a global trade in various forms of vinyl scrap, a trade that Adam Minter describes as "shadowy" in his popular 2013 book on recycling in China, *Junkyard Planet*. (1) Manufacturers have little idea where their recycled PVC is coming from. Many U.S. exports are simply labeled "plastic scrap." Some recycled PVC is recovered from other waste streams, such as cable & scrap, that are primarily recycled for their metal content, not the skins that are ground and used in floors and other PVC products. The PVC that comes from these sources can be highly contaminated, as evidenced by results of tests on the recycled content in 74 PVC floors sold by six major retailers in the United States. The Ecology Center (further details on page 16) found that some floors contained over 1% lead and 2% cadmium, two highly toxic heavy metals.

The origin and chain of custody of recycled PVC materials usually are not disclosed to manufacturers, never mind consumers. Chain of custody information and transparency throughout the supply chain can help target substances to be tested and eliminated from recycled feedstock, when necessary, or to find suitable uses where they will not impact human health or the environment.

Few PVC recycling operations screen their inputs for toxicants. European recyclers acknowledge, in submissions to the European Commission (see page 10), that phthalates and toxic metal stabilizers remain in the recycled PVC feedstocks that they currently produce, and that these substances are present above regulatory thresholds of concern.

However, some flooring manufacturers are providing leadership in the absence of regulations, and are taking preventive action to clean up their supply chains. Armstrong sources only flooring waste for its post-consumer content. Interface does the same for its carpets, sourcing only PVC carpet waste for its post-consumer content. This has the benefit of excluding PVC sources with higher contamination levels, e.g. wire and cable jackets, but does not eliminate all legacy additives from carpets and floors.

Tarkett has adopted an aggressive phthalate standard for its PVC resilient floors and carpets. Tarkett has phased-out the use of virgin phthalates from all their products. Further, Tarkett decided that the best way to prevent their products from being contaminated with phthalates and other toxic substances was to stop using any post-consumer PVC at its plants in Europe and to prohibit its use by suppliers in Asia. In order to ensure that new floors contain no more than 0.1% phthalates, Tarkett's only sourcing of post-consumer PVC comes from vinyl composition tile floors in the U.S. that contain relatively low levels of these plasticizers. In the future, as phthalate-free PVC flooring products reach their end of use, Tarkett has indicated that they intend to reclaim and then incorporate these reformulated floors into new products, as part of a corporate circular economy directive.

Behind the Ratings

1 Feedstock Health and Environmental Hazards

PVC scrap contains a wide variety of ingredients, including substances that are, or will be soon, subject to bans for use in new products. Over time, as new generation PVC products are collected for recycling, the use of alternative plasticizers and stabilizers will reduce the hazards of recycled PVC feedstocks during their use. End of use concerns (e.g. formation of dioxins during incineration, landfill fires and backyard burning), however, will remain.

A. Standard Content

PVC is produced through the polymerization of vinyl chloride monomer. The resulting material is hard and resinous. Many other substances are mixed in to provide key performance characteristics for various applications, such as flexibility or UV protection. Two significant additives are stabilizers, which are used in all types of PVC, and plasticizers, which are used in flexible PVC products like resilient floors, wall coverings, and roofing membranes.

i. Plasticizers

PVC formulators add as much as 50% plasticizer by weight to some products, like vinyl roofing membrane.[3]

Phthalates have long been the standard plasticizers in flexible PVCs, but abundant evidence of human health harm from exposure to phthalates is signaling their demise. Many phthalate plasticizers are known endocrine disrupting chemicals - chemicals that disrupt hormone cell signal pathways – and have toxic effects on reproduction and development. Additionally, some phthalates are known carcinogens and have been identified as likely asthmagens. These additives are not tightly bound to the PVC molecules and are known to migrate from PVC products. They are commonly found in both environmental dust studies in buildings with PVC products and in biomonitoring studies of occupants.

3 Roofing membranes are one of the most commonly recycled PVC wastes in Europe. "European roofing manufacturers have been recycling PVC roof membranes at the end of their service life for well over a decade now," notes Sika Sarnafil, a leading PVC membrane manufacturer. ("Sika Sarnafil PVC Roof Membrane Recycling Program." Sika Sarnafil. Retrieved April 2015 from http://usa.sarnafil.sika.com/en/group/roofing-sustainability/what-is-sustainable-roofing/pvc-roof-recycling.html).

In response to consumer and regulatory pressures, some types of phthalates have been banned in Europe (see Legacy Content section on page 12), and some PVC building product manufacturers have begun to offer phthalate-free products. In 2014, the Healthy Building Network examined six alternative plasticizers being used in building products. HBN's literature review found that all of the non-phthalate plasticizers studied for which data was available present fewer human health hazards than phthalates. (2)

> "More than 80% of the initial volume of lead-based stabilisers has already been phased out and the remainder will soon disappear totally from articles produced in the EU 27. Some residual ('legacy') lead may still be present in articles made from recycled PVC, at levels exceeding the proposed limit of 0.05% [weight for weight]. After 2015 this will be the only source of lead in PVC articles produced in the EU-27."
>
> *– European PVC industry consortium, 2013*

ii. Stabilizers

Heavy metals used as stabilizers include lead, a potent developmental toxicant; cadmium, a potential neurotoxicant and carcinogen; and organotin catalysts, some of which are reproductive and developmental toxicants. US and European manufacturers have replaced lead and cadmium stabilizers with calcium-zinc, barium-zinc and organotin stabilizers in most — but not all — applications. (3)

Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH),[4] the European Union's chemical regulatory system, is about to ban the use of lead stabilizers in many PVC applications.

