Decabromodiphenylether:

An Investigation of Non-Halogen Substitutes in Electronic Enclosure and Textile Applications

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The Lowell Center for Sustainable Production

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The Center is composed of faculty and staff at the University of Massachusetts Lowell who work directly with industrial firms, social services institutions, citizen organizations, and government agencies to promote sustainable production.

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Abbreviations

ABS	Acrylonitrile-butadiene-styrene
ATO	Antimony trioxide
BDP	Bisphenol A bis diphenyl phosphate (same as BPADP)
BEO	Brominated Epoxy Oligomer
BPADP	Bisphenol A diphosphate (same as BDP, also known as BAPP)
Br	Bromine
CA BHFTI	State of California Bureau of Home Furnishings and Thermal Insulation
CA TB	California Technical Bulletin
CFR	Code of Federal Regulations
CPSC	Consumer Product Safety Commission
DecaBDE	Decabromodiphenylether
DPK	Diphenyl cresyl phosphate
FFA	Flammable Fabrics Act
FR	Flame retardant
HIPS	High Impact Polystyrene
HF	Halogen-free
NFPA	National Fire Protection Agency
PC	Polycarbonate
PLA	Polylactide
PPO	Polyphenylene oxide
PPS	Polyphenylene sulfide
PU	Polyurethane
PTFE	Polytetrafluoroethylene
RDP	Resorcinol bis diphenyl phosphate
RoHS	Restriction on Hazardous Substance
Sb	Antimony
TBBPA	Tetrabromobisphenol A
TCEP	Tris(2-chloroethyl) phosphate
TCPP	Tris(1,chloro-2-propyl)phosphate
TDCPP	Tris(1,3,-dichloro-2-propyl) phosphate
TB	Technical Bulletin
TPP	Triphenyl phosphate
TRI	Toxics Release Inventory
UFAC	Upholstered Furniture Action Council
WEEE	Waste Electronics and Electrical Equipment Directive
WHO	World Health Organization

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1 Executive Summary

This study examines non-halogen substitutes for the flame retardant decabromodiphenylether (decaBDE) in its most common applications: electronic enclosures and textiles. The search for substitutes is motivated by concerns that have been raised by some governments, scientists, and other stakeholders about the potential human health and ecological impacts of decaBDE and the desire of many manufacturers to find suitable alternatives. The purpose of this study is to:

1. Identify the primary sectors that use decaBDE in the U.S.
2. Identify substitute flame retardants and materials in electronic enclosures and textiles that meet fire protection standards
3. Assess the availability of these substitutes
4. Delineate examples of where these substitutes are currently used in commerce
5. Assess the costs of these substitutes where data are available.

The report focuses on non-halogenated substitutes to decaBDE in response to a high degree of interest among manufacturers, government officials and public and environmental health advocates. Performing a detailed review of the literature on exposure and human and environmental toxicity of flame retardants was beyond the scope of this study; nonetheless, thorough consideration of the health and ecosystem risks of alternatives is an important aspect of any substitution process. The scope of this study is limited to summarizing the known non-halogenated substitutes to the use of decaBDE in electronic enclosure and textile applications.

DecaBDE Uses

Roughly 80% of decaBDE use in the U.S. is thought to be in electronic enclosures, with the vast majority used in the back and front plates of television sets. Roughly 10% – 20 % is used in textiles. The remaining decaBDE applications include rubber products, wire and cable, and minor uses in paper, mineral wool, connectors, and other applications.

1.1 Electronic Enclosures

The major use of decaBDE in the U.S. is in electronics, with the primary use being the black plastic electronic enclosures used to enclose the rear of the TV. DecaBDE is used in TV enclosures because it is an inexpensive, highly efficient flame retardant that is very compatible with inexpensive high impact polystyrene (HIPS). In a TV enclosure, the back plastic panel and in some cases the front panel will be made from decaBDE HIPS containing roughly 12% decaBDE by weight in combination with antimony trioxide (ATO) at a ratio of roughly three parts decaBDE to one part ATO. DecaBDE HIPS is sometimes used in other electronic enclosures. This study focuses on the substitution in TV enclosures, but the results are broadly applicable to enclosures using decaBDE and HIPS.

The chief fire safety standards for electronic enclosures are the UL 94 component standards. The UL 94 component standards range from UL94 HB (the lowest standard), which involves a horizontal burn, to successively more stringent vertical burning tests (Class UL 94 V-2, V-1, V-0 and 5V). DecaBDE is typically used in

components that require high levels of flame retardancy, V-0 or higher. The default standard for replacement of components using decaBDE is almost always V-0.

Some enclosure manufacturers have been able to redesign their products and separate the voltage supply from ignitable plastics. While these products technically meet the UL standard, manufacturers in the U.S. and increasingly in Europe are still flame retarding the housings to protect them from external ignition sources.

Nonhalogenated Substitutes for decaBDE in Electronic Enclosures

The most cost-effective non-halogenated substitutes for decaBDE HIPS involve changing the resin system and the use of phosphorous-based flame retardants. The most cost-effective non-halogenated substitutes include:

- blends of polycarbonate and acrylonitrile-butadiene-styrene (PC/ABS)
- polycarbonate (PC)
- blends of high-impact polystyrene (HIPS) and polyphenylene oxide (HIPS/PPO)

Other substitutes such as metal, wood or enclosures based on polylactide are possible but not widely employed due to cost and performance issues. These substitute resin systems are commodity resin systems widely used in a variety of applications in the U.S. Of these three replacement systems, only HIPS/PPO is 100% halogen-free. The PC/ABS and PC systems typically contain a very small amount of fluoropolymer (roughly 0.3%) for drip resistance[1]. A fourth alternative system to decaBDE HIPS is straight ABS but this resin system requires brominated flame retardants to achieve a V-0 rating. Table 1 summarizes the three main non-halogen substitutes and includes the resin system, flame retardant, and example uses. Table 1 also includes polylactide (PLA), a promising biopolymer that is 100% halogen free but is in the early commercialization phase.

Substitute Costs for Electronic Enclosures

The cost of various flame retardant amorphous plastics for electronic housings varies tremendously, with flame retardant HIPS being the cheapest and HIPS/PPO blends being the most expensive. The raw material costs for resin enclosures depend on a number of factors including the cost of the resin itself, the cost of the flame retardant, and volume-related pricing. The cost of these substitute systems is roughly $0.40 to $1.00 per pound greater than decaBDE HIPS, which costs roughly $0.87 to $0.98 per, pound. To put these costs in perspective, the cost increase for an average 27-inch TV that sells for roughly $300 using PC/ABS rather than decaBDE HIPS in the rear enclosure would be roughly $4.40 to $7.50, or roughly 1.5 to 2.5% of total purchase price. Note that these costs are raw material costs only and do not include one-time switching costs such as new molds or other cost increases or decreases due to changes in energy use, yield, or cycle time.

[1] Throughout the report, PC/ABS and PC are referred to as “halogen-free”. This term applies to the flame retardants as opposed to the resin system which contains a small amount of fluoropolymer.

Table 1: DecaBDE Substitutes in Electronic Enclosures

Resin System	Flame Retardant(s)	Example Uses
HIPS/PPO	• Resorcinol bis diphenyl phosphate (RDP)	• Used throughout Europe -- roughly 20,000 metric tons in the EU TV enclosure market
PC/ABS	• Bis-phenol A diphosphate (BPADP)	• Sharp AQUOS LCD TV • Philips Electronics flat panel TV
PC	• Phosphate esters	• Apple Computer Monitor • Philips Plasma TV front housing
PLA	• Metal hydroxide	• NEC (currently in developmental products only)

Summary

The vast majority of TV electronic enclosures in the U.S. are made from decaBDE HIPS. Many electronic manufacturers are moving away from decaBDE. For example, in Europe decaBDE is not used in TV enclosures. If market drivers existed in the U.S., nearly all manufacturers have the technology and know-how to meet the demand for decaBDE-free products that meet strict fire safety standards.

1.2 Textiles

Textiles are the second major use of decaBDE examined in this study. Unlike electronic enclosures for which there are a limited number of substitutes currently available, there are many different flame retardants, fibers, and barrier substitutes for textile applications. This makes summarizing the substitutes for textiles more difficult.

Roughly 10 – 20% of U.S. decaBDE use occurs in the textile industry (Hardy 2003). Based on a literature review and an analysis of the U.S. Toxics Release Inventory (TRI), the primary textile uses appear to be in the mattress, drapery, commercial upholstered furniture, and transportation (automotive and airplane) industries. Other niche applications of decaBDE in textiles include tents, awnings, and related fabric applications.

Fire Safety

There are numerous federal, state and voluntary fire safety performance standards that drive the use of flame retardant textiles. The most significant of these include those promulgated by the State of California Bureau of Home Furnishings and Thermal Insulation (CA BHFTI) and the Consumer Product Safety Commission (CPSC). Historically, flame resistance standards were developed mostly for cigarette-type ignition sources. More recently, fire safety officials have begun to develop open-flame standards for textile products. CPSC proposed a rule for mattresses in January 2005, and is in the process of developing regulations for furniture and bedding. According to the CPSC, the total use of flame retardant chemicals is expected to increase somewhat if such requirements are finalized (CPSC 2005). DecaBDE is one of many potential flame retardants that are likely to be used to comply with these standards.

DecaBDE is typically applied to the back of textile fabric in a coating that contains antimony in an acrylic or ethylene-vinyl acetate copolymer. Backcoating methods are used on fabrics where aesthetics of the front face are very important -- such as in furniture, draperies, and mattress ticking. Strategies for substituting decaBDE in textiles include the redesign of products to reduce their fuel load (i.e., eliminate the use of foam), flame retardant chemical treatment, inherently fire-resistant fabrics, and barrier layers.

Reduced Fuel Load

There are limited examples of manufacturers reducing the fuel load of their product. For example, fabric office chairs such as the Aeron from Herman Miller contain no polyurethane foam. Providing comfort without contributing to the fuel load is a potential research and innovation area for the furniture industry.

Chemical Treatment DecaBDE Substitutes

There are several chemically applied decaBDE substitutes commonly available on the market for natural cellulosic fibers such as cotton, wool, rayon, and linen. The most common types of non-halogen decaBDE substitutes for cellulosics include dimethylphosphono (N-methylol) propionamide (phosphonic acid) and tetrakis (hydroxymethyl) phosphonium salt (or chloride) compound with urea.

For synthetic fabrics such as acrylic, acetate, nylon, and polypropylene, a halogenated flame retardant may be used such as decaBDE in an acrylic polymer coating. While some decaBDE substitutes are available on the market, they often have limited durability owing to their water solubility and tendency to wash out during laundering. In these cases, dry cleaning may be required. In some applications, blends of natural and synthetic fibers can be used since natural fibers can be flame retarded without halogens.

Fire-Resistant Fibers

Inherently fire-resistant fibers can be used as decaBDE substitutes for synthetic fibers that require high durability. Some synthetic fibers are manufactured to be inherently fire resistant through the addition of non-halogen additives during the melt spinning process. Common examples include the use of phosphorus-based additives in polypropylene and polyester fibers.

Some fire-resistant fibers require no added flame retardants – their base polymers are inherently fire resistant. They have traditionally been used in high-performance apparel (e.g., fire fighter turnout gear), but have more recently been used in mattresses and upholstered furniture applications. Non-halogen examples include melamine, polyaramides, carbonized acrylic, and glass. Halogenated examples include modacrylic and polyhaloalkenes. Mixtures of inherently flame retardant and less flame-retardant fibers can be used to balance cost, comfort, and fire safety goals.

Fire Barriers and Laminates

Fire barriers are another substitution approach for decaBDE. Manufacturers use fire barrier technologies between the surface fabric and the interior foam core in furniture and mattress construction. Manufacturers also thermally or mechanically bond flame-retardant laminates to the back of fabrics to achieve compliance with fire standards.

To examine the substitute approaches in greater depth, the study examined three product applications that use decaBDE to meet fire performance standards: mattresses, upholstered furniture, and draperies.

Mattresses	DecaBDE has been traditionally used to flame retard the mattress fabric (known as ticking). Non-halogen substitutes based on phosphates are available on the market. To meet more rigorous fire safety standards for products sold in California and in institutional settings such as nursing homes, hospitals, and prisons, manufacturers have turned to fire barriers. According to the CPSC, although decaBDE has been suggested as a candidate for use in mattress ticking, it is not likely to be used to meet the proposed CPSC mattress standard (CPSC 2005). There are numerous mattresses on the market today that meet the most stringent open-flame flammability codes without the use of decaBDE or other brominated flame retardants. For example, the Comfort Care mattress manufactured by the Restonic Mattress Corporation uses a non-halogen inherently flame-retardant resin to meet the strict California mattress fire performance standard.
Upholstered Furniture	Upholstered furniture consists of complex composites of many component pieces including fabrics, cushioning, frame, and barrier layers. Chemical flame retardants are not necessary for panel and upholstery fabrics in order to meet the fire codes for residential upholstered furniture. However, for upholstered furniture sold in California or in certain institutional settings including high-rise office buildings, hotels, and other public places, some synthetic fabrics are treated with decaBDE. Substitutes for the use of decaBDE in office/commercial furniture include non-halogen phosphorus chemically coated flame retardant systems and the use of fire barriers like those used in the mattress industry.
Draperies	Drapes and curtains used in public places are required to meet certain flame retardant standards. Drapery manufacturers use both inherently flame retardant fibers such as polyester as well as chemically applied finishes such as decaBDE to meet these requirements. Natural fiber fabrics and natural/synthetic blends are easiest to flame retard and several firms have products on the market using phosphorus flame retardants as alternatives to decaBDE systems. Synthetic fibers such as acrylics, acetates, nylons, and polypropylene are more difficult to treat for flame retardancy, although some of them can be made flame retardant through the addition of phosphate type compounds during the melt spinning fiber manufacturing process.
Costs	There is little cost information on decaBDE substitutes in the literature. Data from one manufacturer showed that their chemically applied substitute for decaBDE was roughly 2 to 2.5 times more expensive on a per-pound basis. But the price of substitute fibers, inherently fire-resistant fibers and the use of fire barriers are very application specific and the information is closely guarded, making it difficult to generalize about substitution costs.
Summary	For products such as mattresses, upholstered furniture, and draperies, there are numerous non-halogenated fiber, fabric, chemical treatment, and barrier product options that when carefully combined, can replace the use of decaBDE.

