United Nations Industrial Development Organization

November 30, 2011

Guidance Document Submission:
Flexible Polyurethane Foam Waste Management & Recycling

About This Document

The Stockholm Convention is an international treaty aimed at protecting human health and the environment from the threats posed by persistent organic pollutants (POPs). The Convention goals are to restrict and ultimately eliminate the production, use and release of these pollutants and also to establish regulation of their international trade and disposal upon becoming wastes. Parties to the Convention must develop National Implementation Plans (NIPs) for meeting the obligations of the Convention. In order to develop those plans, guidance documents are developed by the United Nations Industrial Development Organization (UNIDO) to assist members of the Convention. The Polyurethane Foam Association (PFA) was invited to submit information to UNIDO. The PFA is grateful for the contributions and reviews provided by a number of related trade associations and industry experts.

Polyurethane Foam Association
www.pfa.org

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Guidance Document Submission: Flexible Polyurethane Foam Waste Management & Recycling

Polyurethane Foam Association
Robert J. Luedeka
Executive Director

I. Introduction

Flexible polyurethane foam (FPF) is a manufactured article with a multitude of end uses. FPF products are used in vehicle interiors for seating, upholstered trim and acoustic panels; in residential and commercial upholstered furniture; in residential and institutional mattresses and top-of-bed products including pillows and mattress pads; in protective packaging applications; in healthcare for restraining, support, pressure-relief, fluid absorption and wound care applications; in air and fluid filtration; in laboratories and testing instruments as an efficient collection and absorption medium; for apparel padding and insulation; in military defense to help prevent fuel-related flash fires in vehicles, vessels and aircraft; and particularly in the United States as a cushion underlayment for residential carpet installation.

While FPF may appear to be a generic commodity product, it is, in fact, often a technical article with specific performance attributes created through proprietary formulations and fabrication processes. Many FPF manufacturers produce more than 150 different FPF products, each having unique characteristics appropriate for specific end uses.

The FPF industry uses two basic production methods: slabstock (outside the US, referred to as "block foam") and moulding. Each production method requires unique product formulations using a number of raw materials including, but not limited to a polyol, diisocyanate, surfactant, catalyst, auxiliary blowing agent and numerous optional specialty additives including, in some instances, flame retardant products.

Within the slabstock and moulding processes, there are two basic types of end-product families depending on the use of either polyether polyols or polyester polyols. The resulting polyether-based or polyester-based products have different performance properties that may be desirable for certain applications. For instance, polyester-based FPF products are often specified for use in heat lamination of foam product to fabric substrate and for use as filtering media of liquids and air. For home furnishings and transportation seating applications, polyether-based products are mainly used for their lower density, surface softness, durability and hydrophobic tendencies.

Formulations for slabstock and moulded products may require adjustment prior to or during production to respond to ambient production conditions including humidity, temperature and barometric pressure. Such formulation adjustments may include variations in concentrations and / or changes in the selection of various raw materials including additives such as optional flame retardants.

With slabstock production, there are two basic production techniques: continuous pouring (Appendix Photo 1) and batch pouring (Appendix Photo 2). Larger volume production operations tend to rely on continuous pouring technologies. Continuous pouring technology involves feeding raw materials into a reaction chamber/mixer (pour head or laydown device) with the reaction mixture flowing onto a moving lined conveyor surface. With liquid carbon dioxide continuous pouring technologies (more common in developed countries), raw materials are highly-pressurized and are passed through tiny orifices in a pour head or laydown device (with openings that may be less than 50 microns in diameter). This is important to note as pressurized systems may limit or exclude the use of certain raw materials that include powders and liquids with solid granules that could impede flow through a pressurized pour head. Melamine is one example of a powdered additive that does not work well in pressurized pouring systems. Pressurized liquid CO_2 systems serve important environmental objectives, eliminating the need for certain auxiliary blowing agents such as methylene chloride and CFCs, which are no longer used in the United States. The carbon dioxide used in the process typically is produced by capturing existing CO_2 from the atmosphere or as a by-product from other material production. New CO_2 is not used as an auxiliary blowing agent.

Production of foam using formulations that include larger powdered (granules > 40 microns) additives require a more "open" pour head or hand mixing. Continuous pouring lines can accommodate limited amounts of powdered additive through the use of only water as the blowing agent (applicable to some higher density formulations), acetone auxiliary blowing agent (a non-HAP, heavier-than-air flammable substance), or, in some unregulated areas, the use of a HAP, such as methylene chloride.

Facilities having lower production volume requirements or financial constraints may rely on batch pouring techniques. Batch pouring facilities are more commonplace in developing countries and where it may be desirable to locate a small-scale foam production facility in close proximity to customers and / or end-users. There are very few batch pouring facilities in the United States. Batch pouring operations involve either mechanical introduction of blended raw materials into a stationary containment vessel, or hand mixing raw materials and literally pouring with buckets into an open containment form such as a box or vertical cylinder. Batch pouring equipment and bucket-pouring techniques rarely permit the use of pressurized systems, often lack significant environmental containment, and may not accommodate use of certain raw materials including several of the brominated, chlorinated and non-halogenated FR additives that are now available as PentaBDE substitutes for production of combustion modified FPF. Flame retardants used in batch pouring operations are not necessarily the same as are used in formulations for continuous pouring systems. Batch pouring FRs may include TBB, TCPP, and possibly some FR products that have been phased out of certain countries such as PentaBDE and TCEP.

Foam moulding technologies are similarly divided into automated and manual moulding operations. And, as is the case with slabstock pouring technologies, automated systems can allow better atmospheric control and are able to utilize a broader selection of raw materials and additives than can manual molding operations.

Raw materials selection may be affected by available production technology. Certain raw materials, including flame retardants, are not universally applicable for continuous pouring, batch production and automated vs. manual foam moulding operations.

No matter the production technology, the manufacturing of FPF products involves an exothermic chemical reaction. Some exothermal reactions may generate sufficient heat to cause undesirable foam discoloration (scorch), physical decomposition, or even product ignition depending on foam density, foam firmness, raw material selection, formulation proportions, certain mechanical issues, and / or ambient production conditions. Selection of possible flame retardant additives requires consideration of potential heat-generating side reactions during the foam making reaction process to avoid internal combustion. Under some conditions, it is possible for flame retardant additives to contribute to foam discoloration, typically disfavored by end-users.