In December 2014, European Union member states in a REACH committee recommended restricting lead in consumer products that children can mouth. "If the European Parliament and Council of Ministers do not oppose the proposal, and it is formally adopted by the European Commission, the restrictions will be added to REACH Annex XVII," *Chemical Week* reported. "Consequently, the articles covered by the restriction will not be allowed on the market if the concentration of lead, expressed as metal, in them or their parts, reaches 0.05% by weight [500 ppm]." (4)

4 REACH entered into force in 2007, and is designed "to improve the protection of human health and the environment from the risks that can be posed by chemicals."

PVC manufacturers have long used lead stabilizers. They continue to incorporate lead stabilizers in rigid PVC products like window frames and pipes. So the European PVC industry resisted the REACH committee's proposed restriction. In 2013, their consortium reported, "more than 80% of the initial volume of lead-based stabilisers has already been phased out and the remainder will soon disappear totally from articles produced in the EU 27. Some residual ("legacy") lead may still be present in articles made from recycled PVC, at levels exceeding the proposed limit of 0.05% [weight for weight]. After 2015 this will be the only source of lead in PVC articles produced in the EU-27." The industry argued that "lead embedded in a PVC plastic matrix has a very low availability" and "most PVC recycling is done into construction or infrastructure products which are either affixed or which have dimensions exceeding the mouthability limits." (5)

Children have been exposed to high levels of lead from deteriorated PVC mini-blinds.

As many studies have demonstrated, children are exposed to lead, in dust form, as they crawl and play on floors. (6) And the recycled PVC used in floors, as revealed by recent Ecology Center tests (see Table 1, page 17), can far exceed the proposed 0.05% limit. The Center tested 74 floors. The lead levels in the inner (recycled content) layers was 0.11%; some reached over 1%.

A report to the California Integrated Waste Management Board noted at least one instance of construction products exposing children to these toxic metal additives. It reported, "Circumstances where children have been exposed to lead-based stabilizers from contact with aged, higher lead content, imported mini-blinds have been documented." (7)

In 1996, the Consumer Products Safety Commission recommended "that consumers remove these vinyl mini-blinds. Young children can ingest lead by wiping their hands on the blinds and then putting their hands in their mouths." CPSC tests found lead levels in the mini-blinds as high as 1.23 percent by weight. Levels of lead on the surface "were high enough to present a lead poisoning hazard to children 6 years of age and younger if they ingested small amounts of dust from the blinds over a short period of time. Some states have identified children with elevated blood lead levels attributable to vinyl mini-blinds." (8)

Where lead and children come in contact, the stakes are high. "No safe threshold of exposure has been scientifically established" at which lead does not impair "the development of children's central nervous systems," reads a REACH background document on the proposed lead restrictions. (9)

The impact of these restrictions will have wide ramifications for PVC recycling, according to the industry. "Legislation restricting the presence of lead in articles might have a negative impact on PVC recycling: lead-containing recycled PVC could no longer be used to produce new PVC articles," argued a July 2014 posting by VinylPlus, a European industry consortium. "This could undermine the PVC industry's commitment to significantly increase the volume of recycled post-consumer PVC waste and thus enhance the sustainability of the PVC chain." (10)

Here, two sustainability goals are yet to be reconciled: the PVC industry's goals to increase recycling rates and chemical and human health experts' efforts to prevent exposures to harmful substances. If the industry were to invest in chemical, rather than mechanical, recycling processing, it could come closer to resolving this dilemma. Another option is to restrict the use of recycled PVC to products that pose no conceivable exposure risk, especially to children.

B. Legacy Content

As noted above, lead stabilizers are still in use, but are on the verge of becoming legacy ingredients in some regions. Another group of common PVC additives recently reached legacy status to a limited extent in Europe: phthalate plasticizers.

Phthalates

On February 21, 2015, under REACH, the European Union (EU) "sunsetted" the production and use of four phthalates, including the most common PVC flooring plasticizer, di(2-ethylhexyl) phthalate (DEHP). There are many loopholes; most significantly, it does not restrict the import of products containing the four plasticizers. Additionally, European PVC recycling companies[5] are seeking authorization to continue their business as usual, without restrictions on DEHP. (11)

The European Chemicals Agency (ECHA), under pressure from the PVC industry, has recommended that the EC "grant certain manufacturers four years for ongoing use of DEHP in PVC production and twelve years for ongoing recycling of PVC," according to the Center for Health, Environment, and Justice. (12) "By granting authorization for the use of DEHP in a wide range of PVC products and in recycled PVC plastic, the Commission will fail the main objective of REACH," argued a petition from 55 European civil society organizations. (13)

The ECHA's recommendation "did not take into account the actual exposure of the European population to DEHP and dismissed both its endocrine disrupting properties and its impacts on adults, newborns and children," they charged. (14) Studies have found that children are exposed to higher levels of phthalates than adults in flexible vinyl floors, in settings such as nursery schools. (15)

PCBs

Another notable class of legacy toxicants may be present in post-consumer PVC: polychlorinated biphenyls (PCBs). These chemicals were widely used in PVC wire and cable insulation until the 1970s. Old wire and cable scrap continues to enter the waste processing stream and may wind up in floors and other products using recycled PVC feedstock.