1.3 Conclusions

Based on an in-depth review of the literature for these applications and interviews with experts from industry, it appears that there are many non-halogenated alternatives to decaBDE available on the market today. Table 2 summarizes availability and cost attributes for these two product groups. Note that these conclusions are based on the availability of substitutes and do not include an evaluation of their potential human health and environmental risks.

Table 2: Availability of Commercial Halogen-Free Materials and Products

Product	Commercial halogen- free material	Commercial halogen-free product	Price of product compared to BFR containing material
Electronic Housings	available	available	more expensive
Furniture Applications (mattress, furniture, draperies)	available	available	unable to determine

In the case of electronic enclosures, the substitute resin systems and flame retardants are well known. Manufacturers in Europe and increasingly here in the U.S. are familiar with these systems. Their higher cost and lack of regulatory drivers has limited their adoption in the U.S.

In the case of textiles, there are many possible substitution approaches. These include substitute flame retardants, alternative fibers, inherently fire resistant fibers, increased use of barrier layers, laminates and nonwovens. For the three product groups investigated, the use of chemically applied flame retardants and inherently ignition-resistant fibers makes decaBDE substitution possible.

2 Introduction

Fires are a common cause of harm to people and property in the United States. In the United States in 2002, on average a fire killed someone nearly every 3 hours and injured someone every 37 minutes. In 2002, four out of every five U.S. fire deaths occurred in homes (Karter 2003). Fires are also sources of pollution and generate a host of acute and chronic pollutants including acid gases and persistent organic pollutants such as dioxins and furans.

Flame retardant and fire protection measures have reduced injury and death (Stevens & Mann 1999). Both at national and state levels, standards have been developed for a host of applications including electronic enclosures and textiles. In addition to preventing injury and property loss, fire prevention measures can also reduce the pollutants generated by fires.

2.1 Study Purpose

While fire prevention regulations have led to a decrease in injuries and deaths, concern has grown regarding the human health and environmental toxicity of some flame retardants. This study examines non-halogen substitutes for one flame retardant - decabromodiphenylether (decaBDE). Because of concerns raised by some governments, scientists, and other stakeholders regarding the potential human health and environmental impacts of decaBDE and other brominated flame retardants, manufacturers, public health officials, and government have increasingly looked to non-halogenated substitutes[2]. The purpose of this study is to examine these alternatives. Specifically, this study aims to:

1. Identify the primary sectors that use decaBDE in the U.S.
2. Identify substitute flame retardants and materials in electronic enclosures and textiles that meet fire protection standards
3. Assess the availability of these substitutes
4. Delineate examples of where these substitutes are currently used in commerce
5. Assess the costs of these substitutes where data are available.

Performing a detailed review of the literature on exposure and human and environmental toxicity of flame retardants was beyond the scope of this study; nonetheless, thorough consideration of the health and ecosystem risks of alternatives is an important aspect of any substitution process.

2.2 Organization of the Report

The report is organized into three main sections. The Background Section reviews Toxics Release Inventory (TRI) release information, human health issues, and regulatory activities associated with decaBDE. The Electronic Enclosures Section examines the safety standards, substitution approaches, various alternatives, and their costs. The Textiles Applications Section reviews the same issues for textiles. The final section contains the report conclusions.

[2] See section 3.3 for a summary of concerns regarding the use of decaBDE.

3 Background

3.1 Decabromodiphenylether

Worldwide, demand for decaBDE ranks second among all brominated flame retardants. Although there are no estimates available for the U.S., demand in the Americas was estimated at 24,500 metric tons in 2001, as shown in Table 3. The data in Table 3 should be interpreted with care as it reflects demand only. Brominated flame retardants in products made elsewhere and imported into the Americas are not reflected in the table.

Table 3: Major Brominated Flame Retardants Volume Estimates

Total Market Demand by Region in 2001 in Metric Tons (MT)

Flame Retardant	Americas	Europe	Asia	Rest of World	Total
TBBPA	18,000	11,600	89,400	600	119,700
HBCD	2,800	9,500	3,900	500	16,700
DecaBDE (DBDPO)	24,500	7,600	23,000	1,050	56,100
OctaBDE (OBDPO)	1,500	610	1,500	180	3,790
PentaBDE (PBDPO)	7,100	150	150	100	7,500
TOTAL	53,900	29,460	117,950	2,430	203,790

Source: www.bsef.org

The exact purity of decaBDE differs from supplier to supplier. The World Health Organization reported that for modern products, the typical composition is roughly 97-98% decabromodiphenylether with 0.3-3.0% of other brominated diphenyl ethers, mainly nonabromodiphenyl ether (WHO 1994). Worldwide, there are four manufacturers of decaBDE: Albemarle Corporation (Arkansas), the Dead Sea Bromine Group (Israel), the Great Lakes Chemical Corporation (Arkansas) and U.S. Tosoh Corporation (Japan). DecaBDE is used at loadings of 10-15% weight in polymers and is typically used in conjunction with antimony trioxide (EU Risk Assessment 2002).

Figure 1: Decabromodiphenylether Structure

Molecular formula: $C_{12}Br_{10}O$

Molecular weight: 959.2

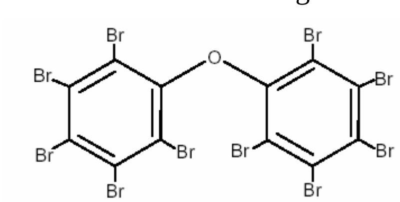
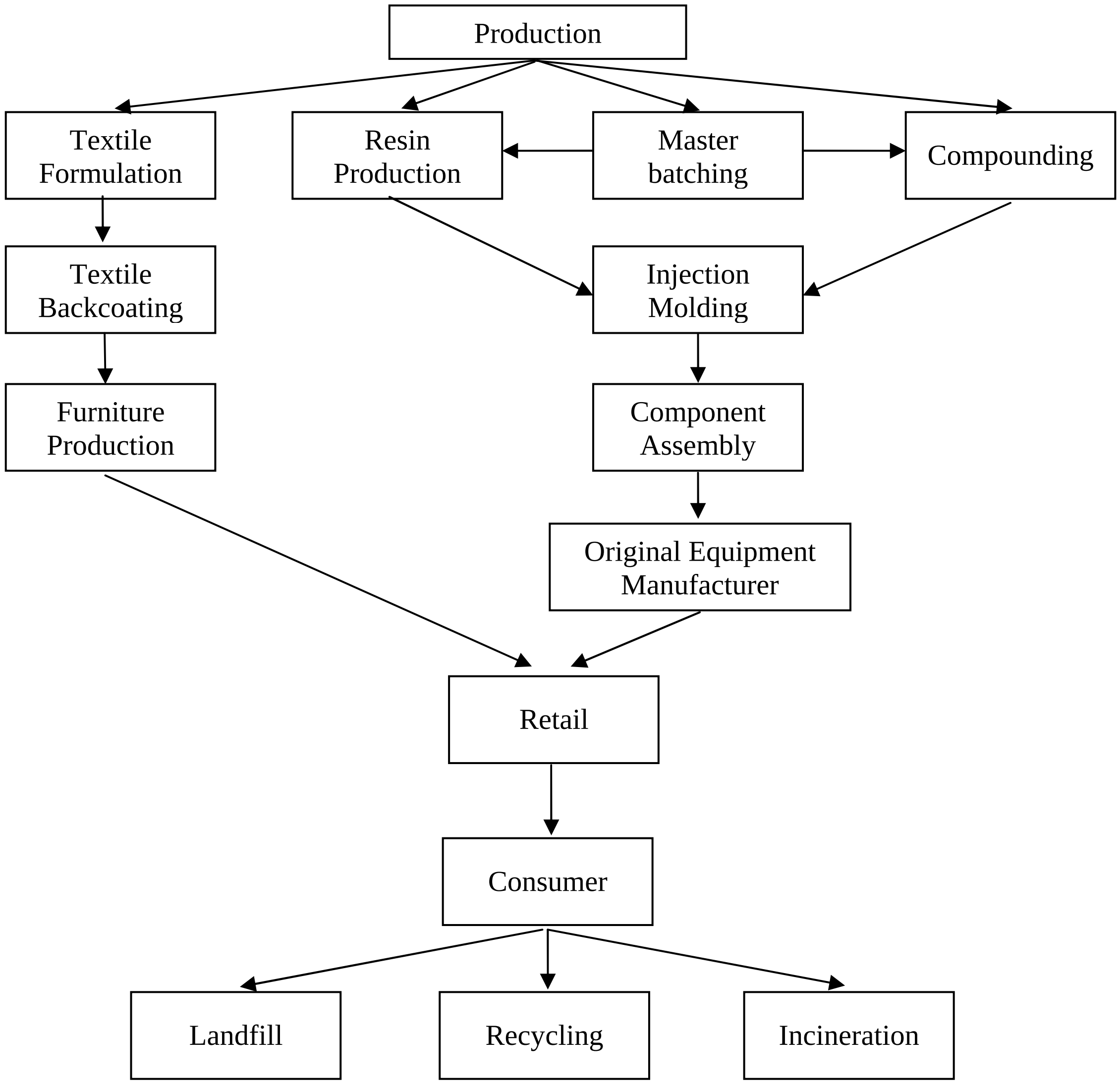


Figure 2 depicts the general flow of decaBDE through the supply chain from manufacture, to formulation, processing in textile or plastic injection molding, retail sale, and end-of-life fate. The figure shows the primary life cycle stages but does not include all use categories (such as rubber products).

Figure 2: Flow of DecaBDE in Commerce



Source: European Union 2004

Polymers and Processes

DecaBDE is a general-purpose flame retardant that can be used in many different polymers. Because decaBDE is an extremely versatile flame retardant that readily compounds with many different types of plastics and elastomers, it can be used in a large variety of substrates. Furthermore, it is an extremely efficient flame retardant, meaning that it can be used at relatively low loadings in plastics and rubber. Lastly, it is relatively inexpensive. Types of polymers and elastomers that can be compounded with decaBDE and that have been cited in the literature are listed in Table 4.

Table 4: DecaBDE Compatable Polymers

- high-impact polystyrene (HIPS)
- nylon
- polypropylene
- polyethylene (PE)
- styrene butadiene rubber (SBR)
- unsaturated polyester
- epoxy
- polyvinyl chloride (PVC)
- polyester resins (PET/PBT)
- acrylonitrile-butadiene-styrene (ABS)
- polycarbonate (PC)
- ethylene-propylene-diene rubber and ethylene-propylene terpolymer (EPDM)

Electronic Enclosures

Roughly 80% of decaBDE use in the U.S. is thought to be in electrical and electronic equipment (Hardy 2003), with the vast majority used in plastic housings of electronic equipment – mainly the back and front plates of television sets (Kingsbury 2002). Other types of housings may, in fairly rare circumstances, use decaBDE. Current use of decaBDE in computer monitors is very rare (Albemarle 2005). DecaBDE is compounded with high-impact polystyrene (HIPS) in these applications to provide an ignition-resistant, high-impact casing at a relatively modest price point. DecaBDE is rare or non-existent in most other resin systems used in electrical and electronic equipment (see Table 5).

Table 5: Use of DecaBDE in Electrical and Electronic Equipment by Resin System

Resin Type	DecaBDE Use
High Impact Polystyrene (HIPS)	Dominant
Nylons	Rare
Thermoplastic Polyesters	Rare
Acrylonitrile-Butadiene-Styrene (ABS)	Not used
Polycarbonate/ABS Alloys (PC/ABS)	Not used
Polyphenylene Oxide/Polystyrene Alloys (PPO/PS)	Not used
Epoxy Resins	Not used

Source: Kingsbury 2002

In order to estimate the amount of decaBDE used in TV enclosures in the U.S., we combined data on 2003 U.S. TV sales with estimates of the amount of decaBDE used in an average size TV. The calculations are presented in

Table 6. We estimate roughly 17,150 metric tons of decaBDE are sold in TV housings in the U.S. each year.

Table 6: DecaBDE in U.S. TV Enclosures

TVs Sold in 2003:	28,354,000
"Average" TV size[a]	27.5 inches
Weight of Housing of "Average" TV[b]	12 lbs
DecaBDE in Housing	12% by weight
DecaBDE Used in U.S. TV Housings[c]	37,800,000 lbs/year
DecaBDE Used in U.S. TV Housings	17,150 metric tons/year

Assumptions

[a] Average TV set according to the U.S. Consumer Electronics Association

[b] Based on estimates provided by Sony (front panel 2.5 kg and back panel 3.5 kg) and GE Plastics (front panel 1.5 kg and back panel 3.5 kg)

[c] 28,354,000 TVs sold/yr * 12 lbs/TV * 0.12 =37,800,000 lbs in U.S. TV sets in 2003.

Textiles

The second greatest use of decaBDE is in textile applications. Estimates for the use of decaBDE range from 10% to 20% of total market demand by volume (Hardy 2003). In textile applications, decaBDE is applied as part of an acrylic or latex coating to the upholstery of office furniture, draperies, and car, plane, and train seating. DecaBDE is not used in clothing.

3.2 Toxics Release Inventory Analysis

The U.S. Toxics Release Inventory (TRI) provides data on the releases of decaBDE but does not include data on the amount of decaBDE incorporated into product[3]. In 2002, 135 firms reported releasing decaBDE from their manufacturing operations. As Table 7 shows, ten firms brought decaBDE into U.S. commerce in 2002, three manufacturing the chemical and seven importing it. Releases in 2002 totaled roughly 1.25 million pounds and include decaBDE emitted in the air, water, and land, and sent for disposal in landfills.

[3] Firms that manufacture or process more than 25,000 lbs or otherwise use more than 10,000 lbs of decaBDE are required to report each year to the EPA. Firms in SIC codes 10 (except 1011, 1081, and 1094), 12 (except 1241), 20–39, 4911, 4931, 4939, 4953, 5169, 5171, and 7389 and all federal facilities are required to report.

The TRI data should be interpreted with caution. Firms that import decaBDE in finished products are not required to report under TRI. Thus decaBDE in TV enclosures manufactured in China or Mexico (the primary places where enclosures for the U.S. market are produced) are not reported in TRI.

