Optimizing Recycling:
Post-Consumer Flexible Polyurethane Foam Scrap Used In Building Products



A collaboration between StopWaste and the Healthy Building Network

2016

This briefing paper and an associated series of research papers on optimizing specific recycled feedstocks can be found at healthybuilding.net/content/research-and-reports.

The Healthy Building Network (HealthyBuilding.net) is a nonprofit organization that works to reduce the use of hazardous chemicals in building products as a means of improving human health and the environment. HBN performs independent, foundational research and product evaluations required to provide building products specifiers with unbiased, up-to-date information about chemical hazards, practical product evaluations and comparisons, and recommendations about the healthfulness of widely-used building products.

StopWaste (StopWaste.org) is a public agency responsible for reducing waste in Alameda County. The agency helps local governments, businesses, schools and residents reduce waste through source reduction and recycling, market development, technical assistance and public education. StopWaste is governed jointly by three boards: the Alameda County Waste Management Authority, the Alameda County Source Reduction and Recycling Board, and the Energy Council.

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About the Optimizing Recycling Series

The Optimizing Recycling Series of reports is a collaboration between the Healthy Building Network (HBN), a non-profit organization whose mission is to protect health in the built environment, and Stop-Waste, a public agency responsible for reducing the waste stream in Alameda County, CA, with support from the San Francisco Department of the Environment. It examines the hazards, supply chains, and economic impacts of recycled feedstock streams found in building products.

This briefing paper on post-consumer flexible polyurethane foam scrap is part of an ongoing series of papers that examine ways to optimize recycled content feedstocks commonly used in building materials. The most common conditions of post-consumer feedstocks, as consumed in California, establish the baseline for assessments found in this report.

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, can reduce feedstock value, impede growth of recycling rates and potentially endanger human and ecosystem health.

We describe the framework for our evaluation of flexible polyurethane foam and other feedstocks in our collaboration's overview report, *Optimizing Recycling: Criteria for Comparing and Improving Recycled Feedstocks in Building Products*. 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.

The Optimizing Recycling series can be found on HBN's website, at http://healthybuilding.net/content/optimize-recycling.

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OVERALL: Until 2014, toxic flame retardant chemicals were added in large quantities to consumer products in California that contained foams in order to meet product flammability standards. The use of these chemicals has contaminated recycled flexible polyurethane foam (FPF) feedstocks, most of which are used in recycled content bonded carpet cushion. As flexible foam manufacturers shift away from using toxic flame retardants, this feedstock will become more acceptable for such use. Today, however, the common contamination of this post-consumer feedstock with flame retardants creates the potential for exposure to these hazardous substances for recycling workers, carpet pad factory workers, and building occupants, particularly young children who are in closest contact with carpet cushion.

The bonded carpet cushion industry consumes almost all of the FPF scrap that is recovered for recycling in the United States. Most of the scrap used in carpet cushion is *pre-consumer (post-industrial)* waste, sourced from furniture manufacturers that have historically been required to use toxic flame retardants to meet product flammability standards. The majority of *post-consumer* FPF currently recovered for recycling comes from old carpet cushion that has incorporated these legacy flame retardants. Bonded carpet pad manufacturers typically use a blend of pre-consumer and post-consumer scrap.

Scientists found that the common practice of mechanically recycling this scrap elevates some workers' body burdens of flame retardants. Recycling these foams into new products disperses these highly toxic substances into homes and, eventually, the global environment. In homes, people, particularly crawling children, can be exposed to hazardous flame retardant chemicals released from carpet pad. The EPA notes that "as carpet padding ages, foam dust will be generated and become airborne with traffic on carpet."[1] Additionally, flame retardants can migrate over the life of the product and deposit in household dust which can expose building occupants through inhalation or ingestion of this dust.

Flame retardant chemicals historically added to FPF are in a class of chemicals considered persistent, bioaccumulative and toxic (PBT). PBTs are long-lived in the environment (persistent) where they concentrate (bioaccumulate) in the food chain and can transfer easily among air, water, and land for generations. Therefore, when the full lifecycle of flame retardant PBT chemicals is considered, there is no safe threshold for their use.

This report presents a snapshot of the industry at the time of this report, given the best information available from industry and other sources. The conclusions and recommendations herein follow a precautionary approach on the usability of FPF foam products in building materials given the current state of the industry and the type and amount of flame retardants expected to be present in today's scrap foam sources.

SUITABLE BUILDING APPLICATIONS: While some analysis suggests that the presence of problematic flame retardant additives in recycled FPF feedstocks is on the decline because they have been phased out of much of the virgin production lines, the post-consumer scrap market supply chain still contains these additives in amounts that likely exceed precautionary exposure levels. There is a need for much more frequent testing for a wide range of flame retardants in recycled FPF feedstocks. Until the feedstock is free of flame retardants, post-consumer recycled content foams are not recommended in building products where their use potentially exposes workers, installers, children, and other vulnerable populations.

PATHWAYS FOR OPTIMIZATION: Recycling materials offers many advantages over other waste management options, but the benefits of recycling must be weighed against negative impacts on humans and the environment. There is no easy solution to the problem of flame retardant contaminated foam, but there is an opportunity to develop pathways for dealing with current contaminated foams and to assure clean future feedstocks.

Many furniture manufacturers have started using flame retardant-free virgin foams, resulting in flame retardant-free pre-consumer trim scrap. Carpet cushion companies are already incorporating flame retardant-free trim scrap into new bonded carpet cushion, but they continue to blend this clean foam with contaminated post-consumer scrap. Furniture manufacturers should remove unnecessary flame retardants in new products, and some form of identification or labeling should be developed to allow for the separation of flame retardant-free feedstocks for use in recycled products. Labeling flame retardant-free products readily identifies clean foam throughout the supply chain for future recycling. This will help to provide a safer feedstock for future materials recycling, increase the value of those feedstocks, and reduce potential health concerns from the use of legacy flame retardants.