5 Vinyloop Ferrara SPA, Plastic Planet SRL, and Stena Recycling AB.

CalRecycle warned in 2006 that "there may be a potential risk of exposure to PCBs in recycled-content PVC products that may contain PCBs as contaminants from old PVC coated wires or electrical components used as recycling feedstock." (16)

C. Processing Operations

Post-consumer PVC scrap containing higher levels of toxicants — and the manufacturing of new products from it — typically ends up in countries with fewer environmental and worker protections than the countries from which the scrap and processing industries have migrated. Although frequently referred to as "mechanical recycling," the dominant method of plastics recycling is actually a *labor intensive* activity in which workers who are poorly trained, poorly informed and poorly protected hand-sort waste streams and glean the plastic in small batches, disassembling products and stripping wires and cables by hand, sometimes burning plastics in open pits in order to extract more precious metals.

The leading processor in the world is China, which handles an estimated 82% of the United States' PVC waste scrap exports. (17) (As with many plastics recycling statistics, it is unclear whether this percentage includes post-consumer, post-industrial, or both types of sources.)

Stories of pollution in China's PVC and electronic waste recycling industry are legion, such as in Taizhou, one of China's major centers of plastic waste recycling. According to a local industrial trade website, "50% of Taizhou City plastic material consumption was imported as scrap." (18) Most of this scrap is low-quality, post-consumer material.

Recycling typically happens at an artisanal level. Small enterprises recover PVC from imported wastes with unsophisticated equipment and little or no personal protection. The processed materials are aggregated and sold to manufacturers in China who make massive volumes of vinyl flooring under contract to retailers in North America and Europe.

Artisanal plastic waste processing exposes workers to phthalates and other substances of concern, and can contaminate the surrounding environment. A study reported in the *Bulletin of Environmental Contamination & Toxicology* (2009) identified some of the impacts of recycling imported wastes in the Taizhou area. "Phthalate esters (PAEs) including dimethyl phthalate (DMP), diethyl phthalate (DEP), di-n-butyl phthalate (DBP), Di-(2-ethylhexyl) phthalate (DEHP) and di-n-octyl phthalate (DnOP) in the e-waste soils were collected and analyzed from sites Fengjiang, Nanshan and Meishu in Taizhou city," reported a local team of scientists. "The result showed that the total PAEs concentrations ranged from 12.566 to 46.669 mg/kg in these three sites. DEHP, DBP and DEP were the major phthalates accounting for more than 94% of total phthalates studied. Comparing to the results from other studies, the e-waste soils from Taizhou city were severely contaminated with PAEs." (19)

"Mechanical recycling of PVC can release additives, including phthalates and stabilizers, which may be dispersed into the recycled products, or the environment or, if they are captured, disposed of on land or in incinerators."

- Joe Thornton, *Environmental Impacts of Polyvinyl Chloride Building Materials*. Healthy Building Network. 2002.

Water pollution from plastic waste recycling near Taizhou city, China.
For more information visit: http://www.tz12345.gov.cn/article/show/1366.htm.

> "Why recycle waste in China, and not Japan or America? Because environmental costs aren't factored into the equation."
>
> – Director Wang Jiuliang

Director Wang Jiuliang's forthcoming documentary, *Plastic China*, takes a deep look at the human and environmental costs of "the huge amount of imported foreign waste that is recycled in China." The director explains, "When the waste arrives in China, whether it is machinery, electronics, paper, or plastic waste, it is all sorted manually in the most primitive way. The process is not mechanized because China has a vast supply of cheap labor. The damage to human health is obvious: allergy, poisoning, and various other kinds of harm and injury, not to mention the water pollution caused by recycling plastics."

He asks, "Why does waste from around the world end up in China? I believe for two reasons. First, as the largest manufacturer of cheap goods, China is hungry for raw materials. Secondly, China sets a relatively low bar for environmental protection standards. If you take the environmental costs of recycling into account, you realize it's not at all cheap. Why recycle waste in China, and not Japan or America? Because environmental costs aren't factored into the equation." (Ina Wang, "Trash Talking, Literally, with China's Determined Documentarian Wang Jiuliang")

D. Elements in Recycled Vinyl Floors: Ecology Center findings

In support of this HBN evaluation of recycled PVC feedstock, the Ecology Center[6] shared results of XRF tests it ran recently on seventy-four (74) PVC floors purchased in 2014 and 2015. The floors were sold by six leading retail stores and were produced by 8 different manufacturing brands. The Ecology Center determined that each floor's top layer was virgin PVC, and that the inner layer contained recycled PVC. The floors' product literature did not advertise the presence of post-consumer PVC; however, the floors' inner layers contained elements like bromine, gold and copper that are not usually found in PVC floors but are more typically components of electronic waste.[7]