Table 7: 2002 TRI Data

Type of Use	No. Reporting
Bring into U.S. Commerce	
Produce	3
Imported	7
Process into a Product	
Reactant	3
Formulation Component	92
Article Component	32
Otherwise Use the Chemical	
Chemical Processing Aid	1
Ancillary Use	2
2002 Recycle on site (lbs)	306,689
2002 Releases (lbs)	1,254,643

The TRI data do not provide information on amount used by a particular facility. The 2002 TRI analysis (see Table 8) shows that the plastic, textile, rubber, and wire and cable industries most frequently reported the use of decaBDE. These uses are generally cited in the literature. There were some interesting additions generally not cited in the literature for decaBDE use including adhesives and sealants, mineral wool manufacturing, and paper manufacturing. Note that only one TV manufacturing facility (Matsushita Kotobuki Electronics) reported. Appendix A contains the full TRI 2002 data set used for this analysis.

Most of the decaBDE used in the U.S. in 2002 was processed into a product as a formulation component or an article component[4]. Eighteen facilities reported recycling roughly 300,000 pounds of decaBDE. Two facilities recycled 93% of the total (Matsushita Kotobuki Electronics 62% and Spartech Polycom 31%). Total releases to the environment from the 135 facilities were roughly 1,250,000 pounds or 569 metric tons.

4 According to Section 313 of the Emergency Planning & Community Right to Know Act (EPCRA), a formulation component is added to a product (or product mixture) prior to further distribution of the product. It acts as a performance enhancer during use of the product. Flame retardants are an example of a formulation component. An article component becomes an integral component of an article distributed for industrial, trade, or consumer use.

Table 8: 2002 TRI Facilities Reporting DecaBDE Use

Sector	SIC	No. Reporting
Compounded Plastic Products	3081, 3083, 3084, 3086, 3087,	39
Textiles	22xx	24
Rubber	3021, 3052, 3069	12
Wire and Cable Manufacturing	3357, 3643	12
Plastics Materials, Synthetic and Resins, etc.	2821	9
Adhesives & Sealants	2891	9
Paper Manufacturing	26xx	8
Miscellaneous	-	6
Mineral Wool Manufacturing	3296	4
Miscellaneous Electrical Equipment	3679, 3699, 3714	3
DecaBDE Manufacturing	1474, 2819	2
Air Conditioning/Air Heating	3585	2
TVs (Household Video & Audio Equip)	3651	1

Trends in Production and Use

While use of flame retardants in plastics continues to grow, the use of decaBDE in consumer electronics appears to be shrinking (WA DOE 2004). As firms prepare for the European Union's Restriction on Hazardous Substances (RoHS) proposed restriction on decaBDE in electrical and electronic equipment slated for July 2006, most major consumer electronics manufacturers have announced that they have phased out or plan to phase out the use of decaBDE. These manufacturers include: Apple, Brother, Compaq, Daikin, Dell, IBM, Matsushita, Samsung, Sharp, Sony, and Xerox.

The demand for flame retardant textiles is expected to increase in response to a national flammability performance standard for residential upholstered furniture under an Advance Notice of Proposed Rulemaking by the Consumer Product Safety Commission (CPSC). The standard does not require the use of fire retardant chemicals, although it could result in their increased use. DecaBDE is one of many potential flame retardants identified that are likely to be used as a means of meeting the standard. The U.S. EPA has developed a Significant New Use Rule (SNUR) on pentaDBE and octaDBE, two other flame retardants whose production has been phased out by their U.S. manufacturer, to complement the CPSC standard. The rule would require notification to and review by EPA of the flame retardants used to meet the standard. EPA is also developing a possible SNUR for flame retardant chemicals that could be used to meet a draft CPSC upholstered furniture standard.

3.3 Concerns Regarding the Use of DecaBDE

There is uncertainty within the scientific community regarding the hazards posed by decaBDE and its breakdown products[5]. For example, there are disagreements among scientists (SCHER 2005) in the European Union on the EU's draft risk assessment (EU RA 2004) on deca-BDE.

While there is disagreement among scientists regarding decaBDE toxicity, potential breakdown byproducts, and interpretation of the European Union's risk assessment results, there has been a strong movement towards implementing substitution despite remaining uncertainty. These concerns have heightened interest worldwide in restricting the use of decaBDE. For example, the State of Washington after a year of study has concluded the following:

> *Recent scientific evidence suggests that decaBDE breaks down into more bioaccumulative and potentially toxic compounds. The amount of decaBDE in use, the expected increase in its use, and its expected breakdown in the environment argue that decaBDE use should not be allowed to increase and should be decreased…*
>
> *… Because decaBDE is present in so many products and is nearly impossible to capture or control, it is necessary to develop and implement a ban on appropriate products containing decaBDE (WA DOE 2005).*

Bills have been introduced in several states including Washington, California, Oregon, Illinois, and Massachusetts to restrict the use of decaBDE. The State of Maine is considering restriction of decaBDE pending studies on whether safer alternatives to decaBDE are available. New York has established a Task Force on Flame Retardant Safety to study the risks associated with decaBDE as well as the availability, safety and effectiveness of alternatives to decaBDE.

There are several European efforts to restrict the use of decaBDE in commerce. In 2003, the European Union passed Directive 2002/95/EC, the Restriction on Hazardous Substances (RoHS) Directive. It focuses on substances used in electrical and electronic equipment. RoHS includes decaBDE as one of six substances to be phased out of electrical and electronic equipment by July 1, 2006.[6] The Directive also directs the European Commission Joint Research Center to research if certain applications of decaBDE should be exempted from the ban.

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[5] The purpose of this section is not to present an exhaustive review of the science on the health and environmental effects of decaBDE, but rather to give the reader a general introduction to main concerns. Readers are encouraged to review recent reports such as the European risk assessment (EU RA 2004), a paper written by Dr. Kim Hooper of the California EPA (Hooper 2004), and a rather comprehensive literature review written by the state of Washington (WA DOE 2004).

[6] As of the publication date of this report (April 15, 2005), the implementation date of the decaBDE restriction remains uncertain.

3.4 Focus on Non-Halogenated Substitutes

The report focuses on non-halogenated substitutes to decaBDE in response to a high degree of interest among manufacturers, government officials and public and environmental health advocates. While the status of attempts to restrict of decaBDE in the European Union and in several U.S. states are uncertain, several market forces are driving interest in non-halogenated substitutes. These include:

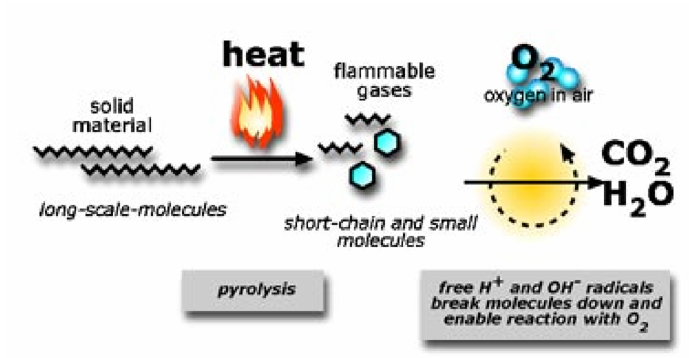
- The need under the European Union Waste Electrical and Electronic Equipment Directive (WEEE) to separate plastic parts containing BFRs prior to recovery and recycling.
- The inclusion of decaBDE and other BFRs into restricted substance lists by electronics manufacturers such as Sony, Xerox, Motorola, and Hitachi. These and other OEMs are pushing for halogen-free components in their supply chains and, in some cases, threaten to cut off suppliers who fail to comply (IPC 2004).
- Eco-labels in the EU, including the EU Flower, the Nordic Swan, the German Blue Angel, and Swedish TCO[7] that restrict PBDEs, BFRs, and in some cases, halogens.

[7] For a good review of how the various European ecolabels treat brominated flame retardants, see section 7.4 of the Danish EPA study: Brominated Flame Retardants: Substance Flow Analysis and Assessment of Alternatives. April 1999.

4 Understanding Flame Retardants

Contrary to conventional wisdom, solid materials do not burn directly. To burn, solid materials must first be decomposed by heat into shorter chain molecules that eventually vaporize as flammable gases. These flammable gases combine with oxygen in the air to produce visible flames. The presence of H+ and OH- free radicals are key to sustaining a fire. These free radical species break down molecules and liberate carbon, which then reacts with oxygen in the air to "burn."

Figure 3: Combustion Process

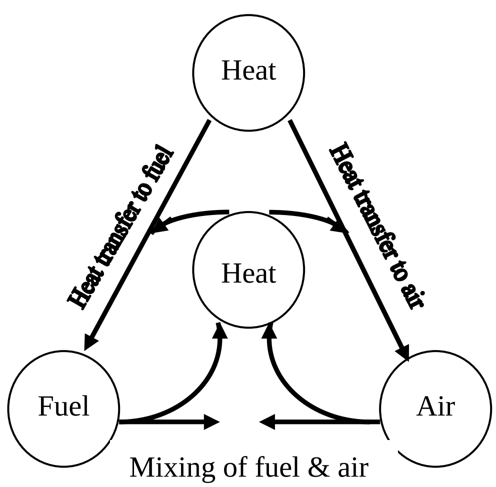


Source: European Flame Retardants Association

When solid materials do not break down into gases, they will typically smolder and produce a char layer. The char layer acts as a barrier to further flame propagation and can lead the material to self extinguish.

The presence of heat, fuel and air in a fire can act in concert to propagate combustion until one or more is removed. Heat causes the thermal degradation of fuel into combustible gases and heats the air, making it more reactive. Flammable gases combine with air to generate a fire. The fire in turn releases heat, which continues the cycle.

Figure 4: Combustion Cycle



Source: Landry 2004

4.1 How Do Flame Retardants Work?

Flame retardants delay the materials from burning. Flame retardants work by interrupting the combustion process. They interfere during heating, thermal decomposition, ignition, or flame spread. Flame retardants can act:

- In the gaseous phase;
- In the condensed phase; or
- Through a physical effect.

Flame retardants act in the gaseous phase with the volatile substances generated during the combustion process. In order to work in the gaseous phase, the flame retardant itself must become volatile and react with the fuel gases to form a noncombustible byproduct.

Flame retardants that work in the condensed phase are in liquid form and interrupt the combustion process and reduce the formation of combustible gases and their combustibility.

Flame retardants that act through a physical effect act in both the gaseous and the condensed phase. Many of the flame retardants that work through physical effect are inorganic such as aluminum trihydride and magnesium oxide. These types of flame retardants can reduce heat generation by reacting to form water, can form a protective non-combustible layer known as "char", and can liberate non-combustible gases such as nitrogen to dilute the combustible gases.

Halogens

Halogenated flame retardants such as decaBDE work primarily in the gaseous phase. DecaBDE decomposes during combustion and releases Br- radicals that react with flammable gases to produce HBr. These compounds react with high-energy H+ and OH- radicals to produce water and lower-energy Br- radicals, which are available to repeat the process all over again. Removing these free radicals slows the combustion process, reducing heat generation and lessening further thermal decomposition.

Phosphorous

Phosphorus-based flame retardant systems are primarily active in the condensed phase. They release phosphoric acid that aids in forming char between the flammable material and the source of oxygen and heat. Phosphorus-based flame retardants comprise many of the substitutes for decaBDE used in electronic enclosure and textiles.

Mineral

Mineral flame retardants such as aluminum trihydride and magnesium oxide are typically classified as acting through physical effect. They are typically compounded at very high levels in plastics and decrease the mass of flammable substance in the product. Mineral flame retardants also release water vapor as a byproduct in a fire which acts to both cool the substrate and dilute the flammable gases.

4.2 Antimony Trioxide Synergist

Antimony trioxide is used in conjunction with decaBDE at a ratio of roughly three parts decaBDE to one part antimony trioxide (ATO). ATO is not a flame retardant itself, but a synergist for halogenated flame retardants. This means that the flame retardant effect is greater when the flame retardant is used with ATO than without ATO.

The synergistic effect occurs in the following way. To be efficient, Br^- radicals must reach the flame in the gas phase to react with volatile (combustible) parts of the polymer. The addition of antimony trioxide facilitates the breakdown of halogenated flame retardants into active molecules. Antimony also reacts with the halogens to produce volatile antimony halogen compounds (such as $SbBr_3$), which are themselves directly effective in removing the high-energy H+ and OH- radicals that feed the flame phase of the fire. Removing these free radicals slows the combustion process, reducing heat generation and lessening further thermal decomposition

One notable exception to the use of ATO as a synergist for decaBDE is in polycarbonate resins. Use of ATO in polycarbonate can significantly degrade the material's structural properties.

4.3 Additive and Reactive flame retardants

How flame retardants are incorporated in their host material is an important distinguishing feature of flame retardants. Flame retardants that are mixed into but not chemically reacted and bound to the host resin material are known as additive flame retardants. Flame retardants that are inserted into the chemical structure of the host material are known as reactive flame retardants.

Additive flame retardants are typically incorporated after the initial manufacture of the plastic resin in a subsequent step known as compounding. Because they are not chemically bound, they tend to migrate more readily into the environment. DecaBDE, most mineral-based, and most phosphorus-based flame retardants are additive in nature.

There are several functional and environmental advantages of reactive flame retardants. Their chemical bond firmly encases the flame-retarding molecule in the resin matrix, rendering it more difficult to migrate from the product into the environment. Reactive flame retardants also do not tend to degrade the physical properties of the host polymer. For example, they tend not to have a plasticizing (softening) effect and do not significantly change the melting temperature.

The substitution of flame retardants in plastics and textiles is a complicated process. Simple drop-in replacements are very rare. Substitution requires an understanding of the effects of the substitution not only on flame resistance, but also on the thermal and mechanical stability of the polymer and processing conditions, including tooling and process operating parameters.

5 Electronic Enclosures

This section focuses on the use of decaBDE in electronic enclosures. Although there are no published estimates regarding the use of decaBDE in enclosures, various industry sources including several decaBDE manufacturers confirm that the major use of decaBDE in the U.S. is in television enclosures – predominately the black plastic used to enclose the rear of the TV (Kingsbury 2002).

The usage of decaBDE in enclosures other than TVs is uncommon. For example, according to the American Plastics Council, 98% of TV enclosures but only 3 % of computer monitors are made from flame retardant HIPS (see Table 9 below). These same data show that decaBDE is not used in printer, copier, scanner and fax enclosures.

