5.0 CONSIDERATIONS FOR SELECTING A REPLACEMENT FOR PENTABDE

Multiple factors must be considered when selecting an appropriate chemical flame retardant. In addition to flame retardancy properties and health and environmental considerations, the flame retardant's use cannot negatively affect the quality of the foam (either physical characteristics or aesthetics that would reduce its desirability in the market place). This is a concern because the chemical will be incorporated in large amounts that may have effects on the foam product (e.g., pentaBDE formulations can make up as much as 8 percent by weight of the final foam product and other flame-retardant formulations have been used at concentrations above 10 percent). Additionally, it must be practical to use the chemical during production and processing of the foam and furniture with existing equipment. Finally, the chemical cannot be cost prohibitive.

The Furniture Flame Retardancy Partnership recognizes the significance of considering practical alternatives. The information in this report is focused on environmental attributes and can be weighed with cost and performance information when selecting alternatives.

5.1 Positive Environmental Attributes

This section identifies a set of positive attributes that companies should consider when formulating or selecting a flame retardant, or flame-retarded raw materials (e.g., foam and textiles) that will meet or exceed existing flammability standards. These attributes are linked to different aspects of what might happen to a chemical substance during its life cycle. While ensuring that fire-safety standards are met, the following environmentally desirable chemical characteristics and attributes, relevant to many flame-retardant chemicals, should be considered general "rules of thumb".

Aerobic Degradation

Biodegradation and incineration are both forms of aerobic degradation or aerobic oxidation of the chemical. Biodegradation is mediated by living organisms and generally slow compared to incineration which is abiotic on a rapid time line. Environmental oxidation can be an abiotic form of aerobic degradation which is generally very slow for most chemicals. Abiotic oxidative processes addressed here occur in the absence of light. For the purposes of this report, two categories of aerobic degradation are being discussed: biodegradation and incineration. Attributes and considerations associated with these categories are discussed in more detail below.

Readily Biodegradable: Low Persistence

Typically, the environmental profile of a chemical improves with its rate of biodegradation. According to the Organization for Economic Cooperation and Development (OECD), a chemical is readily biodegradable if, in a 28-day test, it biodegrades 60 percent or more within 10 days of the time when degradation first reaches 10 percent (70% for DOC-based tests). There are two main features of readily biodegradable substances. Hydrophobic components composed of unsaturated linear alkyl chains (straight chain carbon molecules) biodegrade more rapidly under aerobic conditions in sewage treatment plants and the environment than highly branched chains.

Also, hydrophobic and hydrophilic components that are linked by an easily biodegradable group like a carboxylic acid ester will separate the hydrophobe from the hydrophile during the first step through aerobic biodegradation (i.e., ester hydrolysis).

Keep in mind that while the rate of biodegradation is important, it is equally important to be aware of the byproducts formed through the degradation process. In some cases, the products of biodegradation might be more toxic and persistent than the parent compound.

Incineration: Consideration of Combustion Byproducts

A concern with chemicals introduced into foam products is the formation of hazardous combustion byproducts either during a residential fire or if the consumer product is ultimately disposed to an incinerator. For example, halogenated flame retardants have the potential to combine with other organic compounds during combustion and form halogenated dioxins and furans. The formation of other hazardous combustion byproducts should also be considered.

Low Bioaccumulation Potential and Low Bioavailability: High log K_{ow} (>8); Large Molecule

The ability of a chemical to accumulate is often measured by the bioconcentration factor (BCF). A high BCF indicates a high potential to bioaccumulate. Quantified, chemical-specific BCFs are often not available; however, this property can be estimated by correlating it with another readily-available parameter - the octanol-water partition coefficient (K_{ow}). In general, a log K_{ow} of 3.5 to 5 corresponds to BCFs of approximately 1,000 to 5,000. Both ranges represent a moderate to high bioaccumulation potential. Note that as the log K_{ow} increases above 8, the bioaccumulation potential decreases.

The potential for a molecule to be absorbed and harm an organism is less when the molecule is larger than a certain size. Molecules with the following characteristics are not available for passive uptake through the respiratory membranes of aquatic organisms: (a) molecules with hydrophilic components having large cross-sectional diameters, at least twice as large as hexabromobenzene (i.e., greater than 10 Å), or (b) neutral and anionic surfactants with molecular weights greater than 1,000 daltons. (Large diameters or high molecular weights will limit toxicity to surface effects only and will prevent systemic effects.)