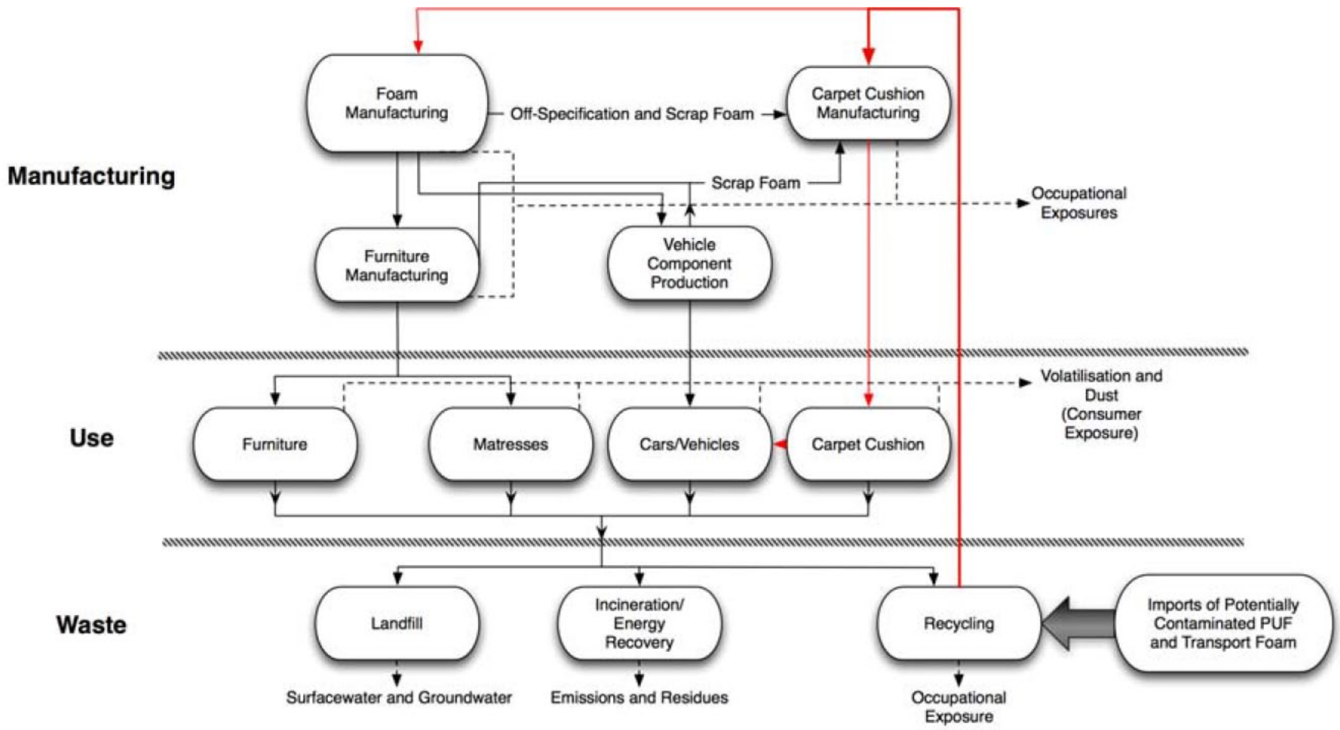
Better understanding of flame retardant use in mattress foam is needed to determine its potential as a post-consumer FPF feedstock. Here, too, a labeling system for the identification of materials as being flame retardant-free would allow downstream users to readily identify and recycle clean foams and pads.

Further development of chemical feedstock recycling practices should be pursued as a method to remove these additives of concern. Any methods for recycling or disposal of contaminated foams should prevent the release of hazardous substances into products, and ultimately, to humans and the global environment.

We present detailed recommendations for various stakeholders at the end of the report.

Introduction

Flexible polyurethane foam (FPF) is found in nearly all upholstered furniture and mattresses, in car seats, and in carpet cushion. More than 600,000 tons are produced and used in the United States each year.[2] At the end of life, these mattresses, carpet cushions, and articles of furniture make their way into the waste stream for disposal. Though some rough estimates exist for the total amount of FPF discarded annually, actual quantities could not be determined based on the sources used in this report. Most post-consumer waste FPF is landfilled or burned, but some old carpet cushion is



Simplified material flows of foam and recycling routes (in red) taken from UNEP POP Review Committee Technical Review [3]

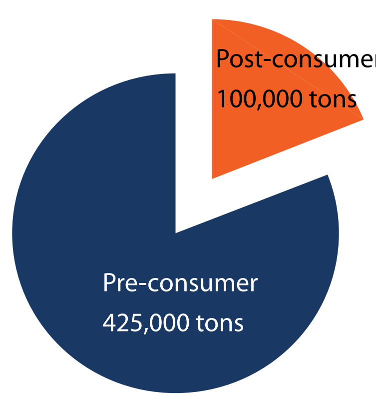
diverted from disposal as post-consumer scrap when taken up during construction renovation projects. In some regions, such as California metro areas, mattresses are increasingly recovered for their valuable metals, clean wood, and foams.

Manufacturers blend post-consumer FPF with pre-consumer waste (such as out of spec foam and trim scrap) to make new carpet pad or cushion, also known as "rebond" or "bonded". The Carpet Cushion Council, an industry association, estimates that in 2015, its members reprocessed up to 100,000 tons of post-consumer FPF into carpet cushion, which is about 19% of the total foam (525,000 tons) recycled into rebond.[4] The rest of the foam (81%) came from pre-consumer sources in the U.S., Europe, or Asia.[5]

As part of the Optimizing Recycling initiative, this report evaluates post-consumer FPF feedstock against a set of four criteria gauging impact on human health and the environment, the extent to which supply chain controls screen for and remove hazardous content, the availability of green jobs, and opportunities to expand use of the feedstock. Each criterion is judged on a three-part scale with green indicating "very good," yellow indicating "room for improvement", and red indicating "significant concerns." The review is focused on California's San Francisco and Alameda counties wherever possible, and on California more generally. The evaluations of health and environmental impact and supply chain controls are broadly applicable throughout the United States. Details regarding job availability and room to grow will vary based on region.