Table 9: Resin Systems for Electronic Enclosures

Resin System	Primary Flame Retardants	Printers	Copiers	TVs	Scanners	Fax	Monitors
FR HIPS	DecaBDE			98%			3%
FR ABS	TBBPA, BEO			2%			34%
FR PC/PS	-						<1%
FR PPO/HIPS	Resorcinol diphosphate						<1%
FR PC	-						<1%
FR PC/ABS	Resorcinol diphosphate	6%	5%				61%
Non FR Plastics	-	94%	95%		100%	100%	

Source: Kingsbury 2002

5.1 Fire Protection Standards for Electronic Enclosures

Fire safety standards for electronic products are established by the National Fire Protection Association (NFPA) and developed by the Underwriters Laboratories (UL). Underwriters Laboratories sets a variety of performance standards for electronic products and components regarding their resistance to ignition and flame propagation. Products must meet these standards to be sold in the U.S.

There are both unit and component UL standards. Testing requirements at the component level are less expensive and easier to conduct than those at the unit level. Unit level testing involves combustion of the entire unit whereas component level testing requires simpler tests on the component itself. For example, UL 1410 for *Television Receivers and High Voltage Video Products* is a unit standard. UL 94 defined as *Tests for Flammability of Plastic Materials for Parts in Devices and Appliances* is a component standard.

When manufacturers are looking to test new resin systems or new flame retardants, the typical approach is to replace a component (e.g., the enclosure) with a similarly rated component.

The UL 94 component standards range from UL 94 HB (the lowest standard), which involves a horizontal burn, to successively more stringent vertical burning tests such as V-2 and V-1, to the most ignition-resistant classifications: V-0 and 5V. These tests simulate ignition sources that may occur in electrical and electronic equipment and impinge on plastic parts of electrical components.

The combustion behavior of thermoplastics used in electronic enclosures depends not only on the material, but also on the shape and wall thickness of the actual part. Under faulty or overload conditions, components or parts may reach a temperature which causes them to melt or lose shape, or they may ignite parts in the nearby area. Thus in addition to UL 94 "V-ratings," the part thickness (e.g. 1.6 mm) is typically listed.

DecaBDE is typically used in components that require high levels of flame retardancy--V-0 or higher. For example, TV enclosures are required to use V-0 material for any plastic that is less than 50mm from a potential ignition source. According to one manufacturer, by using clever design, one can obviate the need to use any V-0 material in the enclosures. Nevertheless, most manufacturers continue to use V-0 materials in the front and rear enclosure to prevent ignition of the TV housing from external sources (e.g. a candle placed next to the enclosure).

5.2 TV, CRT and Other Enclosures

DecaBDE is used in TV enclosures because it is an inexpensive, highly efficient flame retardant that is very compatible with inexpensive HIPS. The decaBDE HIPS system meets the necessary flame retardant standards and impact requirements of TV enclosures at a very low price point. HIPS resins are known for their ease of processing, physical stability, impact strength, and rigidity.

In a TV enclosure, the back plastic panel and in some cases the front panel will be made from decaBDE HIPS containing roughly 12% decaBDE by weight in combination with antimony trioxide (ATO) at a ratio of roughly three parts decaBDE to one part ATO.

TV Trends

Roughly 30 million TV sets are sold in the U.S. each year. TV technology is undergoing several major shifts in technology from analog to digital and from CRT technology to plasma, LCD, and projection technology. While CRTs are projected to be 74% of sales in 2005, this is a significant decrease from 86% of sales in 2003. CRTs are significantly less expensive than the other new technologies – costing roughly $200 per unit compared to $1,604, $1,418, and $2,435 per unit for rear projection, LCD, and plasma units respectively. To compete with thinner plasma and LCD units, CRT manufacturers have made strides in reducing the thickness of CRT units.

The main effect of these changes in TV technology is to reduce demand for flame retardants. This is because the thinner sets require less plastic on the sides of the enclosure. Offsetting this trend is the move towards larger screen sizes that require more plastic in the rear panel.

Other Electronic Enclosures

Generally speaking, HIPS tends not to be used for electronic enclosures other than TVs since it has limited impact strength and is too susceptible to cracking. TV units are rarely moved, but printers, computer CRTs, and other electronic enclosures are moved frequently and are therefore susceptible to being dropped.

European Union regulations such as the Waste Electronics and Electrical Equipment Directive (WEEE) and the Restriction on Hazardous Substances (RoHS) Directive are affecting the use of decaBDE HIPS resins in electronic enclosures sold in the U.S. WEEE requires special handling of plastic waste that contains brominated flame retardants. RoHS currently includes a restriction on the use of decaBDE in certain electrical and electronic equipment. Responding to these regulations as well as pressure from consumers and advocacy organizations, many electronics firms have eliminated or plan to eliminate their use of decaBDE on a global basis. Firms such as Dell, Ericsson, Hewlett Packard, Eizo Nanao, and Sony have phased decaBDE out of their products. Daikin, Matsushita, Mitsubishi Electric, NEC, Philips, Samsung, View Sonic, and Xerox have plans to do so by 2006 or sooner (WA DOE 2004).

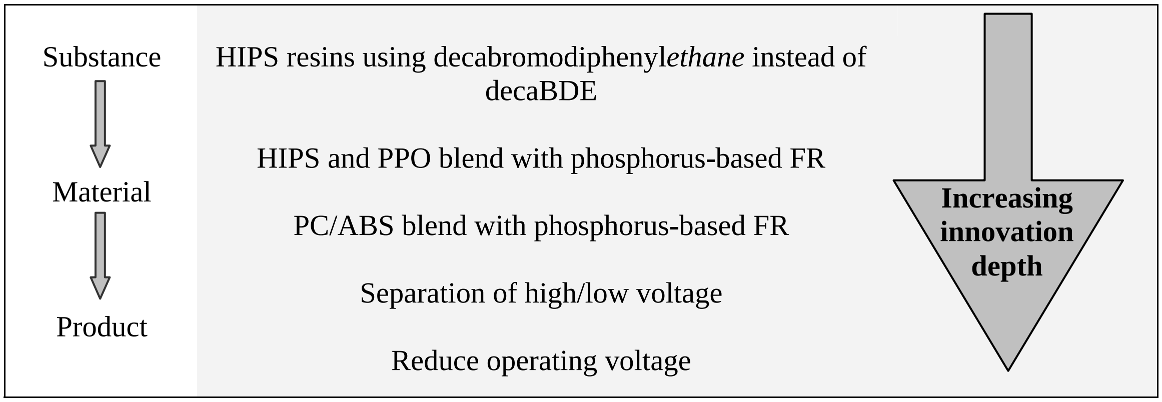
It is likely that some enclosure manufacturers still use decaBDE HIPS in non-TV applications such as CRT monitors. A review of the websites of decaBDE HIPS resin manufacturers such as Dow Chemicals, RTP, and Starex shows that decaBDE HIPS is marketed to the general enclosure market and not only TV enclosures. Other applications cited in the literature where decaBDE is thought to be used in enclosure applications include VCR housings, hair dryers, toasters, curling irons, coffee makers, printers, fax machines, lighting fixtures, and smoke detectors (Danish EPA, 2001).

5.3 DecaBDE Substitution Strategies

There are a number of possible decaBDE substitution strategies ranging from direct substitution of the flame retardant to complete redesign of the product. The figure below, adapted from a European report concerning substitution decisions in complex products and production decisions, shows the range of potential approaches (Oko-Institut 2003).

As Figure 5 shows, substitution options range using very similar brominated additive flame retardants such as decabromodiphenylethane, to more complex options involving substitution of the resin system and flame retardant, to complete redesigns of the product itself such as (i) separating high-voltage components that need greater ignition protection from low-voltage components and (ii) reducing operating voltage requirements and therefore reducing the need for flame-retardant enclosure materials.

Figure 5: DecaBDE Substitution Strategies



Source: Oko-Institut 2003

The following subsections examine various non-halogenated substitution strategies.

5.4 Product Redesign

The notion of redesigning electronic products to reduce or eliminate the need for other BFRs and non-bromine flame retardants is cited in the literature. For example, according to a 2001 market analysis report by Business Communications Corporation, ABS resins have been losing market share due to some shielding of power supplies in printers and related equipment. The shielding of power supplies with metal components lowers flame retardancy requirements, making HIPS without flame retardant a viable alternative to ABS with flame retardant (BCC 2001).

Another product redesign alternative is to remove the power supply from the product. This is common in many devices including printers and rechargeable phones. These separate power supplies are typically black boxes connected to the power cord but not included in the unit itself. The separate power supply reduces the fire retardancy requirements of the electronic enclosure.

While redesigning products to use less or no decaBDE is a viable strategy, few examples of this were found in the literature. While the use of clever design makes it possible for manufacturers to design TV enclosures such that there is at least 50mm of space from any potential ignition source, most manufacturers still wish to flame retard the enclosure from <u>external fire sources</u>. The benefits of such protection have been underscored by tests showing how quickly TV enclosures without flame retardants burn (Simonson et al. 2000).

5.5 Non-Halogenated Flame Retardant Approaches to DecaBDE Substitution

This section examines various non-halogenated approaches to decaBDE substitution, including HIPS, HIPS/PPO blends, PC/ABS, PC, ABS, and others. The various phosphate type flame retardants used in these systems are presented, as are rough cost data.

5.5.1 Non-Halogen Flame Retardants for HIPS

Direct non-halogen substitutes for decaBDE in HIPS are not practical. DecaBDE works well in HIPS because it is a very efficient flame retardant and can be added at a low weight percent, thus having little effect on resin processing or impact strength. Non-halogenated flame retardants in HIPS resins cannot meet the V-0 requirements at loading levels that would be practical in enclosure manufacturing operations.

5.5.2 HIPS/PPO blends

HIPS/PPO blends have been marketed by a number of resin suppliers as substitutes for brominated HIPS resins. Polyphenylene oxide (PPO) is based on polyphenylene ether, a high-heat amorphous polymer that forms a miscible, single-phase blend with polystyrene. The addition of 17 to 20 percent PPO by weight enhances the HIPS charring ability and therefore improves flame retardancy. These resin systems typically employ a phosphorus-based flame retardant such as resorcinol bis diphenyl phosphate. See Table 9 for a list of flame retardants used in HIPS/PPO blends. Fire retardant HIPS/PPO blends are more expensive than fire retardant HIPS, costing roughly $1.90/lb compared to roughly $0.90/lb.

Processing

From a processing standpoint, HIPS/PPO blends have very similar flow properties to HIPS. Flow properties are important in the injection molding process, as resin substitutes with similar flow properties to HIPS mean fewer changes to the expensive tooling and molds used in the molding process. HIPS/PPO blends have high flow, good thermal stability and low plate out[8]. Resins can be processed at low temperatures for faster processing speeds. One of the benefits of using HIPS/PPO blends is their higher heat and mechanical strength when compared to HIPS. This allows for the thinner enclosure walls, reducing the raw material cost of the enclosure.

Figure 6: HIPS/PPO Resin

GE Plastic's Noryl® is an ecolabel-conforming resin useful for thin-all products such as computer monitors, business equipment and TV housings. Noryl N750T is specifically formulated for TV fronts and backs. It has thin-wall capabilities and a V-0 rating at 2.5 mil thickness. (Source: GE Plastics)

Availability

HIPS/PPO blends are commodity resins and are widely available in the U.S. Significant players in the HIPS/PPO market include the RTP Company and GE Polymers. Both firms offer HIPS/PPO grades designed for electronic enclosures that use non-brominated, non-chlorinated flame retardant.

[8] Plate-out: A gradual process in which additives migrate and deposit on the metal surfaces of molds during processing of plastics (Source: Design glossary at www.lnp.com).

Adoption in U.S. This research was unable to confirm any major resin supplier that sells large quantities of HIPS/PPO blends for the U.S. TV enclosure market. However, studies in Minnesota indicate that at least some TV monitors are made from HIPS/PPO blends (Fisher 2000). According to one electronics recycler, roughly 5% of the rear panels TV housing they process are made of HIPS/PPO type resins[9].

` Noryl® is an ecolabel-conforming HIPS/PPO resin produced by GE Plastics. Its sales in the TV enclosure market are significant in the European Union – estimated at roughly 20,000 metric tons in 2004.[10] These sales are due primarily to EU legislation that requires the segregation of bromine-containing plastics in electronic equipment at the end of life. TV electronic enclosures based on Noryl® resins are currently not sold in the U.S. due to their more expensive raw material cost and the lack of market or regulatory drivers.

5.5.3 Bromine- and Chlorine-Free PC/ABS

Most of the major resin manufacturers offer chorine- and bromine-free polycarbonate/acrylonitrile-butadiene-styrene (PC/ABS) blends of one type or another. Some PC/ABS blends include a small percentage (~0.3%) fluoropolymer in the resin for drip resistance. Common products include GE Plastics Cycoloy, a V-O rated chlorine- and bromine-free flame retardant system, and Bayer Bayblend. Nearly all chlorine-and bromine-free PC/ABS resins contain small amounts of polytetrafluoroethylene (PTFE) in concentrations roughly 0.3% by weight as an anti-drip agent and therefore cannot be considered truly “halogen-free” (Danish EPA 1999).

Processability The typical non-halogen flame retardants used for PC/ABS systems include resorcinol bis diphenyl phosphate (RDP) and bisphenol a diphosphate (BPADP). When phosphorus-based flame retardants are used in PC/ABS blends, the processing conditions for injection molding can change dramatically. For example, phosphorus-based flame retardants tend to release gas at molding temperatures. Because polycarbonate has poor formability and a low melt flow rate to begin with, the use of phosphate flame retardants can result in gas defects, sink marks, weld lines, and other surface defects in the cabinet. To overcome these issues, manufacturers must work with their mold and die vendors and resin suppliers to analyze the resin flow and internal pressures within the mold (Sharp 2003).

Availability PC/ABS resins compounded with phosphate flame retardants are commodity products and widely available on the market. Dow Chemical, GE Plastics and Bayer all offer V-0 grades of non-halogen flame retardant PC/ABS blends.