II. Types of Flame Retardants Appropriate for Use In Continuous Pouring Flexible Polyurethane Foam Production

The basic types of flame retardant (FR) additives appropriate for use in continuous pouring include non-reactive halogenated and non-halogenated, and reactive FR additive products. Halogenated FR selections include products that primarily are made with brominated or chlorinated compounds. Other halogen elements (fluorine and iodine) have not been usable in most FPF formulations. Non-halogenated FR products tend to be phosphorous-based compounds. Whether in liquid or solid state at time of production, both non-reactive halogenated and non-halogenated products are true additives and tend to dissolved into or absorbed onto the resulting foam material.

Unlike the previously described non-reactive FR additive technologies, there are a few, reactive FR products available for experimental trials and limited commercial use. Reactive products participate in the foam-making chemical reaction, becoming part of the resulting foam polymer structure. Reactive products theoretically could include bromine, chlorine and phosphorous components. It is believed that reactive FR materials will remain bound into the foam molecular structure and will not be subject to migration from the foam products. While reactive technologies hold promise, it is not known whether reactive flame retardants will be technically or commercially viable in either continuous or batch pouring applications.

To produce a full range of foam products in the densities and firmnesses required to satisfy upholstered furniture cushioning applications for California Technical Bulletin 117 (CA TB117)[1] compliance, often requires the use of

1 State of California Bureau of Consumer Affairs Bureau of Home Furnishings and Thermal Insulation Refer http://www.bhfti.ca.gov/industry/117.pdf

multiple FR additives. No one product is workable in all production conditions, at all firmnesses and at all densities.

While it may be desirable to use only non-halogen phosphorous-based FR additives, they are useful only in foam products within a very narrow density range and to produce foam having rather firm characteristics. Outside of this product range, phosphate ester based FR products can contribute to scorch and foam discoloration. A persistent issue regarding use of phosphorous-based additives is a distinctive and foul odor that may become more noticeable when ambient production conditions include higher temperatures and increased humidity. In the US the most common FR additives are either mixtures of brominated flame retardants and phosphate esters such as Firemaster 550 and 600, or chlorinated phosphate esters such as TDCP. Non halogen flame retardants have a smaller but growing share.

OctaBDE and DecaBDE FR additives are not compatible with flexible polyurethane foam products and have not been used in FPF production. Reported detection of OctaBDE or DecaBDE in FPF products could result from FPF absorption properties possibly related to contact and transfer from fabrics, plastics or wiring insulation scrap having PBDE content, or result from misidentification.

Flame retardants for use in flexible polyurethane foam would ideally contribute the following attributes:

- Provide the desired level of combustion resistance;
- Meet environmental, health and safety objectives;
- Not impair foam physical comfort, support and durability;
- Not contribute to excessive discoloration of FPF during production;
- Be easy to process;
- Not limit the types of FR foams that can be produced, such as products that are very soft and/or have low density;
- Remain in situ and not volatilize during production or end-use;
- Meet economic constraints imposed by customers and consumers;
- Be recyclable.

III. Development of Proprietary Foam Formulations

Development of foam formulations must consider desired end-product physical characteristics, production equipment capabilities, atmospheric conditions, environmental considerations and raw material economics. Developing proprietary formulations and adjusting for atmospheric variations is the science and art of foam manufacturing. Having successful formulations that result in consistently reproducible products is one important way that foam manufacturers are able to compete for business. Foam formulations are considered industry trade secrets by foam producers and are discussed only in general terms in this Guidance Document section.

IV. Availability of Flexible Polyurethane Foam Raw Materials

Based on regional trends in foam manufacturing methods and technology, typical production conditions, common end-product applications, and regulatory considerations, global raw material suppliers may not offer all raw material products to all regions of the world. The regional availability of specific FR additives may be limited. The economics and logistics of manufacturing and distributing relatively small quantities of raw materials often make global availability impractical. There are also a number of regional raw material producers that may not have sales-support or distribution capability beyond limited geographic areas. This can contribute to variations in foam formulations and content in different parts of the world.

V. California TB117 Compliant Furniture And Futon Mattress Foams

In the United Sates, only one regulation exists, promulgated and enforced by the State of California, regarding the flammability of residential upholstered furniture, including futon convertible sofas. CA TB117 specifies flammability tests procedures and performance standards for filling materials used to construct upholstered furniture and convertible futon mattresses manufactured in or for sale within the State of California. Likely because of the relative size of the California population (about 11% of US population) and related logistics and component inventory management considerations, a number of furniture manufacturers, futon convertible sofa manufacturers and foam fabricators have chosen to specify that all component foam materials be compliant with the small-open flame test portion of CA TB117. Compliance with this component flammability standard almost always requires the addition of flame retardant additives. As a result, essentially all of the foam scrap generated by California-based upholstered furniture manufacturers and a significant proportion of manufacturing scrap generated by upholstered furniture plants outside California have significant FR additive content.

The same also would be true of upholstered furniture manufactured outside the United States for export to furniture distribution operations that may sell into California. If cushions are compliant with CA TB117, then foam scrap generated from cushion trimming and upholstering operations would also contain FR additives.

Imported residential upholstered furniture now represents about 34% of annual US wholesale value. In 2010, reported US domestic production was about $8 billion USD (US Census data), while imported residential upholstered furniture represented about $2.7 billion USD based on US Customs declared value. The ten leading exporting countries to the US were: China 74%; Vietnam 6%; Mexico 5%; Italy 3%; Malaysia 2.9%; Canada 2.0%; Indonesia 0.8%; Poland 0.5%; Norway 0.4%; Thailand 0.3%.[2] Products imported from these countries need to be CA TB117 compliant, if they are to be allowed for sale in California, and would now contain mainly chlorinated phosphate ester flame retardants, or brominated flame retardants.

Assuming that all nations achieve similar efficiency in upholstered cushion fabrication, trim scrap generated from cutting and shaping foam for upholstered furniture represents about 15% of foam product produced for this application.[3] This source of scrap represents the greatest volume for FPF manufacturing scrap, from all FPF end-uses. While almost all of the scrap generated from furniture manufacturing in North America is recovered for use in North America carpet cushion manufacturing, far less manufacturing scrap from furniture manufacturing outside the US is recovered for recycling as bonded carpet cushion. In 2010, it was reported that total importation of manufacturing scrap for North American carpet cushion manufacturing was approximately 195 million pounds.[4] The majority of imported FPF scrap is currently provided by Chinese scrap sources, followed by scrap from European countries.