Because post-consumer FPF feedstocks in the form of bonded carpet cushion

Flexible Polyurethane Foam Recycled in the U.S., 2015



Data from Carpet Cushion Council[6]

contain both post-consumer and pre-consumer content themselves, this report also provides some information on pre-consumer foam.

Behind the Ratings

FEEDSTOCK HEALTH AND ENVIRONMENTAL HAZARDS

Flexible polyurethane foam is commonly produced using isocyanates (which are under increasing regulatory scrutiny for respiratory hazards[7]), blowing agents (some of which have been potent ozone-depleting substances and global warming agents in the past[8]), polyols, amine catalysts, and other functional additives, which can include flame retardants and, in some cases, antimicrobials. There is a huge variety in the chemistry of FPF products across the industry and even within a single manufacturer's line of products. One foam manufacturer may produce more than 150 different FPF products, each tailored to have unique properties for specific applications.[9]

While many of the ingredients can harm human health and the environment during their production and life cycles, one of the most significant impacts on recycling FPF arises from the flame retardant additives. Current post-consumer FPF feedstocks are primarily old carpet cushion with a very small but increasing amount of recovered mattress foam.

> **"The padding used under broadloom carpeting is not subject to flammability tests; however, padding often contains harmful flame retardants because the most common "rebond" product is made from recycled polyurethane foam from furniture, which is often loaded with high levels of halogenated flame retardants."**
>
> **- Dedeo & Drake, 2014[12]**
>
> *This situation continues to evolve. With the implementation of TB117-2013, much of the FPF in new furniture and the resulting pre-consumer foam trim scrap no longer contain flame retardants. Take-up post-consumer carpet cushion still likely contains halogenated flame retardants, which were common in furniture when the carpet cushion was manufactured.*

Carpet Cushion

Typically, carpet cushion is installed in residential applications or light-duty offices. Over 85% of carpet cushion sold in the U.S. is bonded carpet cushion (other types include fiber, rubber, and virgin FPF).[10] Bonded foam products are made almost entirely from recycled FPF: pre-consumer furniture and automotive foam scrap and, more recently, starting around 1993, post-consumer foam. Old take-up carpet cushion accounts for the majority of the post-consumer FPF that is recycled.[11] In newly manufactured bonded carpet cushion, manufacturers do not intentionally add any flame retardants.

Upholstered furniture manufacturers extensively used the flame retardant PentaBDE in flexible polyurethane foam from around 1980 until 2005.[13] Bonded carpet cushion companies incorporated a significant amount of pre-consumer foam from furniture manufacturing into their products. PentaBDE is in a class of persistent organic pollutants (POPs) called polybrominated diphenylethers (PBDEs). Some U.S. states, and the European Union, have banned several PBDEs over the past 15 years.[14] These flame retardants are semi-volatile and can migrate from products, concentrate in household dust, and expose building occupants who inhale or ingest this dust. Besides being persistent and bioaccumulative, PBDEs are associated with cancer,[15] exhibit reproductive and neurodevelopmental toxicity, and affect the thyroid hormones of mammals and aquatic organisms.[16]

With the phase out of the use of PentaBDE in foam products in 2005, manufacturers incorporated a suite of other flame retardants into furniture foam applications in order to continue to meet product flammability standards. Firemaster 550, TDCPP, TCEP, TCPP, and V6 (a chlorinated organophosphate also used in automobile foam) have been identified in studies of furniture foam, and these replacement flame retardants have been found to pose similar toxicity concerns as PentaBDE.[17] As with PentaBDE, these replacement flame retardants wound up in pre-consumer scrap and recycling markets, which make their way into carpet cushion.

An EPA assessment found that all of these materials have a high hazard for at least one of the following human health effects: carcinogenicity, acute toxicity, reproductive, developmental, and neurological as well as medium to very high aquatic toxicity.[18] These are all additive flame retardants so are not bound to the foam itself and can migrate out of the material over the life of the product. TDCPP, Firemaster 550, TCEP, and TCPP have been found both in indoor air and dust, as well as in people.[19] All are halogenated flame retardants, a class which has been identified as persistent and bioaccumulative.[20]

Many organizations, including the U.S. EPA and the United Nations, have expressed concerns about consumers' continued exposure to these hazardous flame retardants through reincorporation of recycled materials into new products. "Millions of pounds of foam that is flame retarded with pentaBDE or an alternative have been, and will be, sold and used in homes throughout the United States as carpet cushions. Direct exposure to millions of consumers from these sources is possible," warned the EPA in 2005. The report explains, "as carpet padding ages, foam dust will be generated and become airborne with traffic on carpet. This presents a particular exposure potential for children, who spend time on the floor." Additionally, the flame retardants volatilize and are deposited onto household dust, which creates further potential exposure.[21] Assessment of human exposure to flame retardants has primarily focused on the ingestion of this dust, but a 2016 study indicates that inhalation of dust is also a significant exposure route for several of the replacement flame retardants.[22] The authors report that their results "indicate that in the U.S., overall exposure [to chlorinated organophosphate flame retardants] may be much higher—by one or more orders of magnitude—than previously believed based on dust ingestion as a primary exposure route."