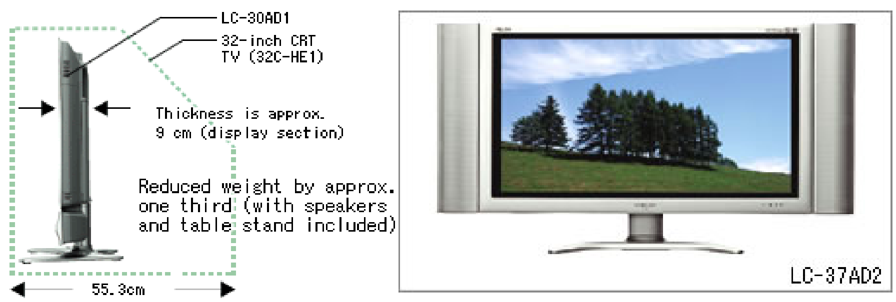
Adoption in the U.S. Roughly 61% of CRT monitors are made with PC/ABS resin systems using phosphate type flame retardants. Original equipment manufactures such as Dell and Hewlett Packard use PC/ABS resins for their monitors. Sharp’s Aquos LCD TV uses a Dow Chemical PC/ABS resin and a phosphorus-based flame retardant (see Figure 7). Dow markets the product for its good flow, heat, and impact properties and

[9] Personal communication with Ron Kobler, Recovery Plastics International, Inc
[10] Assuming that approximately 5.5kg HIPS/PPO are used for an average 27” television, 20,000 metric tons could be used to produce in the range of 3.6 million televisions.

claims it is “ideal for injection molding the thinner, more intricate and lower-weight housing parts required for the next generation of large TV cabinet designs.” The resin is UL94 V-0 certified to meet flammability requirements. According to the Material Safety Data Sheet (MSDS), it contains less than 13% BPADP and other ingredients listed at less than 5% by weight. Philips Electronics uses a similar Dow PC/ABS blend in a flat panel TV product currently available in Europe.

Figure 7: Sharp Aquos LCD TV

In 2003, the Sharp AQUOS held 50.9% of the world LCD TV market. The TV casing is made from PC/ABS resin using a phosphorus-based flame retardant. The cabinet meets the UL V-0 fire resistance standard. A 30-inch unit compared with a CRT TV of equivalent size (32-inch), consumes 38% less power, is one-sixth the depth, and weighs only one-third the CRT TV.



Source: Sharp Corporation

5.5.4 Chlorine-and Bromine-Free Polycarbonate (PC)

Use of halogen-free polycarbonate as a replacement for decaBDE HIPS in electronic enclosures is possible but fairly rare, since PC/ABS blends are typically cheaper replacement technologies. Nearly all chlorine-and bromine-free polycarbonate resins contain small amounts of polytetrafluoroethylene (PTFE) in concentrations roughly 0.3% by weight as an anti-drip agent and therefore cannot be considered truly “halogen-free” (Danish EPA 1999).

Processability

Polycarbonate can be compounded with phosphate esters to meet V-0 requirements. It can be manufactured in a clear form, an aesthetic that is appealing in some niche markets.

Availability

Polycarbonate is a commodity resin manufactured by many major resin suppliers including Dow Chemical and Bayer.

Adoption in the U.S.

Apple Computer used polycarbonate in the manufacture of one version of its IMac computer monitor. The new plasma 42-inch flat screen from Philips uses polycarbonate made by Bayer in the rear housing. The unit projects background lighting built into the rear of the TV onto the wall behind the set to blend the TV into the room décor. According to a Bayer spokesperson, "using polycarbonate to build television housings is a new trend. Our material won out for this application because it boasts excellent flame retardancy while simultaneously offering very high transparency and heat resistance" (Bayer 2004). The material satisfies the stringent U.S. test standard UL 94 V (Underwriters Laboratories) for a specimen three millimeters thick, obtaining the highest classification, V-0.

5.5.5 Halogen-Free Acrylonitrile Butadiene Styrene (ABS)

Most ABS resin systems employ brominated flame retardants such as tetrabromobisphenol A (TBBPA) and brominated epoxy oligomer (BEO) to meet the V-0 fire retardancy requirements for electronic enclosures. While some manufactures such as Torray offer V-2 level fire protection performance for ABS polymer enclosures, the lack of an oxygen-containing copolymer such as polycarbonate makes achieving V-O ratings difficult. The oxygen-containing copolymer reacts with phosphate flame retardants during a fire to form fire retarding char at the resin surface.

5.5.6 Other Halogen-Free Resin Systems for Enclosures

Polylactide

Polylactide (PLA) is a bioplastic derived from natural materials such as corn and other agricultural products. By itself, PLA is too brittle and melts at too low a temperature to be considered for use in electronic enclosure applications. However, recent work by several Japanese electronics firms has shown the potential for modifying PLA for use in electronic enclosure applications.

NEC has been able to manufacture polylactide resin rated at UL94 5V and UL94 V-0 at 1.6mm thickness. NEC's resin is compounded with metal hydroxide mineral flame retardants to improve its fire performance and with kenaf fibers to improve its impact strength. The resin contains no halogenated or phosphorus-based flame retardants. According to NEC, the material's heat resistance, processability, and strength are comparable to those of fiber-reinforced PC. For example, the PLA impact strength is 65 Joules/meter compared to 50 for PC (Modern Plastics 2004). NEC plans to start using the bioplastic in its electronic products starting in 2006.

Other companies introducing PLA in electronics applications include JVC and Sony. JVC introduced a DVD made from PLA in December 2004. Sony and Mitsubishi Electronics are jointly researching PLA resin systems using aluminum hydroxide flame retardants. They plan on developing an ABS-like material, with good mechanical and material flow properties. According to Sony, its process allows PLA to be molded as quickly as ABS plastic and in normal injection molding presses (Hi-Tech Ambiente 2004). However, it is unclear whether the material produced by JVC or Sony is sufficiently flame retardant to be used in applications that currently us decaBDE HIPS.

Polyphenylene Sulfide

Several literature sources have identified the use of polyphenylene sulfide (PPS) in electronic enclosure applications by Toshiba. While PPS is inherently flame retardant and has good chemical resistance, flowability, dimensional stability, and electrical characteristics, Toshiba's application has been in transistor integrated circuit packages and not electronic enclosures. Since PPS is extremely brittle, it must be filled with fibers and fillers to improve its impact strength. It is also expensive compared to competing resins for electronic enclosures making it impractical for most enclosure applications. Other inherently flame retardant plastics exist, but their cost or other properties make their use in electronic enclosures unlikely.

5.5.7 HF Flame Retardants Used in HIPS/PPO, PC/ABS and PC Resins

Each of the resin systems outlined above (HIPS/PPO, PC/ABS, and PC) relies primarily on phosphate-based flame retardants. Table 10 lists the most common phosphate flame retardants, their manufacturer, and their applicable resin system(s). In most instances, the resin manufacturers closely guard the exact flame retardants used in their resins.

Of the halogen-free phosphate base flame retardants, the dominant types include resorcinol bis diphenyl phosphate (RDP) and bisphenol A diphosphate (BAPDP).

Table 10: Phosphate Flame Retardants Used in Electronic Enclosure Applications

Flame Retardant	Acronym (s)	Applicable Resin Systems and Other Notes	Known uses	Manufacturer: Trade Name
Resorcinol bis diphenyl phosphate	RDP	• 11% phosphorus • V0 rating achieved when used in PPO/HIPS blends • *Dominate flame retardant* in PC/ABS and PPO/HIPS systems	• Bayer Bayblend PC/ABS resins • GE Plastics PC/ABS resins • Used in Dell PC/ABS CRT Monitor	• Azko Nobel: Fyroflex®RDP 10 • Great Lakes: Reofos RDP
Bisphenol A diphosphate	BPADP, BAPP, BDP	• Usage growing in PC/ABS and PPO/HIPS applications • 9% phosphorus	• Dow Chemical PC/ABS 7560, used in the Sharp AQUOS LCD TV	• Great Lakes: Reofos BAPP • Albemarle NcendX P-30 • Azko Nobel: Fyroflex®BDP
Diphenyl cresyl phosphate	DPK	• Used in PC/ABS		
Proprietary monophosphate		• PC/ABS	• Low migration, hydrolysis resistant	• Great Lakes: Reofos 507
Triphenyl phosphate	TPP	• Also known as triaryl phosphate • Usage shrinking in PC/ABS and PPO/HIPS applications		• Great Lakes: Reofos TPP •

Sources: Kingsbury 2002, Great Lakes Chemical Company Website, Azko Nobel Website, German EA 2000, GE Plastics Website, Bayer website, Azko Nobel website.

5.5.8 Halogen-Free Raw Material Cost

The cost of various flame retardant amorphous plastics for electronic housings varies tremendously, with HIPS being the cheapest and HIPS/PPO blends being the most expensive. The raw material costs for resin enclosures depend on a number of factors including the cost of the resin itself (HIPS is cheaper to produce than PC for example), the cost of the flame retardant, and volume pricing.

Generally speaking, bromine flame retardants are less expensive than most non-halogenated flame retardants used in electronic enclosure applications. Typically, non-halogen flame retardants cost in the $3.00/lb range whereas the price of bromine is roughly $1.10/lb. Since bromine is a more efficient flame retardant than most non-halogen systems, less is required for a bromine system to meet a UL V-0 rating than non-halogen alternatives.

Table 11 contains the raw material costs of various resins and the estimated resin cost for an average rear enclosure for a TV weighing 7.7 pounds and an average front and back TV enclosure weighing 12 pounds. Figures are provided for rear enclosures only and for both front and rear enclosures combined since some manufacturers use decaBDE HIPS in the rear enclosure only while others use it in both the front and rear enclosure. Note that these are estimates only and that thin-walling and volume-related pricing are not factored into the calculations nor are other cost increases or decreases due to changes in energy use, yield, or cycle time.

Table 11: Cost of Various V-0 FR systems for enclosures

Resin	Halogen-free?	Cost per Pound ($)	Resin Cost for "average" TV rear enclosure	Resin Cost for "average" TV front & rear enclosure
FR HIPS	No, uses decaBDE	0.87 – 0.98	$7.14	$11.21
FR ABS	No, uses TBBPA or BEO	1.05 – 1.35	$9.26	$14.55
FR ABS/PC Alloy	No*****	1.35 – 1.65	$11.57	$18.18
FR PC	No*****	1.66 – 1.97	$14.00	$22.00
FR HIPS/PPO Alloy	Yes	1.90	$14.66	$23.03

***** Contains small amount (~0.3%) of fluoropolymer for drip resistance

All prices by the truckload except HIPS (railcar). "Average" TVs are 27.5 inch CRT Units with a front and rear enclosure weight of 7.7 and 4.3 pounds respectively.
Sources: Plastics Technology - Virgin Resin Prices May 2004; Recycled Resin Prices - September 2004;

To put these costs in perspective, the cost increase for an average 27-inch TV that sells for roughly $300 using PC/ABS rather than decaBDE HIPS in the rear enclosure would be roughly $4.40 to $7.5, or roughly 1.5 to 2.5% of total purchase price.

While specific TV models are generally on the market for roughly 12-18 months, manufacturers utilize some process tooling such as the housing mold for roughly 5-7 years. The new models produced each year are derivatives of the basic design with minor electronic enhancements (AEA Technology Environment, 1999). Thus changes in resin systems that require tooling changes are likely to be done during major redesign cycles.

According to an industry source, the cost difference between decaBDE HIPS and a non-halogen system (such as ABS/PC) is approximately 1 euro per kilogram or $0.60 per pound[11]. This translates into roughly $7.25 for an “average” 28-inch CRT TV with roughly 12 pounds of flame retardant plastic in the front and rear housings and is very close to the estimates developed in Table 11.

5.6 Summary

DecaBDE is primarily used in electronic enclosures to flame retard HIPS used in TV front and rear housings. There are a number of phosphate-based flame retardants that are effective substitutes in HIPS blends and other resin systems. These non-halogen systems are more costly than decaBDE HIPS systems. The price increase, which is estimated at 1.5 to 2.5% of purchase price for an average 27 inch TV, can be more readily absorbed in the high-end TV enclosure market, such as plasma and LCD units, compared with low-cost, highly competitive CRT units. Most decaBDE HIPS replacements require some type of tooling changes in addition to increased costs.

While there are several known applications of non-halogenated TV enclosures in the U.S., the lack of regulatory and market drivers leaves the vast majority of U.S. enclosures made from decaBDE HIPS. In Europe the WEEE and RoHS Directives appear to be driving electrical and electronics manufacturers away from brominated flame retardants in general. If such drivers existed in the U.S., a similar trend might occur, at least for TV enclosures for which several known non-halogenated alternatives exist. Television manufacturers would have the technology and know-how to meet the demand for decaBDE-free electronic enclosures.

[11] Personal correspondence with Peter Evan, Sony.

6 Textile Applications

This section reviews the use of decaBDE in textiles. It focuses on uses in commercial and residential textiles but does not cover the use of decaBDE in transportation such as in some automotive fabrics. The section reviews the products where decaBDE is used, application methods, and substitutes. The focus is on three product categories: mattresses, upholstered furniture, and draperies.

6.1 Where is DecaBDE Used in Textiles?

To determine where decaBDE is used in the textile industry, a literature review and analysis of the 2002 U.S. Toxics Release Inventory (TRI) data were conducted.[12] These reports are separated into SIC codes that represent industrial activities in each facility. Table 12 summarizes the main uses of decaBDE in textiles based on the literature review as well as telephone interviews with industry representatives, flame retardant vendors, and decaBDE TRI reporters.

Table 12: Summary of DecaBDE Use in Commercial Textile Products

Product System	Description of DecaBDE Use
Mattresses	Some manufacturers use decaBDE in mattress ticking.
Drapes	Used in certain commercial applications were required by building codes such as casinos, hotels, and schools
Some Commercial/ Institutional Upholstered Furniture	Used by some manufacturers in cases where building codes require meeting the standard

Table 13 summarizes products where decaBDE is generally not used. This information should be used with caution. It is difficult to generalize about entire product groups because decaBDE can be used on a host of fibers and fabrics.

Table 13: Applications Where DecaBDE is Generally Not Used

Product	Description
Bed Cloth (Comforters, Pillows, etc.)	Current standards do not require ignition resistance. Manufacturers meeting new standards being developed in California are unlikely to use decaBDE as a means of achieving compliance.
Apparel	Most infant sleepwear does not require flame retardant treatment to comply with federal (CPSC) standards. Generally, decaBDE is not used in apparel, including children's clothing and pajamas.
Commercial and Residential Carpet	Most carpet does not have to be fire resistant. In cases where carpet is used in institutional settings

[12] TRI data details decaBDE chemical releases, not use. Therefore is it is an incomplete tool for analyzing decaBDE usage. For the detailed TRI analysis data, see Appendix A.

	with fire performance standards, the primary flame retardant used is aluminum trihydrate.
Residential Upholstered Furniture	Under current standards, residential upholstered furniture does not require decaBDE to meet current fire safety standards. New standards are being developed by the CPSC and are expected in 2005 or 2006.
Cubicle / Wall Fabric	DecaBDE is not used to flame retard cubicle and wall fabrics according to representatives from a major industry supplier.