In addition, high molecular weight molecules (greater than 1,000 daltons) tend to be less volatile and therefore, may exhibit less of a potential for inhalation exposure to vapors during manufacturing and processing of foam and textiles. If exposure occurs high molecular weight molecules are less likely to be absorbed, therefore limiting potential for adverse effects to be expressed.

Reactive Flame Retardants: Even if a chemical has the potential to bioaccumulate, the environmental concerns may be reduced or mitigated if the chemical is permanently incorporated into a commercial product. In this case, the potential for exposure to the chemical is greatly decreased. Reactive flame retardants are generally incorporated into the product (e.g., foam or textile) during the early stages of manufacturing. Additives are mixed throughout the formulation, but are not chemically bound. Therefore, these additives have a much higher potential to migrate, or leach, from the product into the environment under normal conditions.

Low Toxicity: Effects on several human health endpoints should be minimized. These effects include: cancer hazard, skin sensitization, reproductive effects, developmental effects, neurological effects, systemic effects and mutagenicity. Section 4 discusses methods to characterize these effects and presents results of the screening level evaluations for the 14 formulations assessed in this report.

5.2 Aesthetic and Performance Considerations

Scorching is a primary concern in the manufacture of flexible polyurethane foam in general, and is a particular concern for low-density foams. Light scorching results in discoloration or yellowing of the foam, while severe scorching can cause decomposition resulting in permanent damage to the foam. This phenomenon occurs because of the high temperatures that are generated during production of the foam bun.

Scorching is more prevalent in low-density foams because of the necessity to use toluene diisocyanate (TDI), which enables the foam to achieve low densities, better firmness and better support. Methyl diphenyl diisocyanate (MDI) is used to manufacture higher density foams as well as memory foams. The use of TDI causes a more exothermic (heat generating) reaction than the use of MDI. Therefore, a higher thermally resistant flame retardant is required for manufacturing low-density foams.

PentaBDE allows for the manufacture of low-density flame-retarded foam that is “snow white” in color. Because of its aesthetic desirability, it became the industry standard in mattresses and bedding products, as well as in many upholstered furniture applications. Greater acceptance of off-white foams could allow manufacturers to choose from a wider variety of alternative flame retardants. Barrier fabrics are allowing mattress manufacturers to mask the color of foam so that it will not be visible to the consumer. Other characteristics of foam that can be affected by the choice of flame retardants include firmness, durability and flexibility.

5.3 Process and Equipment Considerations

Another important consideration when selecting an alternative for pentaBDE is the feasibility of using the new chemical in an industrial setting. Ideally the alternative should be compatible with existing process equipment at foam manufacturing facilities. If it is not, the plants will be forced to modify their processes and potentially to purchase new equipment. The ideal alternative would be a drop-in replacement that has similar physical and chemical properties such that existing storage and transfer equipment as well as foam production equipment can be used without significant modifications.

For example, most U.S. foam facilities are equipped to store and process liquid flame-retardant formulations through pipes, metering systems and pumps. A solid alternative may require foam plants to make significant investments for conveyorized transfer, dust control systems and solid weighing apparatus. These modifications are feasible, from an engineering point of view, but may be cost prohibitive in certain circumstances.

Similarly, many foam "recipes" and manufacturing procedures are based on the addition of liquid flame-retardant chemicals. Addition of a solid flame retardant may require changes such as additional mixing steps and alteration of the process times. In some cases, these changes can have significant effects on foam quality or cost-effectiveness of manufacture.

5.4 Economic Viability

Foam manufacturing is a very competitive market in the United States and around the world. A flame-retardant alternative that is either more expensive per pound, or requires more flame retardant per linear foot to meet the fire safety standards will increase the foamer's raw material costs. In this situation, a foam manufacturer will attempt to pass the cost on to their customers (e.g., the furniture manufacturer), who will subsequently pass the cost to consumers. If this increase causes a significant market share loss, the foam manufacturer may not be able to compete and may be forced to discontinue use of the alternative, making the alternative economically unfeasible.