Based on an assumption that upholstered furniture manufacturing is located globally in relation to population consumption demand and also influenced by availability of skilled labor, attractive labor costs, and availability of raw materials, it follows that there is significant amount of unused manufacturing scrap generated in China, UK, Germany, Italy, Poland, France and Spain, Viet Nam, and Malaysia. Unless it can be demonstrated that PentaBDE is currently being used in flexible foam production anywhere in the world, it is expected that FR content in non-North American (imported) furniture manufacturing scrap would be limited to certain chlorinated and phosphorous-based combustion modification additives.

Some US furniture manufacturing scrap also is exported to bonded carpet cushion producers in Canada and Mexico. Outside the US, scrap that is not exported for North American carpet cushion manufacturing has little value or use, and likely is destined to landfill or, in the EU, to chemical incinerators for energy recovery.

VI. British Standard 5852 Upholstered Furniture

The United Kingdom established the Furniture and Furnishings (Fire) (Safety) Regulations in 1988 that set levels of fire resistance for domestic upholstered furniture, furnishings and other products containing upholstery fillings. British Standard 5852 (BS 5852) is cited in the regulation and contains flammability testing methods, criteria and performance standards for furniture and other filled products intended for residential use including upholstered furniture, children's furniture, head-boards of beds, sofa-beds, futons and other convertibles, nursery furniture, garden furniture that is suitable for use in a residence, loose cushions, seat pads and pillows, and mattresses made of a single filling material, such as solid foam core mattress. (A different UK standard, BS 7177, is applied to mattresses having 2 or more filling components.)

Filling materials (foam and non-foam) used in product applications covered by the UK regulations must be tested for compliance with the standards included in BS 5852. A small wooden crib (BS 5852 Source 5) ignition source is mandated for foam component testing. This heat source generates significantly more energy than the CA TB 117 small open flame. To achieve compliance with the UK regulations, foam components must be combustion modified using significant amounts of FR additives. Conventional halogenated and non-halogenated FR products do not provide adequate levels of flammability performance. It is necessary to use melamine powder or

2 US Department of Commerce –2010 Annual Summary, NAICS No. 337121 Import Data

3 In 2010, approximately 212 millions pounds of slabstock foam was produced for use in US manufactured upholstered furniture. From all domestic manufacturing sources, in 2010 about 50 million pounds of trim scrap was recovered for use in US bonded carpet cushion production. According to industry participants, essentially all trim scrap used in furniture manufacturing is recovered for domestic carpet cushion use. Furniture manufacturing represents about 75% of new trim scrap used in the US. Therefore, typical trim scrap generation from upholstered furniture manufacturing is 15% of FPF produced for this purpose.

4 American Chemistry Council, Center for the Polyurethanes Industry, 2010 End-Use Survey

expandable graphite (exfoliated graphite) as an additive combined with some chlorinated phosphate content. Melamine is not an effective flame retardant over the entire ignition profile and chlorinated phosphate (PCF) serves that purpose well. Significant amounts of melamine-based FR are required to comply with UK standards, and the result is heavily "filled" foam often having more than 30% FR content by weight. This concentration of foam filler detracts from foam strength properties and can shorten the useful life of polyurethane foam components. Brominated FR products (either PentaBDE or current PentaBDE replacements) are not very effective adjuncts to melamine and would not have been used on their own in foams that comply with the standard. So regarding potential issues related to BFR content in foam, scrap generated from the trimming of UK compliant foam would not present a BFR management concern. However, the high filler content of UK compliant foam products would limit the use of trim scrap, making it undesirable in bonded cushion production primarily due to poor physical strength properties associated with UK compliant foam products.

VII. Flame Retardant Upholstered Furniture For Use In High Risk Applications

Upholstered furniture for use in areas of public occupancy may need to comply with specific ignition and combustion requirements that are significantly above the flammability performance level that may be required for residential furnishings in the US and UK. In the United States, compliance with California Technical Bulletin 133 (CA TB 133) may be required for upholstered furniture items to be used in areas of greater fire risk and where egress may be limited such as in auditoriums, high-rise buildings, prisons and mental health facilities, hospitals and dormitories.[5] In a similar manner, the UK flammability regulations require a higher level of combustion resistance for items to be used in higher risk applications. CA TB 133 is a full-scale flammability test of a finished furniture item. Compliance is achieved through various combinations of ignition and combustion resistant fabrics, ignition barrier materials and FR filling materials. FR Polyurethane foam is rarely used alone to achieve CA TB 133 compliance. More commonly, a barrier technology combined with an inherently combustion resistant fabric and CA TB 117 foam filling is used. To meet UK high-risk flammability requirements, melamine-filled foam with a chlorinated phosphate adjunct plays a larger role in combination with inherently combustion resistant fabrics.

UK flammability requirements for high risk applications apply throughout the UK, while in the US, CA TB 133 is required in high risk applications throughout California, and by some fire marshals in a few larger US cities. Manufacturers of commercial furniture advise that requests for TB 133 compliant furnishings often come from government purchasing entities at federal, state and local levels. Because of the fairly limited scope of regulated product applications and the economics associated with the construction and testing of furnishings products that can achieve high level flammability performance, the volume for high-risk furnishings production is limited. A significant portion of such furnishings also include moulded foam components. Foam trim waste from the manufacture of high performance combustion modified furnishings is minimal, and, due to poor strength properties, of limited use for bonded carpet cushion production. Not all of the foam scrap generated by the manufacture of highly combustion modified commercial and institutional furnishings products contains FR additives.

VIII. Use of CA TB 117 Compliant Foam in Commercial Seating Products

There is a trend among office furniture manufacturers and US commercial furniture buyers to specify CA TB 117 compliance even if the upholstered furniture item is to be used in a location where CA TB 117 products are not required. Research by the Business and Institutional Furniture Manufacturers Association International (BIFMA International), estimates that about $2.6 billion (USD) in commercial seating was produced in the US in 2010.[6] According to US Customs reports, commercial seating products valued at an additional $2.2 billion (USD) were imported in 2010 by US manufacturers, distributors, retailers and large commercial buyers.[7] Therefore about 50% of commercial seating products for sale in the US are now imported. Leading exporting countries include: China 50%, Canada 19%, Mexico 9%, Taiwan 7%, Germany 3%, Italy 2%, and Japan 1%. Adjustable height swivel office chairs represent a large portion of the imported volume. The majority of these products are imported by large retailers and sold to consumers for home office use as

5 California Department of Consumer Affairs Bureau of Home Furnishings and Thermal Insulation, http://www.bhfti.ca.gov/industry/tb133.pdf

6 BIFMA International, The 2010 U.S. Office Furniture Market, Statistics updated 08-04-2011.

7 US Department of Commerce – 2010 Annual Summary, SIC No. 2522 Import Data

well as to commercial businesses. Essentially all imported and domestically produced seating for commercial applications contains CA TB 117 compliant filling materials. Prior to 2005, these products likely contained PentaBDE FR content. After 2005, there should be no PentaBDE content, although other brominated FR materials may be used. Most of the swivel office chairs for clerical use contain molded foam seat and back components that would require less FR content to meet CA TB 117 flammability requirements than cushioning fabricated from slabstock foam. Molded foam production typically results in very little trim scrap, while use of slabstock foam products in this application generates scrap similar to residential furniture manufacturing efficiency – about 15% trim waste.