Of particular concern: the inner layers of 74 floors contained, on average, 1,144 parts per million (ppm) of lead and 1,846 ppm of cadmium (compared to almost none in the top layer). The Ecology Center found maximum levels of 10,608 ppm lead (over 1% of the inner layer) and 22,974 ppm cadmium (>2% of the inner layer). By comparison, the U.S. Consumer Product Safety Commission prohibits the sale of any children's products containing over 100 ppm lead. (20) The European Commission prohibits the use of cadmium in virgin PVC products at levels above 0.01% (100 ppm), or above 0.1% (1,000 ppm) in products, including building materials, that contain "recovered PVC." (21)

6 http://www.ecocenter.org/

7 Jeff Gearhart, research director of the Ecology Center, says "all of these [electronic waste analyses] have elemental characterizations of waste which are comparable to what we are seeing in flooring," and provides these references for comparison:

- Velhlow, Juergen, and Forschungszentrium Karlsruhe. "Electrical and Electronic Plastics Waste Co-Combustion with Municipal Solid Waste for Energy Recovery." NAWTEC V February (1997): 266-374.
- Hall, W., & Williams, P. (2007). "Separation and recovery of materials from scrap printed circuit boards." *Resource, Conservation & Recycling* , 51, 691-709.
- Schlummer, M., Gruber, L., Maurer, A., Wolz, G., & Eldik, R. v. (2007). "Characterization of polymer fraction from waste electrical and electronic equipment (WEEE) and implications for waste management." *Chemosphere*, 67, 1866-1876.
- Stenvall, E., Tostar, S., Boldizar, A., Foreman, M., & Moller, K. (2013). "An analysis of the composition and metal contamination of plastic from waste electrical and electronic equipment (WEEE)." *Waste Management*, 33, 915-922.
- Dimitrakakis, E., Janz, A., Bilitewski, B., & Gidrakos, E. (2009). "Small WEEE: Determining recyclables and hazardous substances in plastics." *Journal of Hazardous Materials*, 161, 913-919.

Table 1. Ecology Center Elemental Analysis of 74 PVC Floors

Element	Inner Layer (recycled)			Top Layer (virgin)		
	Average (ppm)	Maximum (ppm)	% above 10 ppm	Average (ppm)	Maximum (ppm)	% above 10 ppm
Bismuth	52	141	58%	7	72	3%
Gold	107	255	89%	2	28	1%
Mercury	0	0	0%	0	0	0%
Element	Inner Layer (recycled)			Top Layer (virgin)		
	Average (ppm)	Maximum (ppm)	% above 100 ppm	Average (ppm)	Maximum (ppm)	% above 100 ppm
Arsenic	7	451	1%	0	0	0%
Bromine	194	2,328	46%	10	144	1%
Cadmium	1,846	22,974	36%	0	32	0%
Chromium	14	147	4%	0	0	0%
Lead	1,144	10,608	69%	5	82	0%
Manganese	227	754	78%	0	5	0%
Rubidium	127	641	41%	4	61	0%
Strontium	4,519	17,182	96%	19	208	3%
Titanium	12,317	63,623	99%	10,380	149,492	92%
Element	Inner Layer (recycled)			Top Layer (virgin)		
	Average (ppm)	Maximum (ppm)	% above 1,000 ppm	Average (ppm)	Maximum (ppm)	% above 1,000 ppm
Antimony	21,784	134,957	47%	44	1,392	3%
Barium	3,505	40,509	35%	824	9,316	22%
Calcium	524,335	711,766	100%	11,192	189,546	14%
Copper	1,343	2,260	85%	183	1,124	1%
Iron	7,506	44,574	93%	320	3,222	7%
Tin	21,784	134,957	47%	44	1,392	3%
Zinc	2,929	7,460	91%	283	1,082	1%

Source: The Ecology Center, 2015, previously unpublished test results.
Testing Methodology: X-Ray Fluorescence (XRF) analyzer.
See http://www.ecocenter.org/healthy-stuff/methodology for The Ecology Center's methodology. ppm = parts per million.

Our analysis of recycled feedstocks in this first phase of the collaboration, as described in the *Optimizing Recycling* white paper, focuses on the condition of post-consumer feedstocks as delivered to manufacturers of building materials, and not on the fates of these feedstocks in the use phase of these manufacturers' products. But the Ecology Center test results become an inevitable question: if the toxic contents are not in the top layer of flooring, what is the issue? The problem is that products like plastic floors are not stable. They age and deteriorate, and may lead to exposure pathways for inhabitants.

Replacing flooring, even low-price retail store flooring, is expensive, especially for low income housing owners, whose building materials tend to stick around longer in disrepair. A North Carolina Housing Finance Agency survey found that "damaged vinyl flooring or stained/loose carpeting" were among the ten most commonly cited deficiencies in rental dwellings. (22) Making matters worse, low income dwellings tend to have the least durable products. The International Association of Certified Home Inspectors reports, "All vinyl flooring has a wear layer, but the more expensive vinyl generally has a thicker wear layer than the cheaper versions, providing more durability." (23)

Discarded vinyl tile flooring.
Photo by flickr user Marie.
Reproduced under Creative Commons NonCommercial 2.0 Generic license.