In 2009, parties to the Stockholm Convention targeted PentaBDE and other PBDEs for global elimination. But, as global POPs experts Joe DiGangi and Jitka Strakova reported, "the decision included specific exemptions which may last until 2030 allowing the recycling of materials containing these substances such as plastics and foam into new products."[23] A UN review committee, however, subsequently recommended that the Stockholm Convention decision be amended to "eliminate brominated diphenyl ethers from the recycling streams as swiftly as possible." It said "failure to do so will inevitably result in wider human and environmental contamination."[24]

Over the years, tests confirmed the presence of high levels of PentaBDE in new bonded carpet cushion that made use of pre-consumer and post-consumer recycled materials. The composition of post-consumer foam entering today's supply chain is revealed by studies contemporaneous with the time the foam was manufactured, about five to fifteen years ago. What was new then is being discarded or recycled now.[25] The Carpet Cushion Council tested two new bonded carpet cushion samples in 2004 and found up to 0.807% (8,070 ppm) PentaBDE by weight. A study of new cushion conducted from 2005-2006—just after the phase-out of PentaBDE from the pre-consumer feedstock—reported that the average PentaBDE content in the cushion tested was 0.106% by weight (1,060 ppm).[26]

> **"Plastics and foam containing flame retardant chemicals are often recycled into other consumer products. This raises concerns about toxic chemicals moving from one product into another and continuing human and environmental exposure. The Stockholm Convention prohibits disposal operations that may lead to recovery, recycling, reclamation, direct reuse, or alternative uses of the substances. However in 2009, when flame retardant chemicals such as PentaBDE and OctaBDE were listed in the treaty, delegates agreed to make an exemption to allow the recycling of foams and plastics containing these substances. Due to concerns about the practice, they requested the expert committee, the POPs Review Committee (POPRC) to examine the practice. The POPRC recommended eliminating the flame retardant chemicals from recycling '...as swiftly as possible.' The POPRC said that simply recycling the products would disperse the chemicals into other products and continue exposure."**
>
> **-Joseph DiGangi, 2013[30]**

The average quantity of PentaBDE in new carpet cushion has been decreasing as it is diluted into new products. Follow-up test results of new cushion for 2011-2012 showed an average PentaBDE concentration of 0.085% by weight (850 ppm).[27] In December 2015, the CCC reported a mean of approximately 0.02% (200ppm) PentaBDE in newly manufactured recycled-content bonded carpet cushion.[28] These results are from industry tests of approximately 8-12 samples per year,[29] and the CCC provides only an average of all results, rather than a range. Given the variability of the stock, it is questionable whether this average for a small number of samples can be considered representative (the industry creates over 500,000 tons of carpet cushion per year).

All of the above analysis was for PentaBDE content in bonded carpet cushion made from scrap and recycled foams. However, no survey results are available for concentrations of the flame retardants that replaced PentaBDE. Furthermore, only minimal information is available on the amount or degree of carpet cushion contamination with replacement flame retardants. Based on their extensive use in furniture foam, their presence in bonded carpet cushion is expected to be significant. In 2014, the state of Washington tested for and identified replacement flame retardants in new carpet cushion. Of the five products tested, all contained at least four different flame retardants with total flame retardant content ranging from 0.4-8.6% by weight (4,000-86,000 ppm).[31,32]

Mattress Foam

Mattress foam currently represents a very small portion of the post-consumer foam feedstock, but three states are instituting mattress recycling programs in order to improve recovery rates.[33] California's Mattress Stewardship Program took effect in 2016. This program generated a 30% increase in business in just the first eight days of the year at DR3 Mattress Recycling in Oakland, the largest mattress recycler in the United States.[34]

There is conflicting information about the extent of flame retardant use in mattresses. According to the Polyurethane Foam Association (PFA), U.S. consumer mattresses do not contain foam treated with flame retardants (outside a very small number marketed as having specific flame resistance between 2003 and 2006). High-risk institutional mattresses for applications such as prisons or some hospitals, may have contained PentaBDE before the 2005 phase-out and may continue to contain high quantities halogenated FRs in the FPF foam.[35]

A survey released in 2015 by Clean & Healthy NY, says that some new mattresses may still contain flame retardants in the foam. The report states: "When it comes to mattresses, conventional wisdom has been that because the federal flammability standards mandated a decade ago could not be met by relying on FR chemicals in the foam, mattress makers had stopped using them. Our survey suggests that this is not the case..." Of the 11 mattress manufacturers that responded to the survey, five do not actively source flame retardant-free foam for at least some product lines, and one specifies foam free of some, but not all, flame retardant chemicals.[36]

The PFA disputes Clean & Health NY's findings. For clarification, HBN attempted to contact mattress manufacturers directly; unfortunately, the companies declined to answer HBN's questions.[37]

More research (especially manufacturer disclosure) is needed to determine the extent of flame retardant use, if any, in mattress foam, both historically and currently, in order to assess post-consumer mattress foam as a recycled feedstock.

Processing Operations

Current operations to recover and process post-consumer recycled foam from carpet cushion and mattresses are mechanical and potentially very unhealthy. Typically, recovered carpet cushion is visually screened and separated into bales that are then sent to manufacturers who create new bonded carpet cushion.

At recycling facilities, workers roll out the recovered cushions by hand and check them for physical contamination like tack strips and carpet. They separate bonded (recycled) from 'prime' (virgin) scrap. Workers may also sort for other qualities, like density, before baling each type for shipment to a rebond manufacturer.[38] Mattress dismantling is also performed primarily by hand and foam is similarly baled for shipment.[39] Some personal protective equipment (PPE) and safe handling measures by workers who handle these materials were reported—such as wearing gloves or dust masks[40]—though the extent of use of PPE throughout the foam recycling supply chain and the effectiveness in preventing flame retardant chemical exposure were not found in any studies reviewed by our authors.

In 2008, Heather Stapleton et al. found that FPF recycling workers and people who install rebond carpet cushion "have body burdens [of PBDEs] that are an order of magnitude higher" than the general public. Recycling workers and carpet installers may therefore be at higher risk of the negative health impacts associated with exposure to flame retardants.[41] However, conclusive studies on worker exposure or emissions of the PentaBDE replacement flame retardants could not be identified.