IX. Commercial Furniture Recycling

Although there is interest among commercial furniture manufacturers and the international design community to develop programs to recover and recycle commercial upholstered furniture at end-of-life, currently such activity is very limited. Most foam scrap recovery and reuse takes place at the manufacturing level, with manufacturing scrap recovered in the US, Canada and Mexico directed into the production of US bonded carpet cushion, and, to a lesser extent, exported by China and other producing countries for US carpet cushion manufacturing.

X. Automotive Seating And Trim Foam

All interior materials used in US passenger cars, light trucks, multi-purpose vehicles, trucks and buses must comply with Federal Motor Vehicle Safety Standard No. 302 (MVSS 302). The test standard specifies that interior materials shall not exhibit a flame spread of more than 4 inches per minute. The open flame test can be conducted on composite products, cut down to no more than ½ inch thickness. MVSS 302 applies to all seat cushions, seat backs, headliners, arm rests, trim panels, head restraints, floor coverings, sun visors, instrument padding and mattress covers used in vehicles.

For many composite automotive materials, the cover fabric (positioned to face the flame during the test) often plays a major role in achieving compliance. Depending on whether raw foam materials, or composite seating, headliners or floor coverings are tested, compliance with MVSS 302 requires various amounts of FR content. One major global seating supplier reports that between 0.5 – 1.0% FR additives are required for moulded foam products as may be found in seating, arm and head rests. FR concentrations of 2-5% could be found in moulded carpet padding, and, depending on the headliner fabric and grade of foam substrate, up to 15% FR content could be found in foam for lamination to headliner fabric. US of FR additives in headliner products is not universal. In fact, some headliner suppliers report the ability of passing the MVSS 302 test without need of FR content in the headliner foam component. In such cases, the substrate fabric would be resistant to flame spread.

Brominated FR additives are not commonly used for MVSS 302 compliance. TDCP is mainly used with less use of phosphorous additives. Flame resistant fabrics are also used. Automotive foam parts manufacturers advise that new non-halogenated phosphorous FR products hold promise for increased use in the future.

Flexible polyurethane foam content is estimated to represent about 30 – 40 pounds per passenger vehicle.[8] Most of the possible FR foam content of a vehicle would be found in laminated headliners, although FR foam is not always required. When taken as a whole, there is very little FR content in the foam used in motor vehicle interiors and resulting scrap foam at end-of-life.

Regarding automotive waste generation, automated moulding operations tend to be very efficient, generating minimal amounts of manufacturing trim scrap (mould flash), while manual part moulding may be less efficient. There are no industry estimates available for waste generation from global automotive foam moulding operations.

Most foam trim scrap in the automotive industry is typically generated from the cutting of headliner panels. (Appendix Photo 3) Scrap from this operation may not be easily separated into individual recyclable fabric and foam components. One company in Mexico has developed a small business around mechanically shaving (skiving) foam from fabric for component recovery and recycling purposes. (Appendix Photo 4) There is no estimate available for the volume of trim scrap generated from the manufacture of headliners. It has been reported that the majority of trim scrap generated from this product goes to landfill in North America and is converted to energy by incineration in the EU. A number of Asian scrap brokers offer baled headliner scrap for export, but there is limited demand for this product.

8 Estimate provided by The Woodbridge Group, a global manufacturer of foam and interior parts for vehicles.

End-of-life management of motor vehicle scrap is an activity gaining increased global attention. In some countries, there are requirements for vehicle recycling and waste recycling. There are ready markets for metal components, but separation, recovery and reuse of polyurethane foam waste is a more challenging process having much less end-product demand. There are commercial technologies available to recover foam scrap from vehicle shred, but the use of such technologies represents a small portion of the total volume of vehicle waste that could be processed. Current best-available-practice involves fine pulverization of the foam scrap for use as an additive in new foam production. However, the number of facilities capable of separating foam waste content and achieving "micro size" pulverization is limited to a small number of locations worldwide. Even if such facilities were more prevalent, the limit of possible recycle content for new foam production is about 10% by volume, and this level of content is only achievable if addition of other non-reactive additives and fillers is limited or eliminated from the formulation. As a result, there is not significant demand for, or availability of, recycled, micro-ground polyurethane waste for use in new FPF production.

Recovery of polyol from foam scrap by glycolysis is another potential method of recovering value at end-of-life. The process involves reacting foam scrap with an alcohol and exposing the solution to superheated steam to hydrolyze the carbamate produced during dissolution. While technically achievable, this method of waste management is not yet widely available or cost effective, regenerated polyols to date have been of extremely poor quality, limiting use of this technology in foam production. It is possible that a similar process could be used to separate bromine content, but this, too, would be a costly method of foam scrap management.

XI. Minimal Use of Combustion-Modified Foams in Mattress Construction

The worldwide mattress industry divides products into two general classifications: mattresses intended for residential use and products for commercial and institutional use such as in hotels, dormitories, healthcare facilities and prisons. In the United States, there are two federal flammability standards for residential mattresses and mattress sets: 16 CFR 1632, a standard requiring resistance to smoldering ignition such as exposure to lit smoking materials, and 16 CFR 1633, a full-scale severe open flame ignition test of the mattress and box spring or supporting foundation.

The US polyurethane foam industry traces early demand for foam padding in mattresses to 1972 when the US 16 CFR 1632 federal smolder ignition performance requirement was enacted. The addition of a layer of relatively low-density, non-FR flexible polyurethane foam proved to be an effective way of achieving smolder ignition performance. While test cigarettes might burn through the mattress cover fabric, polyurethane foam positioned beneath the cover fabric tended to retreat from the radiant heat source, removing potential fuel for combustion, allowing cigarettes to extinguish without causing open flame ignition of the mattress materials. Thus, using non-FR polyurethane foam in mattress construction became an effective tool to help achieve compliance with US 16 CFR 1632.