As discussed above, children have been exposed to high levels of lead from deteriorated PVC mini-blinds.[8] The levels of lead to which they were exposed were comparable to those found by the Ecology Center in the inner layer of PVC floors. We have identified no research on potential heavy metal exposures from the degradation of PVC floors containing recycled content in the inner layer. But a logical concern is that when floors are damaged, the contents of the inner layer become exposed. The inner layer flooring may reach the surfaces upon which children crawl, and in dust that travels through the air.

Potential pathways for exposure such as these may be researched further in subsequent phases of this ongoing collaboration. In the meantime, the safest course of action is for manufacturers to stop using highly contaminated recycled feedstocks in PVC flooring.

8 Lead has also been found in PVC lunchboxes, baby bibs, garden hoses, children's toys, clothing, and numerous other products.

2 Supply Chain Quality Controls / Transparency

Consumers, when seeing that a product has recycled content, might assume that the content is the same material that would otherwise be used in this product. However, we found that recycled content in PVC floors and carpets are often sourced from substantially different materials, such as cable and wire insulation, pipes, and roofing membranes. (24)

Recycled PVC used in flooring usually is not sourced from PVC flooring scrap. As the US EPA noted in 2014, numerous manufacturers "currently use post-consumer recycled PVC on the back of their products, although the PVC is generally sourced from other PVC products other than discarded vinyl flooring." (25)

For example, Adore Floors manufactures a vinyl tile flooring with post-consumer content in Korea, mainly for export to the USA, in which some of the recycled material is derived from reclaimed pipes and cables.[9] Another example: AGPU, a wing of the European PVC industry, notes on one website that wire and cable insulation jackets are turned into other products, like floor coverings. (26) On another website, AGPU provides an example of industrial floor panels made from recycled cable insulation. (27)

A. Best Practices

Some leading carpet and resilient flooring manufacturers, cognizant of quality concerns, source their recycled PVC only from carpets or vinyl floors.

> "Interface's approach is to develop screening and testing systems to avoid the most clearly problematic waste streams, especially where PBTs may be involved. This is not an easy task, but the alternative is switching back to virgin materials based on fracked natural gas or refined crude oil which virtually guarantees exposure to PBTs for local communities."
>
> – M. Davis, personal communication, April 2 and April 7, 2015

9 An Adore Floors brochure reads, "Through a proprietary reclamation program used in Asia, along with additional PVC from alternate sources, *such as reclaimed piping and cable sheathing*, adore floors is proud to produce a product that deters nearly 1,600 tons of waste PVC from landfills around the world – Per month!" (emphasis added) (Adore Floors, Inc. *Naturelle Care* [Brochure]).

Interface now uses only waste carpet tile for its recycled PVC content. “We’ve tested over one hundred other sources [besides waste carpet], but the additives are all over the map,” Mikhail Davis, Interface’s director of Restorative Enterprise told the Healthy Building Network. “Focusing on carpet tile waste makes the screening challenge manageable because we are familiar with the ingredients and how to manage them safely.”

Davis added, “Where we use virgin additives, Interface is shifting to greener chemicals, but we cannot retroactively redesign the materials in our waste stream; Interface’s approach is to develop screening and testing systems to avoid the most clearly problematic waste streams, especially where PBTs may be involved. This is not an easy task, but the alternative is switching back to virgin materials based on fracked natural gas or refined crude oil which virtually guarantees exposure to PBTs for local communities.” (M. Davis, personal communication, April 2 and April 7, 2015).

Armstrong Commercial Flooring, another large manufacturer of vinyl flooring products, recently launched a program to increase the take-back of used vinyl composition tile (VCT) and luxury vinyl tile (LVT) flooring. (28) Under this new program, Armstrong will reclaim VCT, LVT, and other “qualifying products” from competitors for use as recycled content feedstock in new products. The program requires that incoming VCT material meet “Armstrong’s internal directives for heavy metals (Lead, Cadmium, Chromium VI and Mercury) and DEHP.” (29) Armstrong also does not accept material from buildings built before 1990 because of concerns with potential asbestos contamination. (A. Costello, personal communication, April 10, 2015). Armstrong’s specifications for screening incoming recycled content used in their products, including any limits on toxic content, are not available to the public.

> “Over 6 million pounds of post consumer flooring has been recycled through the Armstrong Floor Recycling Program since 2009, representing 3,000 tons of diverted landfill material.”
>
> - Armstrong brochure, 2015

Armstrong brochure, 2015

Tarkett, which manufactures both resilient floors and carpets, has the industry's most restrictive policies on both recycled content and the use of phthalates, which they have stopped adding intentionally to all of its products. Because of concerns about phthalates and other contents, it does not accept any recycled PVC flooring waste, or any other recycled PVC, with one exception (see discussion on page 22).

The first step toward establishing supply chain quality control in building products is understanding the source of the feedstock being processed into new product. Much more clarity is needed in this industry. Tracking the trail of PVC waste, from production to processing, would help manufacturers identify potential contents of concern. (See table on page 23 for a listing of the top ingredients to be concerned about). From this knowledge, companies can most efficiently target substances for be tested and eliminated from the recycled feedstock.