At the rebond facility, machines complete the mechanical recycling process. Equipment shreds the collected polyurethane foam into small pieces; then mixes the flakes with a polyurethane-based binder, which makes up about 5% to 10% of the product by weight. The mixture is heated and pressed to form shapes from which new foam products are produced.[42,43]

Facilities that shred wastes containing flame retardants can disperse flame retardants into the global environment. According to a 2007 United Nations report, "Studies of the working conditions in [electrical and electronic waste] recycling plants have detected levels of PentaBDE in the indoor air, and indicate that PentaBDE also can be spread as diffuse emissions from recycling plants."[44] These operations are typically mechanical and include shredding the products.

Furthermore, a 2016 study in California found that PBDE levels in the blood of residents that lived within two kilometers of solid waste facilities were higher than those who lived farther away, raising questions about the containment of PBDE's from solid waste facilities into the surrounding environment and populations.[45] No studies considering emissions from carpet cushion manufacturing facilities were identified, but due to the mechanical nature of the process, emissions to the environment are possible.

Rebond carpet cushion manufacturers cite worker safety as a high priority.[46] Mohawk recently invested in new dust collection systems in all five of their rebond facilities to reduce the amount of particulate matter in the air.[47] Improvement in engineering controls is a positive step, reducing the reliance on personal protective equipment to prevent worker exposure. The potential for worker exposure to hazardous flame retardants in foam and dust exists at various steps of the collection and recycling process. The most effective way to protect workers and consumers is to remove these hazardous materials from the supply chain.

SUPPLY CHAIN QUALITY CONTROL AND TRANSPARENCY

Rebond carpet cushion itself is a heterogeneous material with varying content within a single product and even more variation from product to product. The floor covering industry has no standard content labeling for floor covering materials, including new bonded carpet cushion and, therefore, no content information for post-consumer carpet cushion. For example, according to the Carpet Cushion Council, "A bonder would not ordinarily know or reasonably ascertain what PBDEs, if any, are in the post-consumer (take up) foam scrap it is purchasing for use with other flexible polyurethane foam in its mixing formula for bonded."[49] The same logic applies to other flame retardants.

Despite the fact that some states have imposed limits on the quantity of PentaBDE allowed in products, no one along the supply chain routinely tests FPF scrap or new bonded carpet cushion for PentaBDE or other flame retardants. Instead, the industry association, the Carpet Cushion Council (CCC), conducts periodic surveys of random pieces of rebond carpet cushion (8-12 samples), in an industry that operates around two dozen plants in North America. CCC members provide the samples for third-party analysis of PentaBDE content.[50] The relatively low rate of sampling and

> **"The main recycling route, rebonding to carpet padding, is shown to expose recycling workers and carpet installers along with hundreds of thousands or even millions of consumers. Dust ingestion is the main uptake route of PBDE for more highly exposed individuals. The incorporation of PentaBDE in carpet cushion which generates the highest levels of dust in the zones where children are playing is therefore of particular concern. It is notable that dust release increases as carpet ages thus exposing the children of poorer families more heavily – an exposure reflected in the published literature. An indicative assessment of the health costs associated with polyurethane foam recycling shows that total damages can be estimated at close to $USD 6 billion/year. The commercial value of the North American rebond market, by contrast, is estimated to be less than $USD 15 million/year."**
>
> **- UNEP POP Review Committee, 2010** [48]
>
> *This analysis was based on PentaBDE. While PentaBDE is present in new carpet cushion at significantly lower levels than the time of this estimate (cushion produced prior to 2005 may still have significant levels of PentaBDE), other FRs of concern have replaced it. Dust ingestion is still expected to be a significant exposure route, and inhalation has also been shown to be significant for chlorinated flame retardants (whereas this is not the case for PentaBDE).*

testing by the CCC is a result of economics and timeliness; testing for the level of PentaBDE content is costly and takes several days at least to receive the results. Hence, rapid and extensive testing of samples would require significant investment and technological advancements that don't exist at present.

The CCC states that in order "to gauge the PentaBDE-content of the finished product, producers of bonded cushion are obliged to blend post-industrial and post-consumer scrap in the context of what is known about the PentaBDE-content, on average, of post-consumer scrap being collected at the time."[51] Concentrations of other flame retardants have not yet been evaluated by the industry association.

Best Practices

Some bonded manufacturers are taking action to clean up their pre-consumer supply of foam. Over the last three years, Mohawk has worked with its pre-consumer foam supply chain to understand the presence of flame retardants and, where possible, source foam that is flame retardant-free or from suppliers who have a plan to reduce and eventually eliminate flame retardants. They continue to work toward defining content for supply streams that are currently unknown with a long term goal of sourcing only flame retardant-free foam for their bonded carpet cushion. Mohawk does incorporate post-consumer foam in some of their products, stating that it currently must be utilized based on the market of available foam.[52]

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According to the Carpet Cushion Council (CCC), Mohawk's approach is common among their bonded manufacturing members. This goal is challenged by the "complexity of the supply chain, with numerous co-mingled sources of scrap" and the "lack of a practical and cost-effective way to analyze materials in the field to determine FR levels," according to Bob Clark, executive director of the CCC.[53]

To address the void of content information, the United Nations recommends screening flexible polyurethane foam for bromine using XRF or other appropriate technology and segregating these materials (as is done in the electronics industry).[54]

While XRF is a useful screening technique for brominated flame retardants, it does not seem to be as reliable for chlorinated or phosphate-based FRs. Research groups continue to look for faster and cheaper methods of screening for these common flame retardant chemicals. Scientists from the California Department of Toxic Substances Control recently published an article outlining screening methods for flame retardants and found that ICP-OES was a reliable laboratory technique for identifying foams containing organophosphate flame retardants (which include the chlorinated FRs used in FPF).[55] Another recent study identified PIXE (particle-induced X-ray emission) as a rapid screening method for chlorinated flame retardants in polyurethane foam.[56] Cost-effective field techniques that can be integrated into the recycling process are still needed.