16 CFR 1633 was enacted as a US flammability standard for mattress sets in 2006. It is applied in addition to CFR 1632 smolder performance requirements. 16 CFR 1633 is a full-scale test that subjects horizontal and vertical surfaces of the mattress set (combined mattress and supporting box spring or mattress and foundation) to flames from a multi-ported t-shaped gas burner calibrated for release of 75 kW and 200 kW heat fluxes to be applied at different test stages. To be in compliance, the mattress set must not exceed a maximum heat release of 200 kW at any time during the 30-minute test, and not accumulate more than 15 megajoules of total heat release energy during the first 10 minutes of the testing process. This is considered a severe flammability test and the use of FR additives in foam components is not a practical method of achieving full-scale compliance. Mattress manufacturers achieve compliance with 16 CFR 1633 by wrapping a fabric or fiber batting combustion barrier around the foam padding inside a mattress. The barrier protects the interior from ignition. They are made from various combustion resistant fibers that can include boric-acid treated cotton and / or inherently combustion-resistant modacrylic fibers that may be blended with treated rayon fiber.

Mattresses produced for certain high risk institutional applications may contain significant FR content in covers and in interior components. Such products are specially manufactured to meet specifications associated with high risk uses such as in prisons, where arson may be a concern, or some hospital and other healthcare installations where egress is limited and where combustion in the presence of raw oxygen represents a significant hazard. Constructing mattresses to meet high risk specifications often involves use of special ignition-resistant cover fabrics having high chlorine content combined with combustion modified foams that may include melamine-modified polyurethane combined with a chlorine component such as PCF, or synthetic foam rubber (acrylonitrile-butadiene) with significant concentrations of chlorine-based FR-like compounds. Such high-performance combustion modified foams may also be specified for some military vehicle, marine vessel and aircraft cushioning applications. High performance combustion modified foams would not be found in typical consumer products. Such foam products tend to have undesirable comfort characteristics, exhibit poor strength and durability properties and be comparatively costly. After 2005, brominated flame retardant content would not be typically found in mattresses for high hazard applications.

Prior to 2005, a very small number of US mattress manufacturers may have specified CA TB 117 foam components, possibly to support the promotion of specific mattress models offering consumers identified fire safety benefits in advance of the anticipated federal 16 CFR 1633 standard. Some of these products, although sold very limited quantities, may have contained PentaBDE FR-modified foam content. Specialized fire safety mattress products were not sold for very long in retail stores because they did not receive much consumer attention and were soon replaced at retail by standard mattress products that complied with 16 CFR 1633 when the standard became a US federal requirement for all residential mattress sets.

Prior to 16 CFR 1633 coming into effect nationally, compliance with California Technical Bulletin 129 (CA TB 129), Flammability Test Procedure for Mattresses for Use in Public Buildings, may have been specified for mattresses used in high risk applications, as described above. PentaBDE FRs could have been added to foam used in these products until PentaBDE was withdrawn from manufacturing by Great Lakes Chemical Corporation in 2005. The number of mattresses produced to comply with CA TB 129 would have been very small compared to the number of mattresses produced for other purposes.

In the United Kingdom, BS 7177, a combined composite and component test, established flammability performance criteria for mattresses constructed using two or more different filling materials, such as combinations of innersprings, synthetic fiber batting and foam. When multiple filling materials are used, the UK standard applies mass (weight) loss criteria to small open flame tests. To achieve compliance it is likely that an FR additive would be required in polyurethane foam. The combustion modifying agent generally is a chlorinated phosphorous,or melamine with chlorinated phosphate adjunct.

Because mattress, box spring, foundation and divan base shapes are typically rectangular in shape with square corners and flat surfaces, foam scrap generated from mattress construction is minimal. In many cases, substantially all raw trim foam scrap and scrap fabric quilted to foam substrate from mattress panel cutting could be used within the mattress manufacturing facility as corner padding for box springs, foundations and divan bases. As a result, management of soft scrap generated from mattress production has not been a great concern. Relatively small quantities of such scrap have been sent to landfill.

Only a limited number of adult size mattresses would have been manufactured using brominated FR foam components (PentaBDE or brominated replacements). Those mattresses likely would have been innerspring constructions produced in the US between 2003 and 2006 for the purpose of promoting fire safety construction to consumers. Such products were offered in limited retail distribution prior to the compliance date set for 16 CFR 1633. Before withdrawal of PentaBDE FR products in 2005, some of these “fire safe” mattresses could have contained PentaBDE content and after 2005, and until 2006, similar bedding products might have contained brominated PentaBDE substitutes. Chlorinated FRs alternately could have been use to satisfy manufacturer flammability performance specifications. Total foam content would have been limited in innerspring mattress products to typically less than 10 cubic feet of foam in a typical mattress sold in the US during that time period (based on queen size innerspring construction having an average of about 4 inches (total thickness) of foam cushioning across the top and bottom horizontal surfaces of the mattress with minimal FR foam quilted to fabric on vertical side panels).

In the United States, at end of life, most mattresses go to landfill. On a very limited basis, mattress recycling has been conducted in the US by small companies. (Appendix Photo 5) Disassembly of a mattress unit involves stripping the mattress to recover component products. Certain components have value: cotton for cleansing and reuse, steel as scrap for steel making feedstock, wood for various purposes, and foam for bonded carpet cushion raw material. Only about 2% of mattresses are recycled annually in the US. Information indicates that mattress recycling in European countries is similarly limited. Without efficient mechanized processes for stripping used mattresses, available inexpensive labor and sufficient value and demand for recovered components, business economics will be unfavorable for mattress recycling. For now, incineration for energy recovery, as practiced in some European countries, is likely the most cost effective means of managing mattresses at end of life. Incineration for energy recovery is not as extensive in North America as in parts of Europe.

XII. Bonded Carpet Cushion Use of Manufacturing and Post-Consumer Scrap

The North American bonded foam carpet cushion industry represents a major end-use for flexible polyurethane foam manufacturing trim scrap generated throughout the world, but particularly in North America. To a lesser degree, the North American bonded carpet cushion industry also consumes significant amounts of US post-consumer polyurethane foam scrap, mainly obtained by take-up of used polyurethane foam carpet cushion during installation of replacement carpet. In 2010, it was estimated that about 700 million pounds of bonded carpet cushion were produced in the United States, Canada and Mexico.[9] Bonded polyurethane pads are also manufactured in China primarily for export as carpet cushion and for reported vehicle and mattress padding applications.