5.5 Alternatives Technologies (General)

Potential alternatives for pentaBDE can be separated into two categories: (1) alternative chemicals, and (2) alternative technologies. Chemical alternatives are the focus of this report; however this section provides a brief discussion of three currently-available alternative technologies being considered for further investigation by the Furniture Flame Retardancy Partnership: barrier technologies, graphite impregnated foam and surface treatment. Graphite impregnated foam and surface treatments have limited commercial uses; therefore, they are only briefly discussed. Barrier technologies are predominantly used in mattress manufacturing rather than residential upholstered furniture. However, there is considerable interest in future applications for furniture. Future partnership activities may focus on barrier technologies if appropriate.

In addition to the following technologies, it should be noted that some furniture designs exclude the use of filling materials, and even fabric altogether. Design therefore, should be considered when evaluating alternative means for achieving flame retardancy in furniture.

5.5.1 Barrier Technologies

Flame-retardant barrier materials can be a primary defense in protecting padding for furniture and mattresses. Manufacturers can layer barrier materials to improve the flame retardancy of their products. This layering approach allows a product to maintain its fire resistance even if one layer is compromised.

There are many types of barrier materials available. Fabrics composed of natural fibers such as cotton that are chemically treated to make them flame retardant are flame-retardant barrier materials. The hazards of these chemical treatments have not been assessed in this report. Fabrics composed of synthetic fibers that are inherently flame retardant are also flame-retardant barrier materials. Plastic films derived from flame-retardant resins are also flame-retardant barrier materials. These materials are designed and manufactured to meet specific flammability standards. This also explains the large number of flame-retardant barrier materials that are available. Flame-retardant barrier materials can be characterized by cost, resulting in three primary groups.

The first group of flame-retardant materials is the chemically treated, primarily boric acid treated, cotton-based materials. These materials are the least expensive flame-retardant barrier materials available. Mattress manufacturers that base their material decisions predominantly on cost prefer these flame retardants.

The second group of flame-retardant materials is a blend of inexpensive natural fibers and expensive synthetic fibers. Synthetic fibers used in these blends include VISIL, Basofil, Polybenzimidazole, KEVLAR, NOMEX and fiberglass. Smaller manufacturers of furniture and mattresses in niche markets use these materials. These blends are commonly used in bus and airplane seating.

The third group of flame-retardant materials is composed solely of expensive, high-performance synthetic fibers. They are generally used in industrial or high-performance applications such as firemen's coats and astronaut space suits.

Barrier materials can also be divided into woven or nonwoven fabrics. Woven fabrics tend to use general weaving technology to manufacture the fabrics. Manufacturers can customize fabrics to meet specific customer needs. Nonwoven fabrics are created using quite different technologies. Thermally bonded fabrics are a type of nonwoven fabrics. These materials consist of a core, typically cotton, which is fed with one or two outer layers of melt blown and/or spunbond polypropylene webs. The polypropylene web serves as the binder in this process. The core and the web pass between a smooth and a patterned calendar. The calendars are heated and thermally bind the core to the web. This process creates thermally bonded laminates. Another type of nonwoven fabrics is needle-punched nonwovens. In this process, a spun bonded or carded web passes under a needle board that contains thousands of needles. As the needle passes into the web, a barb catches a fiber and passes it through the web, interlocking the fibers.

One unique group of barrier materials is flame-retardant films. The films do not have the strength or texture to be used as an external barrier. The film can be used to wrap the foam cushions or it can be quilted with flame-retardant fabrics for added support and an extra layer of fire protection. Neoprene film is a common flame-retardant film. One type of material that competes with neoprene film is fiberglass fabric.

Mattress manufacturers are now using barrier technology to meet new fire safety standards in the state of California (California Technical Bulletin 603).