Even with appropriate screening technology, testing would be most feasible for large, uniform pieces of foam like mattresses and virgin FPF carpet cushion. Use of screening methods for bonded carpet cushion (which is made up of many small pieces of foam from different sources) and smaller foam scraps may be infeasible, so instituting content tracking and pursuing other recycling methods, like chemical recycling, may be better options for these types of materials.

Chemical recycling breaks down the foam into its constituent substances and could potentially be used to remove legacy flame retardants from FPF feedstocks. Depolymerization of polyurethane foam and further processing can produce high quality polyols.[57] This process requires grinding of the foam,[58] so controls are still needed to prevent worker exposure and environmental releases.

While researchers have been studying chemical recycling of polyurethane foam for a while, large scale reprocessing is still in the early stages and removal of contaminants has not been a focus. There does, however, seem to be progress, at least on the pre-consumer side. In 2013, a Polish slabstock manufacturer began operating "the world's first industrial-scale system to recover polyol from flexible foam waste," which is used in a pre-consumer, closed-loop application.[59]

In 2015, Emery Oleochemicals opened an industrial-scale facility for production of their INFIGREEN® recycled content polyols in Cincinnati, OH. It makes polyols from recycled polyurethane foam scrap (flexible and rigid), which can be used as "a direct replacement for petroleum-based polyols."[60] The current focus is on pre-consumer scrap, largely for closed-loop processes. Because of the closed loop nature (recycled content polyols go back into the same polyurethane foam process from which they originated), there has not been a need to remove flame retardants or other additives. Mark Kinkelaar, the Business Director for Emery's Eco-Friendly Polyols, noted that chemical recycling of post-consumer foam can be done in principle, but at this point, demand is only emerging. "As mattress recycling is mandated more broadly and the Circular Economy starts to take off in the EU," Mr. Kinkelaar said, "many in the foam industry are anticipating an oversupply of scrap – leading to anticipated demand for chemical recycling. These markets don't change quickly, so we need to develop the technology ahead of the anticipated market trend. I expect this to be a critical market need in the next five years."[61] Emery advertises six recycled content polyols that manufacturers can use for a variety of construction and building products.[62]

The Stockholm Convention notes the challenges for thermal conversion facilities in dealing with high halogen content wastes such as those containing PBDEs. The use of "optimally efficient combustion chambers" is necessary to avoid generation of incomplete combustion products like hazardous dioxins and dibenzofurans.[63] Due to the intense management necessary for proper waste incineration processes to control for optimal combustion, incineration does not appear to be a viable disposal option at this time. The Green Science Policy Institute, with support from the National Science Foundation, is currently developing guidelines for the safest possible end of life disposal of flame retardant chemicals and will have recommendations later this year.

Industry Associations

In general, U.S. carpet cushion manufacturers have no mechanisms in place to screen for or remove flame retardants from FPF feedstock. The Carpet Cushion Council argues that "[t]he ability to continue recycling such foams in the production of new bonded carpet cushion is in the public interest as the process dilutes the PentaBDE content and helps reduce the necessity of disposing of the bulky solid waste in landfills."[64] In contrast, the Stockholm Convention POPs Review Committee says that continuing to process and dilute these persistent, bioaccumulative, and toxic materials through recycling is not in our best interest and instead will lead to "wider human and environmental contamination."[65] Diluting the concentration of persistent, bioaccumulative compounds like halogenated flame retardants by expanding the number of products that contain them is not a solution because it does not decrease the overall amount that exists in the environment. While dilution lowers levels of contamination in individual end products, safe thresholds for exposure have not been established for all flame retardants or for the many pathways by which people can become exposed to them. By their nature, persistent bioaccumulative toxicants that have been diluted in products will re-concentrate in species up the food chain (such as humans) over time.

State and Federal Law

Past state and federal regulations led to unnecessary inclusion of toxic flame retardants in FPF products. The open flame requirements for furniture foam in California TB117, which had become the de facto national standard, generally could not be easily met without the inclusion of flame retardants. In 2014, California removed this part of the requirement due to evidence of negative health impacts of added flame retardants and the limited benefit in terms of fire safety.[66] California and seven other states have also enacted laws prohibiting use of PentaBDE at greater than 0.1% (1,000 ppm), but there are often exemptions for recycled materials.[67]

Transparency

Foam manufacturers do not generally disclose the flame retardants they use, citing this information as proprietary.[68] End use manufacturers who source foam for use in furniture and mattresses may not even know the specific flame retardants used in the foam they incorporate into their products.[69]

The flexible polyurethane foam industry advocates for a degree of transparency through its CertiPUR-US® program. The CertiPUR-US testing applies to the foam itself, and the certification label can be applied to products that incorporate certified foam. This voluntary industry-run program uses independent laboratory testing to certify that polyurethane foam does not contain ozone depleting chemicals, certain flame retardants, heavy metals, or certain phthalates, and is low-VOC.[70] The program prohibits use of certain flame retardants including PBDEs and, as of January 15, 2015, TDCPP and TCEP, but does not prohibit all flame retardants and thus does not certify whether foam is flame retardant-free.[71] CertiPUR-US applies only to prime (or virgin) FPF, so rebond products cannot be certified under this program.

The Carpet Cushion Council has an indoor air quality program and label (CRI Green Label and the new Green Label Plus), but this only requires testing for specific VOCs.[72] The flame retardants found in carpet cushion are generally semi-volatile organic compounds which can escape into air and dust, but are not covered by this testing.