In the US, bonded foam carpet cushion represents approximately 90% of all carpet cushion products sold. (Appendix Photo 6) There is very little use of bonded foam products in vehicle and mattress padding applications in the US. In 2010, industry estimates indicate that the following recovered foam materials were used in bonded polyurethane pad production:

- Imported scrap (primarily furniture manufacturing trim with some post-consumer content) *196 million pounds.*
- Domestic manufacturing scrap (primarily from furniture trim) *50 million pounds*
- Domestic post-consumer take-up scrap *265 million pounds*[10]

The vast majority of carpet, and therefore carpet cushion, are used in English speaking countries, specifically the US, UK and Australia. Little carpet cushion is used in the rest of the world.

In formulating for bonded polyurethane foam production, the percentage of post-consumer scrap tends to increase as the density of the bonded cushion increases. Typically, the percentage of post-consumer take-up foam used in new bonded carpet cushion products varies between 5% - 20% (for medium density products) and 40% - 55% (for high density products).

Prior to 2005, PentaBDE could have been present both in the furniture manufacturing trim scrap and post-consumer take-up scrap foam used to make new bonded carpet cushion. The amount of PentaBDE used in furniture manufacturing varied by density. Higher density foam products typically required less PentaBDE FR content to meet CA TB 117 test requirements. Compliance with the MVSS 302 standard required much less use of PentaBDE FR than compliance with CA TB 117 for furniture filling materials. The manufacturing scrap recovered from these industries was part of the raw materials mixture used in the production of bonded carpet cushion.

No PBDEs (no Penta, Octa, or Deca PBDE products) have been intentionally added to carpet cushion. Recent offers of "fire retardant rebond" carpet cushion products from Chinese suppliers are confusing as there are no flammability requirements for residential carpet cushion and there is no need for FR additives. Very little bonded carpet cushion is used in commercial applications such as for private and public buildings, schools, retail stores, institutions and healthcare facilities. There are no federal flammability regulations for carpet cushion in commercial applications.

Since 2005, the only known source of PentaBDE in new bonded carpet cushion has been post-consumer take-up scrap recovered by US carpet replacement installers.

Eight US states including California, Hawaii, Illinois, Maine, Maryland, Michigan, Minnesota, New York, Oregon, Rhode Island, and Washington have enacted laws prohibiting manufacture or sale of products containing PentaBDE content. Exclusions are permitted to allow continued diversion from landfill and sale of recycled materials having PentaBDE content of no more than 0.1% by weight (about 1,000 parts per million).

Managing PentaBDE content in bonded carpet cushion requires some type of procedure. It is not practical to

9 Center for The Polyurethane Industry, American Chemistry Council "End-User Survey, 2010", September, 2011

10 Center for the Polyurethanes Industry, American Chemistry Council "End-Use Survey 2010", September 2011

apply gas chromatography/mass spectroscopy (GS/MS) analytical procedures. GS/MS testing facilities are limited in number. GS/MS lab work is costly and time consuming. It is not a detection method that could be used on site.

The random mixed nature of FPF scrap also makes it impractical to test each piece of scrap by X-Ray Fluorescence (XRF) instrument as each piece of scrap would need to be tested by physical contact. With resilient, porous materials, it is necessary to press an XRF instrument into the materials, beneath the surface to obtain reading for possible bromine content. Since foam scrap is of many sizes and shapes and usually thoroughly mixed, use of XRF detection procedures would not be practical. Also, the cost of XRF detection equipment is too great for small businesses. XRF technology is unable to distinguish between PentaBDE and other BFRs. If all bromine content were to be separated, a large volume of potentially useable scrap might be unnecessarily excluded from bonded cushion manufacturing. The most effective means of compliance with the 0.1% limitation on PentaBDE content, as imposed by some states within the US, was determined to be blending old and new scrap using mathematical modeling.

Management of PentaBDE content in finished products can be achieved by bonded cushion manufacturers by blending collected manufacturing scrap from domestic and import sources (Part A) with newly produced shredded foam, sometimes produced for specific use in bonded cushion production (Part B), and polymer binders (Part C). At medium – high density levels, some post-consumer scrap (Part D) can be added. The percent of Parts A, B, C and D are varied by end-product density and blended using content modeling to achieve compliance with 0.1% PentaBDE limits.

The Carpet Cushion Council, the United States trade association for carpet cushion producers, began systematic spot-monitoring of PentaDBE content in bonded carpet cushion in 2006.

In 2006 and 2007, samples of bonded foam products with various densities from multiple collection points in the United States were evaluated by an independent university laboratory using GS/MS analysis for PentaBDE content. The average PentaBDE content was 0.1%. The mean did not take into account the fact that low density bonded cushion formulations cannot accommodate any post-consumer foam scrap content.[4]

Continued spot-monitoring by Carpet Cushion Council indicates that the average PentaBDE content in bonded foam cushion produced in the United States is now less than 0.1% This demonstrates that PentaBDE laden foam waste can be efficiently modeled and managed to allow continued bonded foam production in compliance with allowed PentaBDE limits.[4]

Depending of carpet construction, foot traffic and consumer desire for replacement, carpet (and cushion underlay) tends to be replaced at intervals of between 5 and 15 years. As used residential carpet cushion continues to be collected and replaced with new bonded product having much less PentaBDE content. As this cycle continues, there should come a time when PentaBDE content in new bonded carpet cushion is near zero.[11]

It is very important that use of PentaBDE be discontinued in flexible foam production worldwide. If use of PentaBDE FRs continues in foam manufacturing, existing blending models for bonded cushion will no longer be an effective and reliable means of estimating maximum PentaBDE content in finished cushion products.