Although decaBDE used in transportation sector textiles was not a focus of this study, industry sources noted that decaBDE is not used in automotive carpets but is used in some cases for automotive fabrics.

6.2 Regulations Driving the Use of Flame Retardants in U.S. Textiles

In the U.S., there are a number of regulations dictating fire safety and flame resistance in various sectors of the textile industry. The textile regulations apply to different consumer products and come from a number of regulatory agencies including the State of California Bureau of Home Furnishings and Thermal Insulation (CA BHFTI) and the Consumer Product Safety Commission (CPSC).

Beginning in the 1970s, state and federal jurisdictions began setting flame resistance standards, mostly for cigarette-type ignition sources. These standards were meant to minimize fires from smolder-prone materials. They were tremendously effective and reduced fires in mattresses, upholstered furniture, and other textile products (see Table 14).[13]

Table 14: Impact of Fire Regulations in the U.S.

Substrate	Time Period	Reduction in All Fires	Reduction in Cigarette Caused Fires	Reduction in Open Flame Caused Fires
Mattress/Bedding Fires	1980 - 1998	73%	81%	73%
Upholstered Furniture	1978 – 1998	76%	83%	76%

Source: Ray 2001.

Similar reductions have been achieved for fires from other products. Since 1989, fire protection officials have noticed a trend towards greater fire and fire injuries from open-flame ignition than from cigarettes. As a result, standard-setting agencies have been developing open-flame requirements for textile products. Examples include the recent California regulation, California Technical Bulletin (CA TB) 603, for mattresses and the efforts by the CPSC to set open-flame requirements for upholstered furniture, mattresses, and bedding (Handermann 2004). Appendix B

[13] Studies examining the role of flame retardants in reducing fires include Ray 2001, Clarke 1997, Simonson 2002, Smith 2002, and Stevens 1998.

provides a summary of federal and state regulations for mattresses, upholstered furniture, and draperies.

Component and Composite Standards

Fire protection standards for mattresses and upholstered furniture can be divided into two types: component and composite. Component standards apply to individual parts such as the fabric, the foam, or barriers. Composite standards apply to the entire unit. Composite standards are much more expensive to test for compliance, since an entire unit is tested as opposed to a single component. In some U.S. jurisdictions, mattresses and upholstered furniture must comply with both types of standards. Both types of ignition hazard (smoldering and open flame) must be protected against since it is possible that a product can pass one test but not another.

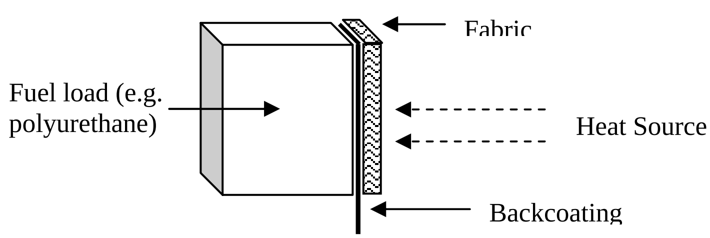
6.3 DecaBDE Application Methods and Formulation

Between 10% and 20% of the world production of decaBDE ends up in textiles. DecaBDE is used in textiles because of its high thermal stability and durability. As in polymer applications, the flame retardancy of decaBDE in textiles is enhanced with synergists such as antimony oxide (ATO). The flame retardancy of decaBDE in textiles is based on the synergy between antimony and bromine. DecaBDE is used as a flame retardant in draperies, upholstered furniture backing, and in transportation applications (KemI 2004).

Application Methods

The decaBDE/antimony flame retardant can be applied to the textile in a number of different ways depending on the material treated and its end use. When the decaBDE/antimony mix is applied to a backcoating, it protects the interior (e.g. furniture foam) from combustion. Back coating methods are used on fabrics where aesthetics of the front face are very important, i.e. furniture fabrics, drapes, and mattress ticking - see Figure 8 (NAP 2000). These backcoatings or resin binders can be an acrylic copolymer, styrene butadiene co-polymers, or ethylene-vinyl acetate copolymer. DecaBDE application methods include doctor blade or knife coating methods. The flame retardant formulation is usually a paste or foam.

Figure 8: Textile Back Coating



The deca/antimony flame retardant can also be applied using an immerse/dry technique. In this case, the material is soaked in the flame retardant and then it is dried. This is used in some textile applications including draperies.

Formulation

The maximum loading levels used for all fabric with decaBDE, assuming a range of fabric weights between 6 and 12 ounces, are outlined in Table 15.

Table 15: Example DecaBDE Formulation

Weight flame retardant / weight of fabric (%)	*Flame retardant add-on (weight% of fabric)*	*Add-on on 11oz fabric*
12% Br, 7% Sb	~ 25%	3oz = 2oz DecaBDE and 1oz Sb_2O_3

Source: NAP 2000

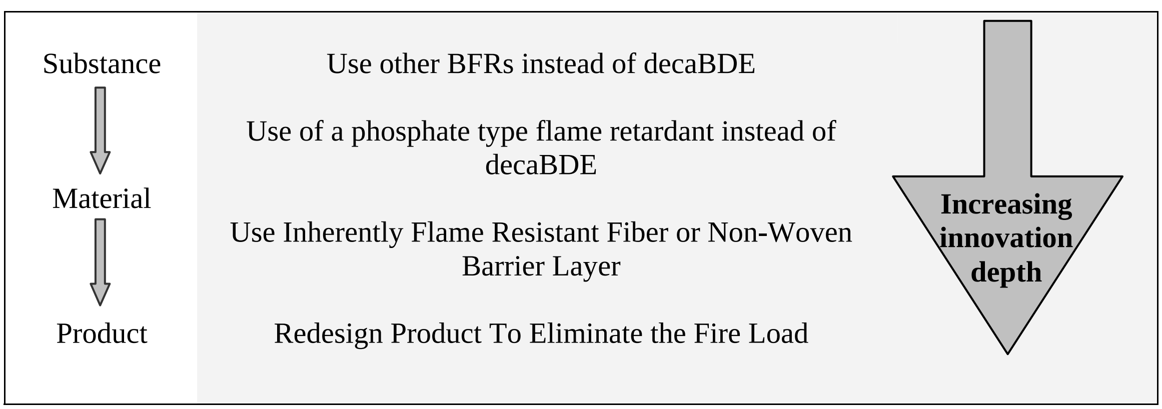
Lighter fabrics generally require higher flame-retardant loadings than heavier fabrics. Fabrics containing thermoplastic fibers (e.g. polyester, polyamide, or polypropylene) require higher loading levels because of the need to provide a charring scaffold sufficient to maintain a barrier in spite of the melting fiber characteristics (NAP 2000).

6.4 Strategies for DecaBDE Substitution in Textiles

There are a number of possible decaBDE substitution strategies ranging from direct substitution of the flame retardant to complete redesign of the product. Figure 9, adapted from a European report concerning substitution decisions in complex products and production decisions, shows the range of potential approaches (Oko-Institut 2003).

As Figure 9 shows, substitution options range from using very similar brominated additive flame retardants such as decabromodiphenylethane, to more complex options involving substitution of the fabric, use of nonwoven barrier layers, and complete product redesign to reduce or eliminate the fire load.

Figure 9: DecaBDE Textile Substitution Strategies



Source: Oko-Institut 2003

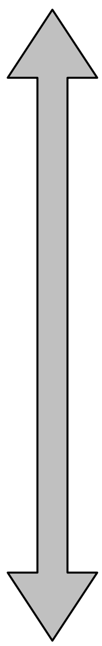
The following sections examine substance, material and product substitutions for decaBDE. The sections begin with a discussion of various fiber types and decaBDE substitutes. Next, nonwoven and woven barriers using mixed fibers are reviewed. Finally, specific substitution strategies for specific products are discussed.

6.5 Flame Retarding Fibers

There is a tremendous variation in the flame resistance of various fibers and fabrics. As Figure 10 shows, natural cellulosic fibers such as cotton and linen can ignite readily whereas some synthetic fibers such as aramids and melamines actually self-extinguish.

Figure 10: Burning Characteristics of Fibers

Less Flame Resistant



More Flame Resistant

cotton/linen	Burns with a hot, vigorous flame. Does not melt or draw away from the flames.
rayon/lyocell	Burns similarly to cotton and linen, except that it may shrink up.
acetate	Burns with a rapid flame and melts when burning. May melt and pull away from small flames without igniting.
acrylic	Burns similarly to acetate, except that it burns with a very heavy, dense, black smoke. It drips excessively.
nylon, polypropylene, polyester, and spandex	Burns slowly and melts when burning. May melt and pull away from small flames without igniting. May self-extinguish.
wool and silk	Burns slowly and is difficult to ignite. May self-extinguish.
modacrylic and saran	Burns very slowly with melting. May melt and pull away from small flames without igniting. Self-extinguishes
aramid, novoloid, melamine	Chars, does not burn.

Source: Iowa State 2003

Fibers that are not inherently fire resistant can be made flame resistant using one of three main mechanisms:

1. Chemical post treatment – the fiber is treated with flame retardant chemicals (e.g. decaBDE or organophosphorus type). Chemical post treatments include textile fabric coating and exhausting flame retardants into fibers during the dying process.

2. Additive in the fiber melt spinning process – flame retardants are added into the molten plastic during the spinning process and become physically part of the fiber matrix (e.g. organophosphorus added to viscose fibers).
3. Modified copolymer – two or more different monomers are mixed and polymerized to form a more flame retardant plastic fiber.

Depending on the fiber type, one of these strategies can be employed to make the fiber more ignition resistant. However, not all fiber treatments produce a highly durable level of fire retardancy.

6.5.1 Durability

Flame retardant durability is an important consideration in textile applications. More durable flame retardants tend to be associated with lower potential for human exposure and environmental release. Durability is affected by laundering, exposure to UV light, heat, and air pollutants. Matching the durability to the fabric application is very important. Generally speaking, the inherently flame retardant fabrics are the most durable. Textiles with reactive flame retardants that are chemically bound to the polymer are also durable. Additive type flame retardants that are mixed into but not chemically bound to the polymer matrix are generally thought to be durable.

For flame retardant chemical treatments, durability depends on the strength of the bonds between the flame retardant formulation and the fiber surface. DecaBDE and antimony mixtures are generally considered durable since the resin that is co-applied with decaBDE bonds to the fiber. Techniques that bind the flame retardant treatment to the fiber either covalently or physically may be even more durable. The less durable types of flame retardants include some chemically applied phosphate chemistries that are water-soluble. When less durable flame retardants are used in applications such as upholstery or draperies, the fabric must be labeled to limit laundering or to recommend dry cleaning only.

It is important to note that there are no standards that define durability for flame retarded fabrics. Some manufacturers define it as the fabric meeting its performance standard after 50 washes while others claim that a product that maintains its fire performance after 10 washes is durable.

6.5.2 Treatments for Specific Fibers

Wool

Although wool is an inherently flame retardant fabric, it is not sufficient for certain applications such as aircraft carpets. Aircraft carpets made of wool often have a flame retardant coating of zirconium hexafluoride salts. These salts increase the ability of wool to char and reduce emissions of its highly toxic smoke fumes (KemI 2004). DecaBDE systems with antimony synergists are used for wool in some cases as well. Both types of treatments are highly durable.

Polyamides (Nylon)

There are few applications for polyamides that involve fire-safety requirements. Nylon is typically used in lightweight clothing. In cases where fire-safety requirements are specified, phosphorus type flame retardants are added to the melt at the time of fiber spinning and therefore compounded into the polyamide fiber (KemI

2004). In addition, polyamide fabric can be flame retarded with a thiourea formaldehyde resin finish (Fire Sciences 2004).

Polyurethane (Spandex) Polyurethane (PU) fiber and fabric, known as spandex, rarely contains decaBDE. Polyurethane foam is often flame retarded, but not with decaBDE. PU foam has traditionally been made flame retardant with other brominated flame retardants (e.g., pentabromodiphenyl ether) or chlorinated phosphates.

Polypropylene Polypropylene is the most common polyolefin used in textiles. Wallpaper is an example of a polypropylene application. Options for flame retarding polypropylene fibers include both halogen and non-halogen approaches in which the fire retardant is added during the melt spinning process (KemI 2004). Examples include Flamestab NOR™ 116 by Ciba, a non-halogen melt processable flame-retardant for polyolefins, especially PP fibers.

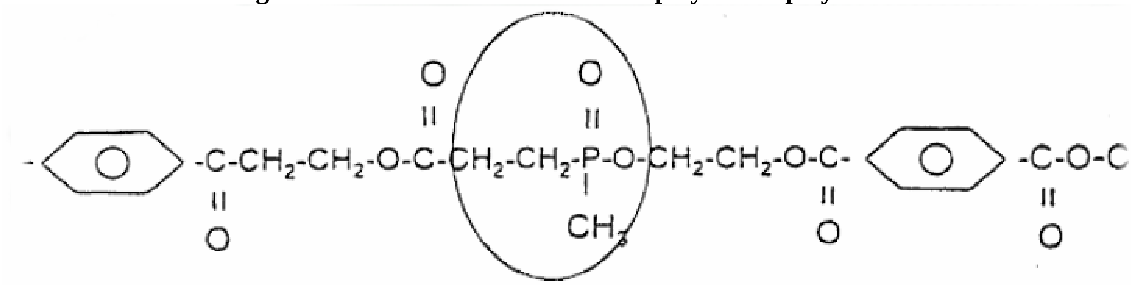
Cotton Roughly 40% of all textile fibers are cotton. Although antimony/decaBDE flame retardants could be applied to cotton, these flame retardants are not used today. Phosphorus-based compounds are the flame retardants of choice for cellulose/cotton. Many cotton treatments are wash-resistant, meaning they can withstand at least ten wash cycles without losing flame-retardant properties. Specific cotton flame retardants are described below:

Dimethylphosphono (N-methylol) propionamide (also known as phosphonic acid (2-((hydroxymethyl)carbamyl)ethyl)-dimethyl ester) is one of the most widely used flame retardant chemicals for cellulose/cotton. This flame retardant is applied using a pad-dry-bake technique with a melamine resin, a fabric softener and phosphoric acid. After padding, the fabric is dried and cured. The molecule is chemically bound to the cellulose through the melamine resin and is wash resistant. A drawback of this flame retardant is the emission of formaldehyde from the resin during application. This arises from the chemical reaction between resin, the flame retardant, and cellulose. A market has developed for resins that emit very low or no formaldehyde. (KemI 2004)

Tetrakis (hydroxymethyl) phosphonium salt (or chloride) compound with urea requires the inclusion of an ammonia-based preparation. It is not as widely used as dimethylphosphono (N-methylol) propionamide. The flame retardant works because tetrakis salt is polymerized with ammonia in the cavities of the cellulose fiber. It is held so firmly by the cellulose/cotton that it is regarded as wash-resistant. Applications of this flame retardant include clothing and interior products (KemI 2004)

Polyester Polyester accounts for 30% of world fiber production. Applications include clothing and draperies. The most common flame retardant for polyester is polyethylene terephthalate with built-in phosphorus on the polyester backbone (see Figure 11). This modified polyester is used in the majority of textile applications, is wash resistant, and is thought to be a good substitute for the decaBDE/antimony flame retardant.