Manufacturers like Armstrong, Interface and Tarkett, have established proactive practices to optimize recycled content feedstocks. The next phase of the optimizing recycling collaboration will seek increased dialogue between product manufacturers like these, along with other stakeholders, to establish best practices for screening feedstocks.

B. Chemical Recycling

Most processors use mechanical recycling processes that do not remove problematic additives from the feedstock, instead of more costly chemical recycling operations that can strip PVC of its problematic additives.

"The benefit of mechanically recycling PVC is that new products can achieve equal quality to originals.... The downside is that this process cannot remove any toxicants from PVC. At best, mechanical recycling can lower the need for new PVC production and dilute PVC toxicity through the addition of new material," writes Melissa Murphy in SFGate. (30) Chemical recycling, she says, is "a solution for the most contaminated PVC compounds."[10]

"Once plasticizers have been added to PVC they are not removed during the mechanical recycling process," explains a state of California report. But in chemical recycling, "mixed PVC wastes are degraded into their chemical components and used again as raw material in the production of virgin PVC." (31)

Minimal chemical recycling of PVC takes place today. It faces a big financial hurdle; the technologies are far more expensive than the hardworking laborers who process plastic waste by hand in Taizhou city.

PVC wastes can be chemically recycled through thermal cracking, by pyrolysis, gasification or hydrogenation. Pyrolysis at 500-900°C is the most explored method of thermal cracking. At high temperatures, PVC is separated into gaseous components that can become raw materials, such as ammonia, carbon monoxide, and hydrogen chloride. These may be used as feedstocks for producing industrial chemicals like vinyl chloride monomer, ammonia, and methanol. (32) Unfortunately, removing hydrochloric acid from the pyrolysis gas "can result in the formation of toxic dioxins in some stages," according to Dr. Dimitris Achilias et. al. (33)

10 See also "Green Paper: Environmental issues of PVC." Commission of the European Communities (EC). July 26, 2000. pp 16-23. http://ec.europa.eu/environment/waste/pvc/pdf/en.pdf

Tarkett's Limits on Post-Consumer PVC

Tarkett, one of the world's largest vinyl flooring companies, has the most restrictive policy on post-consumer PVC use in the industry. With one exception, Tarkett is not accepting any post-consumer PVC until phthalate-free floors reach the end of service life.

"Our goal is to recycle the product we are making currently because we know what they [sic] are made of," said Dr. Feliks Bezati, Tarkett's Environmental Responsibility Manager. (Dr. F. Bezati, personal communication with Jim Vallette, February 12 & 16, 2015)

Tarkett's policy is driven by two concerns: 1) getting the total phthalate content in its floors below 0.1% by weight and 2) other contaminants found in recycled PVC scrap used to make its floors in Asia.

For all floors purchased from third parties in Asia, "we are requesting our suppliers not to use recycled material in order to control the contamination," said Dr. Bezati.

Tarkett also has stopped using post-consumer PVC in its factories in North America and Europe, with one exception: post-use returns of their own vinyl composition tile (VCT) in the United States. According to Dr. Bezati, VCT made in the U.S. contains post-consumer scrap because "we are controlling the contamination level below 1,000 parts per million" (or 0.1% by weight, the same upper threshold authorized under REACH).

"VCT is a product containing 85% by weight filler and 1-3% by weight phthalates. We have tested the final phthalate contamination in our VCT product and the value is below 1000 ppm, the number EPA uses as acceptable for mouthing toys and food contact. Based on this value of contamination we have decided to collect post-use VCT instead of landfilling," he said.

Other forms of vinyl flooring, such as heterogeneous sheet, can contain upwards of 30% plasticizers. Tarkett does not use recycled vinyl sheet floors.

In 2009, Tarkett began using bio-based plasticizers instead of phthalates in one line of its floors. By 2014, all of its plants producing PVC stopped using virgin phthalates.

"The good thing is that we are not intentionally purchasing phthalates as a plasticizer in either North America or Europe," said Dr. Bezati. "We have developed protocols and are not accepting material contaminated with phthalates (except VCT in the U.S.)."

Diane Martel, Tarkett's Vice President of Environmental Planning and Strategy, added, "Finding methods to turn waste back into resources as quickly as resources are consumed is one of the most effective ways of managing our ecological footprint. Participating in the movement to verify the chain of custody for all components of manufactured products is just one way to build a healthy, sustainable future." (34)