New labeling requirements have gone into effect in California (SB1019) that require upholstered furniture labels to indicate whether or not there are added flame retardants. The Center for Environmental Health reports in a recent survey that, despite the fact that labeling is only required in California, 78% of the 37 residential furniture companies surveyed report that they are labeling products nationwide regarding their flame retardant content.[73] These requirements do not currently apply to mattresses or carpet cushion.

GREEN JOBS AND OTHER LOCAL ECONOMIC IMPACTS

Most of the recycling of post-consumer polyurethane foam scrap takes place in the United States and Canada.[74] Given that this recycling industry is largely domestic and employs Californians in related facilities, these jobs are found "close to home." But we can not give FPF a "Green Jobs" green rating at this point, given recycling workers' potentially elevated body burden of flame retardants.[75]

Bay Area/California Connections

There are several bonded manufacturing facilities located in California and in close proximity to the Bay Area: Leggett & Platt in Tracy, Carpenter Co. in Lathrop, CA, and FXI in San Leandro.[76]

There are also several carpet pad collection facilities in California and the Bay Area. See CalRecycle's web page for a full list.[77]

The largest mattress recycling facility in North America is California-based DR3 with locations in Oakland and Woodland.[78] In 2014, DR3 recycled 130,000 mattresses in California[79]. That translates to about 620 tons of foam annually.[80] But there is significant room to grow green jobs in mattress recycling (see next section for further explanation).

ROOM TO GROW

According to an industry market survey released in 2000, the carpet cushion industry used about 55,000 tons of post-consumer foam annually, accounting for 13% of the FPF recycled into bonded cushion.[81] This amount has since fluctuated; for several years it was estimated to be at least triple the levels reported in 2000, but has since fallen to about twice the 2000 levels.

In 2005, according to the Carpet Cushion Council, the industry recycled about 150,000 to 200,000 tons of post-consumer carpet cushion annually with estimates remaining the same for 2011. This accounted for an estimated 30-40% of the total recycled FPF used in carpet cushion (the remainder being pre-consumer, both imported and domestic).[82] The increase in the percentage of recycled foam that is post-consumer may be tied to polyurethane foam industry efforts to decrease the amount of pre-consumer scrap generated (meaning less pre-consumer scrap is available) as well as implementation of the Carpet America Recovery Effort (CARE) initiated in 2002 to divert carpet from landfills (many carpet recyclers also accept polyurethane carpet cushion, including bonded).

Industry estimates from 2015 indicate that the amount and proportion of post-consumer foam being used in carpet cushion dropped considerably since 2011. The Carpet Cushion Council reported that its members used about 100,000 tons of post-consumer foam, approximately 19% of the total foam recycled into rebond (the remaining 81% is pre-consumer scrap recycling).[83]

Due to the frequent contamination of post-consumer foam with legacy flame retardants, mechanically recycling this waste into new building products without adequate screening practices and worker protections is not recommended.

Labeling, screening, and tracking flame retardant-free foam would enable uncontaminated material to be separated from foams containing flame retardants. Current known sources of uncontaminated material include post-consumer virgin FPF carpet cushion and flame retardant-free pre-consumer foam. To best utilize recycled FPF feedstocks, the foam and carpet cushion industries should investigate chemical recycling methods for removing hazardous flame retardants from contaminated foams like post-consumer rebond. Additionally, organizations like the Green Science Policy Institute, with support from the National Science Foundation, are researching responsible disposal methods for foam containing flame retardants.[84]

Post-consumer mattress foam represents a potential opportunity to develop the recycled FPF feedstock. Additional work is needed to determine the extent of flame retardant use and identify field screening techniques to segregate foams with flame retardants.

According to the Mattress Recycling Council, in the U.S., up to 20 million mattresses and boxsprings are discarded each year.[85] This is an estimated 60,000 tons of FPF annually.[86] In a 2012 report from the PFA, they noted that only about 2% of mattresses were recycled nationwide.[87] In California, according to a 2012 CalRecycle Case Study, an estimated 4.2 million mattresses and box springs (with an estimated 12,500 tons of FPF) were discarded in California alone, and less than 5% were recycled.[88]

CalRecycle estimated that based on this recycling rate "fewer than 30 full time employees work in mattress recycling [in California]. The recycling of all 4.2 million units would require around 575 fulltime employees. Additional jobs would be created in the industries that process the secondary outputs of the mattress recyclers, i.e. the steel scrap, the polyurethane foam, the cotton, the cover (toppers), and the wood. EPR measures that lead to the collection and recycling of 4.2 million mattress and box spring units per year are therefore estimated to generate in the order of 1,000 jobs, most of which are entry-level positions."[89]

California's Mattress Stewardship Program, which took effect at the start of 2016, is already impacting recycling businesses. DR3 Mattress Recycling manager Robert Jaco reported a dramatic uptick in business in just the first few days of the year and that it was possible a second crew would be needed by the end of January.[90] As the recycling of mattresses continues to increase, recyclers should identify and implement screening processes to segregate foam that contains flame retardants and ensure that workers doing this screening are not exposed to flame retardants.

Properly screened imported scrap is another potential source of uncontaminated foam. Flame retardants have primarily been used in products sold to North America and the United Kingdom,[91] so pre-consumer and post-consumer scrap from other countries may prove to be good sources for clean scrap. Additional study is needed to determine specific markets.

Over the longer term, improved transparency and chain of custody throughout the supply chain could result in the availability of a much larger quantity of flame retardant-free post-consumer foam. The recent changes to CA TB117 allow for flame retardant-free furniture foam, and a new survey indicates that many furniture manufacturers are already sourcing flame retardant-free foam.[92] Pre-consumer FPF scrap without flame retardants is already becoming available for use in bonded carpet cushion. A December 2015 report from the Commission for Environmental Cooperation noted industry speculation that up to 90% of upholstered furniture companies would stop use of flame retardants in foam, yet the report did not provide a timeline or overall quantity estimates.[93] However, the PFA says that less than 1% of U.S. slabstock foam production for use in residential upholstered furniture is projected to be combustion modified (that is, rendered flame retardant through additives) in 2016.[94]

Conclusions

Standard practices of post-consumer FPF recycling create potential exposure for workers in the recycling and carpet installation industries as well as for children and other building occupants. However, there are at least two pathways to optimize the use of this waste stream.