Figure 11: Flame-resistant modified polymer of polyester



Source: KemI 2004

6.5.3 Inherently Flame-Resistant Fibers

Some synthetic fibers are inherently flame resistant, including aramid, novoloid and melamine. Some of these fibers are beginning to be significantly used in furniture upholstery and mattresses. Traditionally, they have been used to meet the strictest standards for applications such as fire fighter turnout gear, clothing for astronauts, and clothing for racecar drivers. Some inherently flame resistant fibers such as polyhaloalkenes contain halogens such as polyvinyl chloride and vinyl bromide, while others are halogen free, including polyaramides and melamine fibers. Table 16 lists durably finished and inherently flame-retardant fibers in common use. The table includes information on fibers, flame retardants, mode of application, whether the fiber is halogen free, and specific examples.

Table 16: Durably Finished and Inherently Flame Retarding Fibers in Common Use

Fiber	Protection Against Flame	Mode of Application	Halogen -free?	Examples
Natural fiber				
Cotton	Organophosphorus and nitrogen-containing monomers or reactive groups.	F	Y	Proban CC (Albright & Wilson) Pyrovatex CP (Ciba) Aflammit P and KWB (Thor) Flacavon WP (Schill & Seilacher)
Wool	Antimony-organo-halogen systems	F	N	Flacavon F12/97 (Schill & Seilacher) Myflam (BF Goodrich)
	Zirconium hexafluoride complex	F	N	Zipro (IWS) Pyrovatex CP (Ciba) Aflammit ZR (Thor)
Regenerated				
Viscose	Organophosphorus and nitrogen/sulfur-containing species	A	Y	Sandoflam 5060 (Clariant)
	Polysilicic acid complex	A	Y	Visil AP (Sateri)
Synthetic				
Polyester	Organophosphorus components (e.g. phosphinic acidic comonomers and phosphorous additives)	C/A	Y	Trevira CS (Trevira) Fidion FR (Montefiber)
Modacrylic	Acrylic/Halogenated comonomer: e.g., Vinyl bromide (VBr) at 35-50 % w/w plus antimony compounds	C	N	Velicren (Montefiber) Kanecaron (Kaneka Corp.)
Polypropylene	Both halogen and non-halogen additives incorporated into the melt spinning process	A	N/Y	Sandoflam 5072 (Clariant) Ciba® Flamestab® NOR™ 116
Inherently Flame-resistant				
Melamine	Melamine units joined by methylene and dimethylene ether linkages	H	Y	Basofil (BASF)
Polyhaloalkenes	Polyvinyl chloride Polyvinylidene chloride	H	N	Clevyl (Rhone-Poulenc) Saran (Saran Corp.)
Polyaramides	Poly(m-phenylene isophthalamide) Poly(p-phenylene terephthalamide)	Ar	Y	Nomex (DuPont) & Conex (Teijin) Kevlar (DuPont), Twaron (Acordis) & Technora (Teijin)
Poly (aramide-arimide)		Ar	Y	Kermel (Rhone-Poulenc)
Glass Fibers			Y	
Polybenzimidazole		Ar	Y	PBI (Hoechst-Celanse)
Carbonized acrylic	Carbon fibers from polyacrylonitrile	Ar	Y	Pyron (Zoltek)

Key:
F: chemical post-treatment
A: additive in fiber melt spinning
C: modified copolymer. Copolymers are made up of two or more different monomers.
H: homopolymers constructed as a single type of monomer.
Ar: aromatic homo- or copolymer

Sources: NAP 2000, KemI 2004, Manufacturer websites

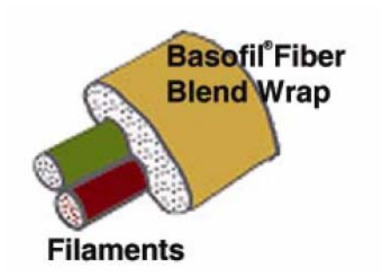
6.6 Fabrics

Fabrics are made from single or multiple types of fibers. The way a fabric is made (knit, weave, lace, etc.) will affect how it burns. Heavy tight structures will burn more slowly while thin or open fabrics will combust more quickly. In some cases, fibers with a better "feel" such as cotton or polyester can be combined with more flame resistant fibers, such as melamine, to form a fabric that performs well in both comfort and fire performance. Some fire-resistant fabrics used in upholstery, mattress, and drapery applications are made from blends of two to five fibers using a mix of inherently fire resistant fibers (which are typically more costly) and fibers with lower flame performance. Figure 12 profiles a woven fabric made from a combination of fibers with various levels of fire resistance chosen to balance fabric properties such as cost, fire performance, durability, and comfort.

Figure 12: Alessandra Flame Resistant Fabrics

Five different fibers are combined together to make Alessandra yarn. Basofil, modacylic and polyester fibers are wrapped around a filament fiber made of glass and nylon. Basofil, modacylic and glass are inherently fire resistant materials while nylon and polyester are not. The advantage of this construction is that the majority of the yarn is made from low-cost fibers such as polyester. When exposed to flame, woven Alessandra fabric forms a woven glass-like grid covered with a carbon char that fills the lattice spaces. The system prevents flame from penetrating into the underlying flammable filling materials in products such as mattresses and furniture.

A.



B.

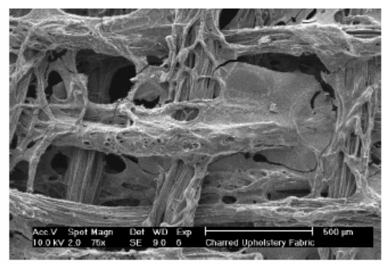


Figure A depicts Alessandra yarn. Figure B is a scanning electron microscope (SEM) photo of Alessandra fabric burned using the CA TB 133 upholstered chair test. The glass grid and carbon char are evident in the photo. While no chemical treatments are applied to the fiber, the fabric is not 100% halogen-free. Modacrylic fibers used in the yarn contain halogens such as vinyl bromide as an acrylic comonomer.

Source: Handermann 2004

Most textile fabrics are made from the four main types of fibers:

- Staple Fiber – filaments cut into specific lengths – usually spun into yarn
- Chopped Fiber – coarser, cut to specific, often short, lengths to add to mixture
- Monofilament – a single (large) continuous filament yarn – like fishing line
- Multifilament – extruded continuously with many filaments in the bundle.

These basic fiber types are then further processed into one of four major converted forms:

- Spun yarn
- Knitted fabric
- Woven fabric
- Nonwoven fabric

Yarn, woven fabrics and knitted fabrics are familiar fiber forms. Nonwoven fabrics are less well known. Nonwoven materials are produced primarily from man-made fibers such as polypropylene and polyesters (mainly polyethylene terephthalate or PET). Manufacturers make nonwoven fabrics by combining small fibers together in a random pattern in a flat sheet and then binding them together. Nonwovens are cheap to manufacture, are typically weak, and do not stretch. Binding methods include:

- adhesives
- thermal bonding: calendering through heated rollers
- mechanical entanglement: entangling fibers by using either high pressure water jets or rapidly oscillating needles

Barrier Technologies

An important aspect of furniture and mattress fire protection is the use of barrier technologies between the surface fabric and the interior foam core. In addition to the blends of inexpensive fibers and expensive inherently fire-resistant fibers, many manufacturers use cotton-batting materials treated with boric acid. These cotton materials are the lowest-cost barrier technology and are used to help meet fire safety requirements. They provide comfort and are used as an inner layer between the fiber and the inner flammable polyurethane foam. Plastic films have also been used in the industry, especially films made of inherently flame-resistant plastics such as neoprene (polychloroprene).

Bonded Substrates

In addition to treating fibers and fabrics, manufacturers bond flame-retardant substrates to the back of fabrics. The substrates can be thermally bonded or mechanically joined via needle punch. These laminated materials maintain the feel of the exterior fabric. Bonding the barrier to the fabric reduces the furniture manufacturing labor costs and eliminates air space between the barrier and the fabric. Minimizing the airspace between these layers provides better fire retardant performance.

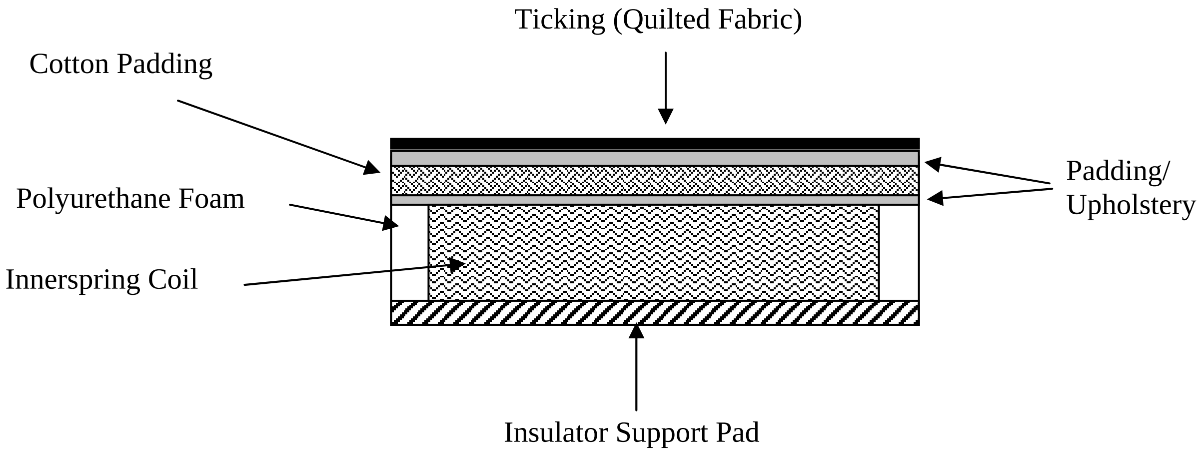
6.7 Substitutes for Products Using DecaBDE

As can be seen from the previous section, there are many ways to modify fibers and fabrics to meet existing and proposed flame retardant standards. In cases where decaBDE is used, there appear to be many possible commercially available substitute chemical finishes as well as the potential to use inherently flame retardant fibers and fabrics as substitutes. This section reviews substitution efforts in three main product areas where decaBDE has historically been used – mattresses, upholstered furniture, and draperies.

6.7.1 Mattresses

Bed sets are complicated products which can be manufactured using eight to 12 fabric and cushioning components. For example, a typical innerspring mattress could include ticking, binding tape, quilt cushioning with one or more separation layers, quilt backing fabric, thread, cushioning with one or more separate layers, flanging, spring insulator pad, spring unit and side panels (Bedtimes 2002). Figure 13 depicts one of many possible mattress constructions on the market.

Figure 13: Mattress Cross-Section



New mattresses are typically designed to meet two types of fire performance standards – the cigarette ignition test such as CPSC CFR 1632 and the open flame test such as CA TB 603.[14]

Use of DecaBDE

Many manufacturers have historically used decaBDE to meet fire standards by applying it on the back of the mattress ticking. For example, Burlington Industries applies decaBDE to the underside of ticking used in mattresses. [15] In cases where more than just a simple backcoating is needed to protect the interior fuel load from fire, manufacturers have traditionally used a combination of fire-resistant fabrics, boric acid-treated cotton batting, and cushioning components to meet the open-flame type tests (Bedtimes 2002).

DecaBDE Alternatives

Alternatives to the use of decaBDE in mattresses fall into two categories. The first is the use of non-halogenated phosphate type coatings for backcoating mattress fabrics. Examples include products made by Manufacturers Chemical and the Felters Group. Their proprietary backcoating technology uses a phosphate-based intumescent technology to meet the NFPA 701 and the TB 603 requirements.

The second and increasingly common alternative is the use of fire barriers (Bedtimes 2002). Fire barriers are usually fire-resistant materials placed either between the exterior cover fabric of the product and the first layer of cushioning materials, or beneath one or more "sacrificial layers" of cushioning. These sacrificial layers are close to the product's exterior surface and provide an aesthetic feel or look. While

[14] These tests are outlined in detail in Appendix B.
[15] Source: TRI data review and telephone correspondence with Burlington Industries.

they may be consumed in a fire, they can be used with a fire blocking system that protects the majority of the interior cushion fuel load.

Fire barriers are made from inherently flame-retardant fibers such as para-aramids, melamines, modacrylics, or glass, and therefore do not rely on the use of flame retardant chemicals. Many of these fibers are made from non-halogen materials. These barriers protect the mattress, futon or box spring core material from combustion. They fully encapsulate the interior materials and must be combined with fire-resistant border seams, tape, and threads (ISPA 2005). Depending on the type of flame-resistant barrier system used to protect the interior of the mattress or box spring, flame retardant mattress ticking might not be necessary for the finished mattress to meet CA TB 603 (ISPA).

Availability and Use

There are many bedding products that do not use halogenated flame retardants. According to the president of the International Sleep Products Association (ISPA), which represents a number of U.S. manufacturers, all of ISPA's members are using fire-resistant barriers made from synthetic fibers and thereby avoiding the application of fire-retardant chemicals to the filling material. However, according to industry officials, the use of various flame-retardant chemicals is still a possibility, especially in cheaper and imported beds. (Thomas 2005).