Table 2. Substances of Concern in Recycled PVC Feedstock

Chemical (CAS RN)	Hazards	Function	Notes
BIOCIDES			
10,10'-oxybisphenoxarsine (OBPA) (58-36-6)	PBT; Known human carcinogen; Developmental neurotoxicant	antimicrobial in plasticized PVC	See Hansen, 2014.
Diuron (330-54-1)	Known to cause cancer	biocide in roofing membrane	See Pharos Project, 2012.
Triclosan (3380-34-5)	PBT; Endocrine disruptor	antimicrobial in carpet backing	"Should be assumed to migrate [from the product during use] but fairly slow... Judged to stay in the plastic by mechanical recycling." (Hansen, 2014)
FLAME RETARDANTS			
Antimony trioxide (1309-64-4)	Known to cause cancer and reproductive toxicity	Flame retardant in plasticized PVC	"Plasticized PVC products contain flammable plasticizers and must be flame retarded. They contain a high enough chlorine content so that an additional halogen is usually not necessary, and in these cases 1 % to 10% antimony oxide by weight is used." (US Antimony Corporation, 2013)
Bis(2-ethylhexyl) tetrabromophthalate (TBPH) (26040-51-7)	PBT; Developmental toxicant; Endocrine disruptor	Flame retardant; plasticizer	"In addition to its uses as a flame retardant, TBPH is also marketed as a plasticizer for flexible polyvinylchloride and for use in wire and cable insulation, film and sheeting, carpet backing, coated fabrics, wall coverings and adhesives." (OEHHA, 2008)
Polychlorinated biphenyls (PCBs) (compound group)	PBT; Cancer; Developmental toxicant; Endocrine disruptor	legacy contaminant; formerly used as flame retardant in PVC wire and cable insulation	Largely phased out by 1978. "There may be a potential risk of exposure to PCBs in recycled-content PVC products that may contain PCBs as contaminants from old PVC coated wires or electrical components used as recycling feedstock. However, this occurrence has not been documented or quantified. This theoretical risk can be essentially eliminated by sampling and testing for PCBs in recycled PVC feed stock. Testing for PCBs in recycling efforts, especially those dealing with electrical wiring, is in some cases routine." (California EPA, 2006)
PLASTICIZERS			
Benzyl butyl phthalate (BBP) (85-68-7)	SVHC; Clear evidence of adverse developmental toxicant effects; Toxic to reproduction; Endocrine disruptor.	common plasticizer	41% of BBP use is in vinyl flooring. (Hansen, 2014)
Di-2(ethylhexyl) terephthalate) (DEHP) (117-81-7)	SVHC; Clear evidence of adverse developmental toxicant effects; Toxic to reproduction; Endocrine disruptor.	common plasticizer	"DEHP has for many years been one of the dominant plasticisers for flexible PVC and used in almost all kind of products made of flexible PVC." (Hansen, 2014)
Dialkyl(C7-11-branched and linear) phthalate (DHNUP) (68515-42-4)	Developmental and Reproductive toxicant	plasticizer in W&C insulation	See Hansen, 2014.

continued on the next page

Table 2. Substances of Concern in Recycled PVC Feedstock (continued)

Chemical (CAS RN)	Hazards	Function	Notes
Dibutyl phthalate (84-74-2)	SVHC; Reproductive and developmental toxicant	plasticizer	"DBP has for many years been one of the dominant plasticisers for flexible PVC and used in many products made of flexible PVC." (Hansen, 2014)
Diisononyl phthalate (DINP) (28553-12-0 / 68515-48-0)	Known to cause cancer	plasticizer, often replacing DEHP	"All types of phthalate plasticisers will migrate from the soft PVC as they are not chemically bound and as they are fairly low molecular weight plasticisers.... Will migrate. Release rates by migration are probably in the range of 0.1-1% per year or below (estimate based on [ECB 2008]). Given sufficient time, a significant part of the substance will probably be released by leaching to the surface followed by evaporation or removal by washing. Tear and wear will also take place but be of minor importance. Judged to stay in the plastic by mechanical recycling. By feedstock [chemical] recycling... will be decomposed." (Hansen, 2014)
STABILIZERS			
Cadmium and cadmium compounds (7440-43-9)	PBT; Carcinogen; Developmental and Reproductive Toxicant	legacy UV stabilizer, widely used in rigid PVC	"Cadmium was the dominating UV-stabilizer in PVC-windows and doors up to the end of the 1980s.... Used mainly for outdoor purposes... After that time it was in Denmark replaced by lead stabilizers (again replaced by other stabilizers about the year 2000). ... Solid bound in plastics. release by wear and tear." Unlikely potential for consumer exposure due to low concentrations in the plastic. Will remain in plastic through mechanical recycling. (Hansen, 2014)
Dibasic lead phthalate (17976-43-1)	PBT; Reproductive and developmental toxicant	heat stabilizer	Present in cable up to 1% by weight. (US EPA, 2008)
Lead and lead compounds, including tribasic lead sulfate (multiple, including 12202-17-4)	SVHC; PBT; Cancer; Developmental neurotoxicant; reproductive toxicant	stabilizers; pigments, in PVC roofing membranes, W&C, pipes, windows & doors.	"Lead stabilisers are dominantly used for (PVC) pipes, gutters, outdoor products inclusive of windows and doors (and) electrical cables and wires... PVC producers in EU expect total substitution in 2015." (Hansen, 2014) Scientists have found that rigid PVC products are much less likely to release stabilizers than their flexible (i.e., plasticized), counterparts…. Metal-based stabilizers are not readily absorbed through the skin so casual dermal contact with building material surfaces is not expected to be a significant route of exposure. Metal-based stabilizers can, however, be absorbed once ingested, primarily by mouth or secondarily through hand-to-mouth contact, or when inhaled as particles. Circumstances where children have been exposed to lead-based stabilizers from contact with aged, higher lead content, imported mini-blinds have been documented." (California EPA, 2006) Present in cable up to 1.8% by weight. (US EPA, 2008)
Nonylphenol phosphite (3:1) (TNPP) (26523-78-4)	PBT, Developmental and Reproductive Toxicant; Endocrine disruptor	stabilizer; secondary antioxidant, in vinyl floorings	Used in PVC shower curtains, floorings and wall coverings. Release potential and consumer exposure are "possible, but likely to be low." Will decompose in chemical recycling process, "assumed to remain" through mechanical recycling. (Hansen, 2014)

Acronyms:
PBT = Persistent Bioaccumulative Toxicant
SVHC = "Substances of Very High Concern" that are banned in the European Union, under REACH, unless authorized.
W&C = Wire & Cable.