More information on barrier fabrics can be found in the following sources:

Decabromodiphenylether: An Investigation of Non-Halogen Substitutes in Electronic Enclosure and Textile Applications (Lowell, 2005)

Survey and Technical Assessment of Alternatives to Decabromodiphenyl Ether (decaBDE) in Textile Applications (Posner, 2004)

5.5.2 Graphite Impregnated Foams

Graphite impregnated foam (GIF) can be considered an “inherently flame-resistant foam” that is self-extinguishing and highly resistant to combustion. It is a relatively new technology and is largely used in niche markets such as for general aircraft seating. GIF technology produces foam that can meet airline fire safety standards for the seats with a reduced dependency on flame-retarded fabric. By minimizing the expense associated with flame-retardant fabric, GIF modified foams can be priced competitively.

GIF technology reportedly allows the design and fabrication of complex, comfortable and aesthetically pleasing seating for private aircraft. While GIF foam seating promises the possibility of eliminating the need for barrier fabrics, there are tradeoffs. When the barrier is removed, comprehensive composite flammability testing will be required on each new seat design to meet current fire safety standards (Federal Airways Regulation Part 25 Appendix F).

5.5.3 Surface Treatments

Surface treatments are also used in some applications and niche markets and may be appropriate for some textile manufacturing and furniture manufacturing readers of this document. However, surface treatments may not be viable as industry-wide replacements for pentaBDE for use in low-density foam for the following reasons:

There have been many proposals to achieve good resistance to ignition by post impregnation of foam with a variety of additives including borates, phosphates, various ammonium salts, etc. In addition to durability concerns (many surface treatments wash off or degrade over time), there are other considerations that limit their use.

The main concern is difficulty in achieving uniform impregnation of a foam cushion, which may be 5 or 6 inches thick. In addition, many of these systems are water-based and the impregnated pieces then have to be dried, which is a slow and expensive process. The drying process also tends to produce a thin crust of the additive on the surface of the flexible polyurethane foam cushion. A variation of this approach has been to surface treat the finished upholstered cushion. This process must occur at the furniture assembly plants, which are not typically equipped for chemical processing. Some surface treatments can also leave an undesirable coating on the fabric cover or the cushion that is subject to disruption by friction during use.

5.6 Methods for Selecting Chemical Flame Retardants

The Partnership designed this report to provide stakeholders with the ability to impose their own values on which chemicals to select and weigh information based on multiple considerations, focusing on environmental and human health attributes. Various governmental, commercial and non-governmental organizations have developed tools and methods to assist with complex decision-making, some of it specific to creating chemical rankings.

The Analytic Hierarchy Process (AHP) is a widely used technique for multi-attribute decision making. The process was developed by TL Saaty (*The Analytical Hierarchy Process*, McGraw-Hill, 1980), and uses a complex weighting system for comparing pairwise criteria, which can be further broken down into sub-criteria. A useful guide for investigating MCA tools is OECD's

Technical Guidance Document on the Use of Socio-Economic Analysis in Chemical Risk-Management Decision Making. Another useful guide is found at http://farmweb.jrc.cec.eu.int/ci/S6_weighting.htm.

Due to the complexity of the calculations, commercial software has been developed to assist analysts (www.expertchoice.com), though the calculations can be done without specialized software (http://mdm.gwu.edu/forman/Reproducing%20AHP%20calculations.pdf).

Two resources specific to creating chemical rankings, and which are applicable to the data generated from this report are:

1. CARS – Chemical Assessment and Ranking System found at: http://www.zerowaste.org/cars/

2. Substitution of PBT (persistent, bioaccumulative, toxic) substances in products and processed. Guidance for the use of environmentally sound substances.

   A. www.umweltdaten.de/umweltvertraegliche-stoffe-e/part1.pdf
   B. www.umweltdaten.de/umweltvertraegliche-stoffe-e/part2.pdf

The methodology in the second web site is particularly relevant. While it is written to address chemicals relevant to the aquatic environment, it could be modified to add concerns for releases to air as well.

Regulations that restrict the use of particular chemicals may also be useful to stakeholders when making decisions about flame retardancy methods. Appendix C provides a list of regulations that readers may reference to locate sources of information.

The information in this report is intended to aid industry in incorporating environmental information into their decision-making processes. Consumer groups may also find this information useful. While the information in this report is static, the Partnership will continue to work together to update this information and identify environmentally preferable options for both furniture and mattress fire safety. Current information on the Partnership is available on the web at http://www.epa.gov/dfe/projects/flameret/index.htm.