In Europe, about 165 – 175 million pounds (75– 80,000 metric tonnes) of bonded foam are produced for consumer goods, of which, about 110- 120 million pounds (50 – 55,000 tonnes) are converted into carpet cushion mainly for sale in the UK. European production of bonded foam is based entirely on post-manufacturing industrial waste, generated by foam manufacturing and foam fabricating operations. This trim scrap does not contain any brominated flame retardants, but may contain chlorinated FRs such as TCPP and, less commonly, TDCP.[12]

XIII. Flexible Foam Products That May Include BFR Content

While a number of different types of FR additives may be available, the focus of this section is on the use of brominated flame retardants in flexible polyurethane foam products, past and present. Prior to the later part of 2004, the selection of brominated FR products in the United States, Canada and Mexico was basically limited to a single PentaBDE product, Firemaster 500, which

4 Carpet Cushion Council reports and presentations

4 IBID

11 IBID

12 Europur, the association of European block foam producers, 2010 estimate

was introduced by Great Lakes Chemical Corporation to the foam industry in the mid-1980s. Firemaster 500 blended Pentabromodiphenyl ether with proprietary components, resulting in a final product that contained about 70% active PentaBDE content. From the later part of 2004 to present time, Firemaster 500 has been replaced by Firemaster 550 and Firemaster 600 products, which contain bromine components, but no PBDE. The two products represent all of the commercial brominated flame retardant additives available for use in North American countries. Use of brominated flame retardants outside of North America is very limited. ICL-Americas offers a product called Saffron 7700 which contains a reactive bromine component. Use of Saffron 7700 is limited in the United States. Flame retardant products including PentaBDE components (CAS 32534-81-9) are still offered for sale by companies located in certain Asian countries where restrictions on product manufacturing and use are not in place.[13] More investigation regarding possible availability of such FR products is needed.

Foam and foam-cushioned products that could have contained PentaBDE FR additives prior to 2005 include:

- Foam for use in CA TB117 compliant upholstered furniture and compliant convertible futon sofa seating / mattresses;
- Headliner for vehicles;
- Bulk inventories of FPF purchased by California foam fabricating and distribution businesses;
- Any foam product that was specified by the buyer to comply with CA TB117 open flame testing requirements including –
    - i. A portion of CA TB 133 compliant commercial seating;
    - ii. A portion of CA TB 129 compliant institutional mattresses;
- Bonded carpet cushion that contained manufacturing scrap obtained from fabrication of CA TB117-compliant furniture cushions and / or post-consumer waste obtained from take-up of bonded carpet cushion installations at end-of-use;
- Molded foam vehicle seats for MVSS 302 compliance – very little, if any content;
- Very few adult mattresses marketed as "fire safety" models during a 3-year period;
- Some foam-filled children's articles such as automobile safety seats, upholstered children's furniture and foam-filled nursery items that were made to comply with CA TB117.

Production of PentaBDE was discontinued by Great Lakes at the end of 2005, so after 2005, the same end-products could have contained BFR replacements for PentaBDE.

XIV. Foam Recycling Operations

Throughout the world, foam collection and recycling operations tend to be small businesses. In the United States, manufacturing scrap may be accumulated at the foam trim site for pick-up by the original foam supplier (buy back arrangement) or sold in an open market based on spot-quotes from potential buyers. An examination of the American Chemistry Council US polyurethane foam recycling database shows a number of scrap buyers distributed across the United States ranging in size from very small operations to larger companies who buy scrap for direct production of bonded cushion products. Most bonded cushion manufacturers are classified by the US Department of Labor as small businesses.

Foreign collection of manufacturing scrap operates in a similar fashion, with scrap collection companies often assisting larger furniture manufacturers in managing foam waste disposal. Some provide storage containers and waste bailing machinery to facilitate waste storage until collection. (Appendix Photo 7) Foreign scrap brokers typically consolidate manufacturing waste gathered from a number of sources for shipment to North American and Asian buyers. Post-consumer foam waste from auto, furniture, packaging or mattress recycling has been found mixed with the manufacturing scrap materials.

Collection and recycling of US carpet cushion is dependent on involvement by new carpet installers. Used carpet cushion (take-up) is collected by hundreds of carpet installers across the United States. Old cushion must be free of metal parts and be relatively clean without loose debris. The take-up waste is usually mechanically or hand-baled for storage pending sale to recycling specialists. In some cases larger carpet installation firms may sell directly to bonded carpet cushion producers.

Bonded carpet cushion manufacturers purchase baled post-consumer scrap from recycling consolidators and

13 Examples include: Shi Jiazhuang Luchi Chemical Co., Ltd.; Yick-Vic Chemicals & Pharmaceuticals (HK) Ltd; Weifang Sinobrom Imp & Exp Corp.,Ltd.; Tianjin Chengyi International Trading Co., Ltd.;
Dalian Jinbosheng Chemical Co., Ltd; Jia Xiang Industry Co.,Ltd; XiaoShuLin, HeBei District, TianJin; Shenyang Jiutongyuan Chemicals Co., Ltd; Shijiazhuang Hengsikai Chemical Imp&Exp Co.,Ltd;
Shijiazhuang Kunli Chemical Co. Ltd; Zenith Chemicals Ltd. (HK)

larger carpet installation companies. (Appendix Photo 8) Post-consumer take-up scrap is kept separate from manufacturing scrap for blending purposes. Scrap is graded by weight and origination. Blends are selected from baled inventory for shredding into pieces ranging from about ¼ inch to 1 inch diameter for use in bonded foam production.

XV. Recycling Options

Recycling options for flexible polyurethane foam products are limited in number. In areas where incineration for energy recovery is available, converting foam scrap to energy provides an acceptable means of managing foam at end-life. In other areas of the world, recovering manufacturing and post-consumer scrap for use in bonded cushion production provides a good alternative. Unless it is shown that PentaBDE is still being used in foam production outside the US, concerns about possible PentaBDE content should not be an issue with scrap that is being produced outside the US.

With growing emphasis on environmental sustainability, landfill of foam scrap materials should be considered only after other alternatives.

XVI. Separation Methodology for Foam Scrap

Scrap foam from various sources is quickly comingled during collection and handling. Foam scrap collection and recycling businesses are mainly small operations with limited technical capabilities. Screening waste product for BFR content using costly XRF instruments or submitting foam samples for offsite GS/MS analysis is time consuming and expensive. Therefore, XRF or GS/MS analysis is not a practical method for commercial application. The best solution will probably be found through education and communications. Informing foam producers that use FR additives and end-users who specify foam product FR attributes understand possible flammability codes and requirements (or the absence of such requirements), and the importance of maintaining compatibility with environmental, safety and health objectives at end-of-life will be important to successful long term solid waste management.

XVII. Summary and Conclusions

Of the many possible applications for flexible polyurethane foam, scrap generated from upholstered furniture manufacturing presents the greatest challenge for end-of-life management. As long as CA TB 117 continues to require that upholstered furniture filling materials be subjected to small open flame testing, flame retardant content will continue to be present in foam materials generated from manufacturing and from post-consumer carpet cushion sources and there likely will be end-of-life management issues.

Besides incineration for energy recovery, modeled scrap blending during bonded cushion manufacturing has proven to be successful and will continue to be a viable alternative in the United States for managing foam waste that may contain PentaBDE additives.