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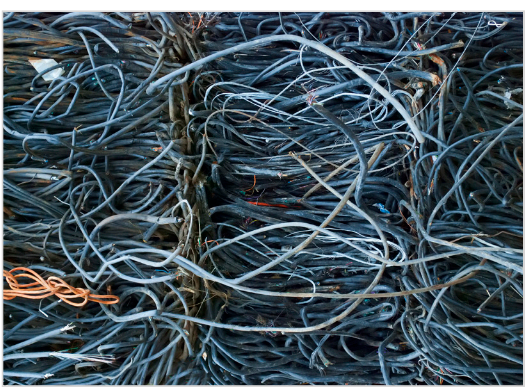

Scrap Electric Wire with PVC skin.

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3 Green Jobs and other local economic impacts

> "Few American, European, or Japanese scrap-plastics exporters have any idea who recycles the material that they export. Instead, they sell to brokers or other middlemen who sell to Chinese importers, often near ports, who then resell the scrap plastics to small traders. . . It's a shadowy trade: unlike the multimillion dollar trade in recyclable metals, plastics are traded in small lots."
>
> \- Adam Minter, *Junkyard Planet*

According to the Institute for Local Self-Reliance, recycling-based plastic manufacturers create 93 jobs per 10,000 tons per year of plastics recycled. (35) But far more PVC scrap generated from the US is being recycled overseas than domestically.

The phenomenon of manufacturing technology and low-cost labor forces in Asia have meant that scrap PVC from the United States are largely sent overseas for processing. Unfortunately, legacy toxic additives and manufacturing processes, including mercury cell technology, are still in common use in these overseas markets.

According to factfish.com, PVC waste or scrap exports from the US grew from 13,339 metric tons in 1993 to 228,747 tons in 2013 — a 1,715% increase in 20 years. (36)

Shipping records (obtained by subscription from the Panjiva trade database) provide hints about the types of PVC scrap being exported, including wastes shipped from above ground pool manufacturers and wire & cable manufacturers. More typically, plastic scrap brokers handle this business. Many manifests state the cargo as simply "PVC scrap," or, even more vaguely, "plastic scrap."

4 Room To Grow

Recycling rates for PVC are very low compared to other plastics. An EPA summary of plastics waste recovery rates stated that "0%" — none — of the 910,000 tons of PVC waste collected in the USA in 2010 were recovered for recycling." (37)

However, Scott Gibson, in a *Green Building Advisor* article, notes the Vinyl Institute has stated that "between 50 million and 100 million pounds [25,000 to 50,000 tons] of post-consumer PVC are recycled annually. Assuming those estimates are correct, post-consumer PVC represents ... about one-third of 1% of the annual production of PVC building materials." (38)

In Europe, VinylPlus, a PVC industry consortium, has set a target of recycling 800,000 tons of waste per year by 2020. (39) In 2013, according to a KPMG-certified report for VinylPlus, 444,468 tons of PVC were recycled in Europe, including:

- 192,419 tons of window profiles
- 103,131 tons of cables
- 77,319 tons of membranes (roofing, waterproofing)
- 40,887 tons of pipes & fittings
- 19,431 tons of rigid PVC films
- 7,663 tons of coated fabrics
- and 3,618 tons of flooring. (40)

VinylPlus's definition of recycling combines post-industrial and post-consumer waste, so it is not possible to identify which waste streams are byproducts of current production, and which are coming from discarded products. Regardless, the figure of 444,468 tons of recycled PVC, while much higher than zero, represents a small share (7%) of Europe's 6.1 million ton PVC demand in Europe in 2013.[11] High quality PVC recycling is not happening on a large scale.

Quality concerns are constricting the growth of PVC recycling. Major flooring manufacturers restrict the use of non-flooring post-consumer PVC. One restricts the use of any recycled PVC except a limited subset of post-consumer tile floors. And as public awareness about contamination in recycled PVC rises, more building product manufacturers may refrain from using recycled PVC, especially in interior products.

In the longer term, the outlook is a bit brighter. Reformulated PVC products that do not contain phthalates or heavy metal stabilizers eventually will enter the waste stream. Once they do, mechanical PVC recycling might not expose workers or building occupants to harmful ingredients during processing. Reformulated PVC products will create more room for the PVC recycling industry to grow.

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Post-Consumer Polyvinyl Chloride (PVC) in Building Products

Healthy Building Network Mission

Transform the market for building materials to advance the best environmental, health and social practices.

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