Source domestic flame retardant-free foams whenever possible and test when flame retardant content is unknown:
As more upholstered furniture products are labeled with content information, this information can be transferred through the pre-consumer FPF supply chain with foam scrap and can also be used to identify flame retardant-free post-consumer furniture foam in the future. Additional study is needed to determine the degree of flame retardant use in mattress foam domestically and its potential as a flame retardant-free post-consumer feedstock. In the meantime, mattress manufacturers and bonded manufacturers using only flame retardant-free foam should also label products for future recycling. If transparency about content is propagated throughout the supply chain, safer post-consumer FPF feedstocks can be domestically sourced in the future.

Chemical feedstock recycling:
Research and investments in these technologies could potentially segregate hazardous flame retardants from feedstocks being reused in building products. Progress has been made in industrial scale chemical recycling of polyurethane foam, but efforts are needed in exploring this avenue for post-consumer FPF, including the effective removal of flame retardants.

Recycling foams is a great benefit to the environment, reducing not only landfilling impacts at end of life, but also decreasing the upstream impacts of new foam production. These benefits must be balanced against the multi-billion dollar per year health impact, according to the United Nations, that current recycling practices create.[95] Therefore, investigating ways to optimize FPF recycling via improved labeling, screening, and recycling technologies is a relatively small price to pay.

Recommendations

For the Recycling Industry:
Sources of FPF that do not contain flame retardants are increasingly available, especially from new post-industrial and post-fabrication scrap sources. As more consumers become aware of the health hazards of flame retardants in foam products, they will value flame retardant-free feedstocks. Track, label and separate these flame retardant-free foams from other contaminated recycled sources.

Track sources of scrap foam (post-consumer and pre-consumer) that are known or suspected to contain flame retardants; separate those from sources that are flame retardant-free, and label accordingly.

Work with researchers and agencies to evaluate and implement screening processes when presence of flame retardants in foam is unknown. Invest in research and development of chemical recycling for removal of toxic flame retardants.

For recycling entities involved in the handling, processing, and transportation of FPF, institute occupational protections including deployment and use of additional inhalation and dermal exposure personal protective equipment (PPE) when needed. Work to minimize and contain exposure pathways to all work areas where hazardous flame retardant chemicals may be in the materials that are collected, processed, or transported.

For Manufacturers:
Prefer sources of post-consumer recycled foam that are flame retardant-free. If not readily available, specify only flame retardant-free pre-consumer or virgin feedstocks whenever possible. Incorporate methods to track composition throughout the supply chain. For bonded products containing only pre-consumer content, identify and label those that are flame retardant-free for future post-consumer recycling.

FPF can be recycled several times if the feedstock is of suitable quality. Therefore, foam producers should remove scrap containing flame retardants from new foam production whenever possible. To prevent contamination of future recycling streams, label products and scrap indicating whether the foam contains flame retardants.

Foam fabricators who trim foam for use in furniture should separate and label scrap indicating whether or not flame retardants are present for tracking throughout the recycling supply chain.

Mattress and furniture manufacturers should specify flame retardant-free foams whenever possible. Label products and scrap indicating whether flame retardants are present for tracking throughout the recycling supply chain.

Train all workers on best practices in handling materials that contain flame retardants. Create manufacturer precautionary information and instructions to reduce occupational exposures for workers who may collect, process, or transport possible hazardous flame retardant chemicals.

For Purchasers:
Encourage a flame retardant-free supply chain by purchasing materials that are labeled and verified to be flame retardant-free, and continue with clear labeling down to the end consumer. If flame retardant-free materials are unavailable, encourage full transparency about all material contents including the presence of residuals and contaminants by prefer-

ring products with disclosure down to at least 100ppm (0.01%) by a standardized format such as the Health Product Declaration.

For Certifiers:
Expand the CertiPUR-US® certification program to include all flame retardants within the program's scope, including screening of whether or not products are flame retardant-free. Label or otherwise communicate these results to purchasers of foam in the supply chain.

Seek labeling or other indicators of the CertiPUR-US certification information that stay with the materials throughout the recycling supply chain. Include this information with scrap so that recycled content building products—such as bonded carpet cushion—can be certified if made with certified foam.

The CRI Green Label Plus program—a label for end consumers of carpet and carpet products—should add criteria in its labeling system to indicate flame retardant-free products.

For Regulatory Agencies:
Review current consumer product fire safety requirements for cases where flame retardants are not needed to ensure fire safety, and set requirements accordingly. Invest in research to determine the extent of historical and current flame retardant use in mattress foam. Investigate other sources of foam that may end up in the recycling supply chain, such as packaging foam, automotive/airline foams, and institutional furniture. Support studies of the scalability of testing and screening techniques to detect the presence of flame retardants in foam feedstocks and subsidize equipment if necessary. Incentivize supply chain quality controls and labeling to track flame retardant content throughout the recycling supply chain.

Encourage development of chemical recycling infrastructure that can remove flame retardants during the recycling process. For foams that should not be recycled, investigate responsible disposal methods that do not release hazardous chemicals into the environment (air, water or land).

Encourage circular manufacturing processes by seeking solutions that encourage or require manufacturers of these products to help carry physical and/or financial responsibility for their fate at end of life. Encourage extended producer responsibility (EPR) programs, regulation, or other incentives for manufacturers to take-back or be responsible for disposal costs if suitable recycling markets are not available for products.

Work with recycling processors to ensure worker exposure is minimized by the use and deployment of adequate personal protective equipment. Assess processing facilities to ensure facilities are not creating conditions of public exposure.

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