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XIX. Appendix

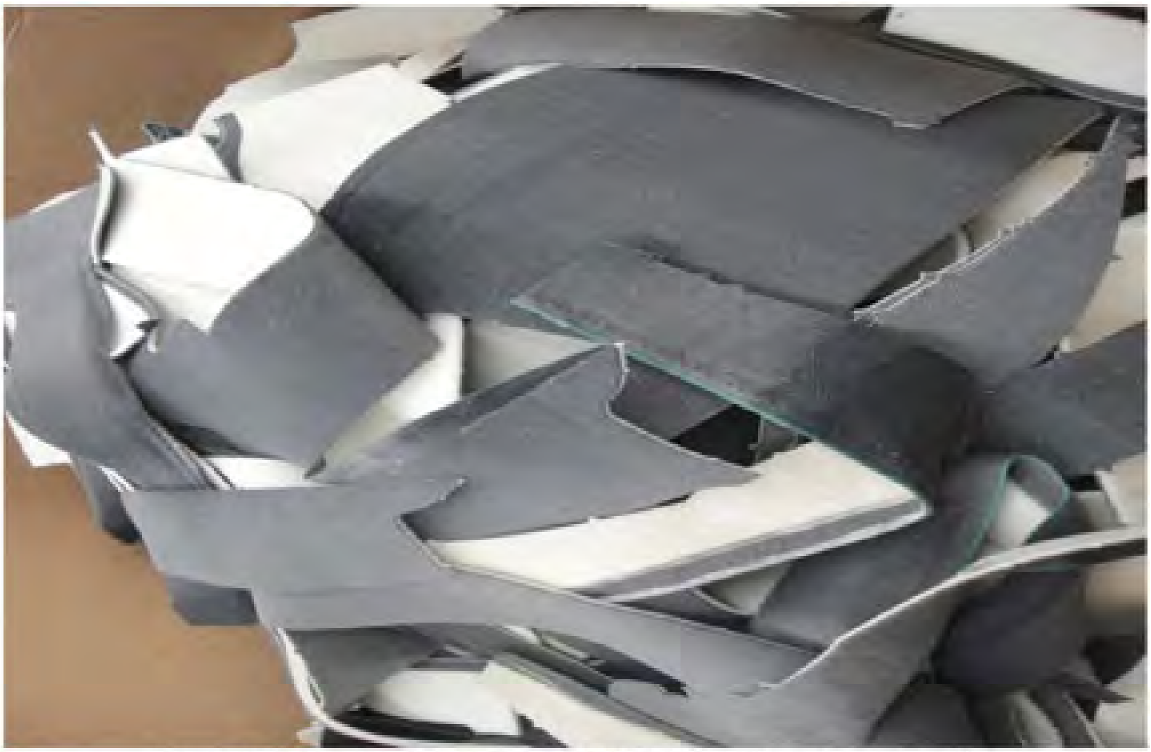
Photo 1

Continuous Processing Method of Producing Flexible Polyurethane Foam. Italy 2007

Photo 2

Bucket pouring procedure for batch manufacture of flexible polyurethane foam. China 2005

Photo 3



Automobile Headliner Scrap with Flexible Polyurethane Foam Backing

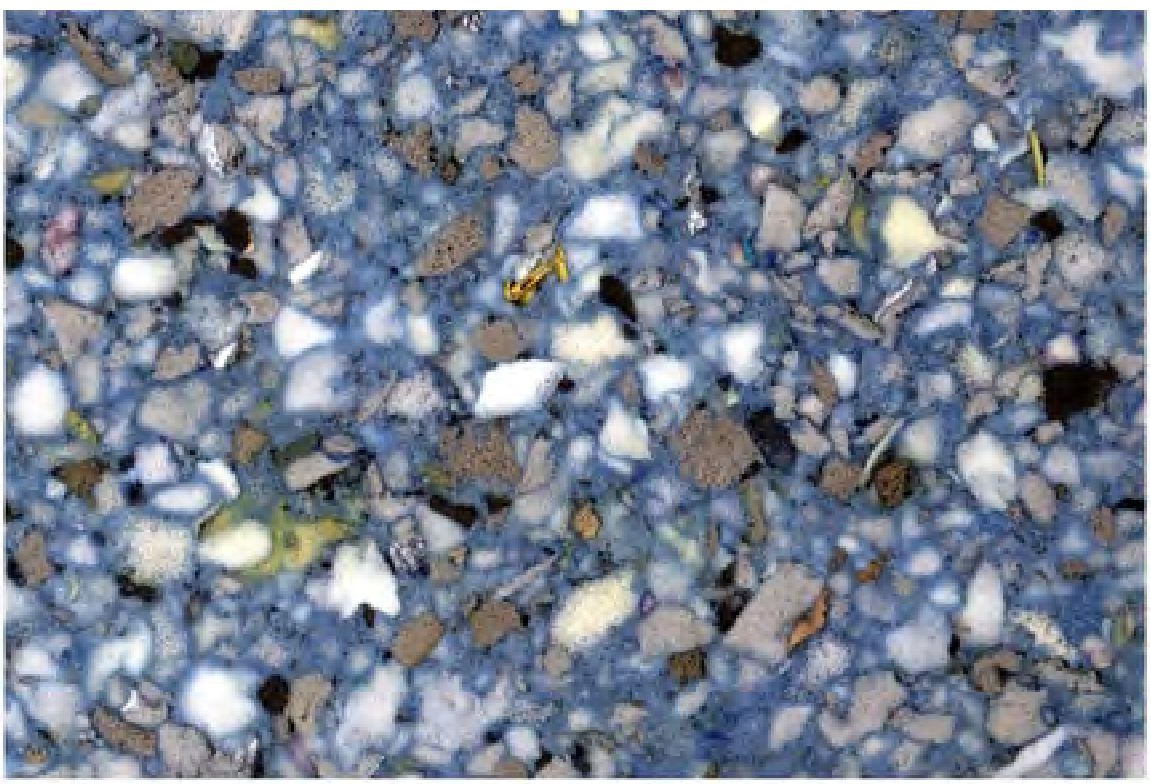
Photo 4

Skiving Headliner Fabric From Polyurethane Substrate For Recycling. Mexico 2010

Photo 5

Mattress Recycling. Boston, Massachusetts 2003

Photo 6



Bonded Carpet Cushion (Rebond) Close-up

Photo 7

Mixed Flexible Polyurethane Scrap From Collection Point

Photo 8

Flexible Polyurethane Foam Scrap Offered by Chinese Broker