Examples of products that use this approach include the Comfort Care mattress manufactured by the Restonic Mattress Corporation. Restonic's product uses a non-halogen inherently flame-retardant resin made by GE called ULTEM polyetherimide (PEI) resin (see Figure 14). GE provides PEI material in resin form. Western Nonwovens, Inc converts the resin into a fiber and then uses the fiber to create a flame-retardant barrier that meets the new CA TB 603 standard. The ULTEM resin-based barrier is sandwiched between the mattress foam core and the outer ticking, creating a fire barrier that separates the foam from the fire and helps to inhibit flame spread (Fiber 2 Fashion 2005).

Figure 14: Comfort Care Mattress

6.7.2 Furniture

While there is a voluntary Upholstered Furniture Action Council (UFAC) standard, there is no federal regulation dictating an upholstered furniture flame retardant standard for residential furniture in the U.S. According to knowledgeable industry sources, chemical flame retardants are not necessary in 99% of cases for panel and upholstery fabrics to meet the fire codes for residential upholstered furniture. This applies to all types of fabrics including nylon, polypropylene, polyethylene, acrylic, and cotton blends. As long as there is some thermoplastic in the mix, these fabrics can meet CA TB 116 (for cigarette testing of upholstered furniture).

DecaBDE Substitutes

According to industry sources, chemical coating flame retardants such as decaBDE are used to meet CA TB 133 (test for seating furniture to be used in public places). Substitutes for the use of decaBDE in office/commercial furniture include:

- Non-halogen phosphorus type chemical-coated flame retardant systems applied to the back of the fabric
- The use of fire barriers (similar to the mattress industry) to protect the interior cushioning fire load in upholstered furniture.

Each of these approaches can affect the comfort, look, and cost of the upholstered furniture product. A review of industry trade press and discussions with manufacturers of alternative non-halogenated decaBDE replacements indicates that replacements are widely available for chemically treating natural fibers and blends of natural and synthetic fibers.

According to the Nonwovens Industry website (http://nonwovens-industry.com), the EPA Furniture Partnership has become interested in the use of barrier fabrics. Barrier technologies have recently seen widespread adoption in the mattress industry and they are seen as a possible approach to providing fire safety in the upholstered furniture industry due to their widespread availability and relative affordability (Mayberry and Franken 2005).

The Illinois National Fireproofing Company is an example of a furniture textile coater that offers non-halogen flame retardant coatings. Their Flamex PF, based on a blend of polyphosphonophosphates, is used on upholstered furniture in restaurants, nightclubs, high-rise hotels, apartments, nursing homes, schools, theatres, etc. Andrewsville Hospitality Furniture, a manufacturer of hotel furniture and other goods, uses inherently flame retardant polyester fabric on some of their upholstered furniture products (www.andrewsville.com).

Availability

While there are numerous non-halogenated materials and treatments available for upholstery fabric, there are very few manufacturers that market their products as free of halogenated flame retardants. When the Consumer Product Safety Commission issues its new rules for open-flame fire performance, manufacturers are likely to respond similarly to how the mattress industry combined materials and technologies (e.g. barrier layers or inherently flame resistant fibers) in new ways to meet the mattress performance standard.

6.7.3 Drapes

Drapes and curtains used in public places are required to meet certain flame retardant standards including NFPA 701 and California Health and Safety Code 13119 and 13115. Draperies manufacturers use both inherently flame retardant fibers such as polyester as well as chemically applied finishes such as decaBDE to meet these requirements. Some manufactures have traditionally used decaBDE because it is less expensive and stands up to repeated washings. Manufacturers contacted for this report including Hanes Finishing, Tietex, and Rockland Industries used decaBDE on draperies.

Fabrics

Generally speaking, natural fiber fabrics are the best choice when choosing a drapery fabric to flame retard with chemicals. Natural fibers (cotton, silk, linen, wool, etc.) absorb the flame retardant readily and can be treated with non-halogen phosphate type treatments to meet the most stringent flammability standards (for example, see treatments for various natural fibers on page in section 6.5.2)

Synthetic fibers are more difficult to treat for flame retardancy. Acrylics, acetates, nylons, and polypropylene fabrics are not recommended for drapery use. If these fabrics are used, a backcoating is typically applied (such as decaBDE/antimony in an acrylic polymer coating). Substitutes for decaBDE for polyester, polypropylene and rayon fibers involve the use of phosphate-type additives in the polymer/fiber manufacturing process.

Blends of natural and synthetic fibers are common in draperies. The greater the natural fiber content, the better the results from chemical fiber treatment. High synthetic fiber blends may require backcoating to meet vertical flame tests.

Substitutes and Availability

One approach to substituting decaBDE in draperies is the use of non-decaBDE chemically applied flame retardants. There are many firms offering these types of treatments, including Schneider-Banks Inc. (SBI). SBI's flame-retardant finishing process treats natural fabrics and natural/synthetic blends with phosphonate type flame retardants to meet demanding flame retardant standards, including NFPA 701 for draperies. Synthetic and natural fiber blends also can be treated with this process but usually require a more substantial treatment. SBI advises that 100% acrylic, acetate nylon and polypropylene fabrics and blends high in these fibers are difficult to treat using its system. Treated fabrics should be dry cleaned repeatedly in no-water cleaning systems. The flame retardant will be partially or completely removed by water washing.

A second substitution approach in draperies is the use of inherently flame-resistant fibers. A host of manufactures use inherently flame resistant polyester, including Agua Fabrics, Diamond Drapery Co., A.R. Nelson Co., Cubicle Curtain Factory, and Quality Stage Drapery LTD. Draperies that employ inherently flame resistant fibers can be laundered in water since the phosphate flame retardants are part of the polymer backbone and are not water soluble.

6.7.4 Costs of Halogen-Free DecaBDE Substitutes

There is relatively little information available concerning the costs for decaBDE replacements. For composite products such as mattresses and upholstered furniture, the substitution costs are complex for replacing decaBDE backcoated fabric with a barrier layer or inherently flame-retardant fiber. The costs potentially involve several new materials such as fabric, barrier layer, foam, and other layers for comfort or performance characteristics. These substitution costs are generally not divulged by the manufacturers and are an area of competitive advantage.

In cases where decaBDE is directly substituted with another chemically applied flame retardant, the cost analysis is more straightforward. Still, few manufactures provide data on the cost of alternatives. Data obtained from one manufacturer shows that phosphate type replacements cost 2 to 2.5 times as much as decaBDE approaches (see Table 17).

Table 17: DecaBDE Substitutes for Draperies

Chemically Applied Flame Retardant Product	Flame Retardant Type	Rough Cost per Pound
Halogen/Antimony	DecaBDE/Antimony Oxide	$1.40
Pyromescent: Amitech	Phosphorous	$3-4
Pyrozoyl 6P: Amitech	Phosphorous/ halogen (no penta, octa or deca)	$3
Pyrozyl M73: Amitech	Phosphorous	$4

Source: Amitech

6.8 Summary

Producing flame-retardant textile fabrics requires understanding complicated fire safety rules as well as the many types of fibers, fiber blends, barriers, nonwovens, fire retardant treatments, and other materials available on the market today. Manufacturers of mattresses and upholstered furniture in particular have a huge array of material choices to make their products from.

DecaBDE is a low-cost method for treating textiles. There are a multitude of non-halogen replacements on the market, including alternative flame retardants, fibers, fiber blends, barrier layers, nonwovens, and other approaches. These substitutes have their own individual cost, performance, and aesthetic tradeoffs. While there is no single replacement for decaBDE for textiles, the multitude of options on the market make it clear that viable market-ready approaches exist.

7 Conclusions

DecaBDE is a widely used flame retardant in electronic enclosures and textile applications. Based on an in-depth review of the literature for these applications, it appears that there are many non-halogenated alternative materials to decaBDE available on the market today. These conclusions are based on the availability of substitutes and do not include a thorough consideration of their potential health and environmental risks. Table 18 summarizes availability and cost attributes for these two product groups.

Table 18: Availability of Commercial Halogen-free Materials and Products

Product	Commercial halogen- free material	Price of product compared to BFR containing material	Commercial halogen-free product
Electronic Housings	available	more expensive	available
Furniture Applications (Mattress, Furniture, Draperies)	available	unable to determine	available

In the case of electronic enclosures, the substitute resin systems and flame retardants are well established. Manufacturers in Europe and increasingly here in the U.S. are familiar with these systems. Their higher cost and lack of regulatory drivers has limited their adoption in the U.S. Efforts to assess the alternatives to decaBDE would benefit from more publicly available information and analysis of the environmental health and safety impacts of substitutes.

In the case of textiles, substitution is a much more complicated endeavor given the complexity of the end products and the array of possible substitution approaches. These approaches include substitute flame retardants, alternative fibers, inherently fire resistant fibers, barrier layers, and nonwovens.

In cases where substitute chemically applied flame retardants are used in textiles, most of the non-halogenated approaches involve various types of phosphate flame retardants. While these chemicals have a long history of use in the industry, there is need for more study regarding their human and environmental health effects.

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9 Appendix A: 2002 DecaBDE TRI Analysis

Sic Code	SIC Description	Facility Name	City Name	State	Recycled (lb)	Releases (lb)
DecaBDE Manufacturers						
1474	Potash, Soda, and Borate Minerals	Albemarle Corp South Plant	Magnolia	AR		46,000
2819	Industrial Inorganic Chemicals, NEC (recovering sulfur from natural gas)	Great Lakes Chemical Central	El Dorado	AR		136,079
Textiles						
2211	Broadwoven Fabric Mills, Cotton	Blumenthal Mills Inc	Marion	SC		620
2211	Broadwoven Fabric Mills, Cotton	Interface Fabrics Inc	Elkin	NC		45
2211	Broadwoven Fabric Mills, Cotton	Mount Vernon Mills Lafrance Div	La France	SC		
2221	Broadwoven Fabric Mills, Manmade Fiber and	Southern Phenix	Phenix City	AL		2,510
2258	Lace and Warp Knit Fabric Mills (except finishing)	Guilford Mills Inc Guilford East Site	Kenansville	NC		1,461
2258	Lace and Warp Knit Fabric Mills (except finishing)	Collins & Aikman Prods. Co.	Farmville	NC		1,050
2259	Knitting Mills NEC (finished articles of weft knit fabric)	Collins & Aikman Prods. Co	Roxboro	NC		5,049
2261	Finishers of Broadwoven Fabrics of Cotton	Mf&H Textiles Inc	Butler	GA		1,555
2261	Finishers of Broadwoven Fabrics of Cotton	Rockland Bleach & Dye Works	Baltimore	MD		
2261	Finishers of Broadwoven Fabrics of Cotton	Rockland-Bamberg Industries	Bamberg	SC		
2262	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	Synthetics Finishing	Hickory	NC	74	52
2262	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	Synthetics Finishing 321 Plant	Hickory	NC	137	-
2262	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	Milliken Abbeville Plant	Abbeville	SC		2,435
2262	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	Burlington House Finishing Plant	Burlington	NC		1,977
2262	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	Gold Mills Inc Penn Dye & Finishing	Pine Grove	PA		467
2269	Finishers of Textiles, NEC	Hanes Dye And Finishing Co -	Butner	NC		21,495
2269	Finishers of Textiles, NEC	Tietex International Ltd	Spartanburg	SC		10,041
2273	Carpets and Rugs	Landrum Mills	Landrum	SC	937	
2273	Carpets and Rugs	Aladdin Mills Antioch Rd Plant	Dalton	GA		
2273	Carpets and Rugs	Mohawk Industries Durkan Finishing	Dalton	GA		
2295	Coated Fabrics, Not Rubberized	John Boyle & Co Inc	Statesville	NC		
2295	Coated Fabrics, Not Rubberized	Reeves Brothers Inc	Rutherfordton	NC		
2295	Coated Fabrics, Not Rubberized	Reeves Brothers Inc./Printing Prods.	Spartanburg	SC		
2297	Nonwoven Fabrics	Lydall Thermal/Acoustical Inc	Green Island	NY		11,766
2299	Textile Goods, NEC	Sunbeam Products Inc	Waynesboro	MS		16,203
Paper						
2621	Paper Mills (except newsprint mills)	Hollingsworth & Vose Co	Greenwich	NY		14,714
2621	Paper Mills (except newsprint mills)	Hollingsworth & Vose Co	Hawkinsville	GA		7,300

2621	Paper Mills (except newsprint mills)	Hollingsworth & Vose Co	Greenwich	NY		5,400
2653	Corrugated and Solid Fiber Boxes	Atco Rubber Products Inc	Cartersville	GA		1,010
2671	Packaging Paper and Plastics Film, Coated and Laminated	Cleveland Laminating Corp	Cleveland	OH		5,450
2672	Coated and Laminated Paper, NEC	Shurtape Technologies Llc	Stony Point	NC		788
2679	Converted Paper and Paperboard Products, NEC	Compac Corp	Netcong	NJ		13,085
2679	Converted Paper and Paperboard Products, NEC	Lamtec Corp	Flanders	NJ	6,006	52,184
Plastics and Chemical Manufacturing						
2819	Industrial Inorganic Chemicals, NEC	Dow Chemical Co Midland	Midland	MI		425
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Solvay Advanced Polymers Llc	Marietta	OH		1,206
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Nylon Corp Of America	Manchester	NH		383
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Parachem Southern Inc	Simpsonville	SC		1
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	3m Co Decatur	Decatur	AL		-
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Ticona Polymers Inc	Bishop	TX		165
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Noveon Inc	Gastonia	NC		1
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Bound Brook Plant Union Carbide Corp	Piscataway	NJ		17,476
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Nova Chemicals Inc	Chesapeake	VA		91
2821	Plastics Materials, Synthetic and Resins, and Nonvulcanizable Elastomers	Dow Chemical Co Torrance Facility	Torrance	CA		13
Adhesives and Sealants						
2891	Adhesives and Sealants	Permacel Saint Louis Inc	Saint Louis	MO	200	771
2891	Adhesives and Sealants	Parachem Southern Inc.	Philadelphia	PA		476
2891	Adhesives and Sealants	Heveatex Corp	Fall River	MA		
2891	Adhesives and Sealants	Coat-It Inc	Detroit	MI		
2891	Adhesives and Sealants	Tanner Chemical Inc	Greenville	SC	4,001	2,002
2891	Adhesives and Sealants	Noveon Inc	Lawrence	MA		52
2891	Adhesives and Sealants	Bostik Findley Inc	Marshall	MI		
2891	Adhesives and Sealants	Polyset Co Inc	Mechanicville	NY		
2891	Adhesives and Sealants	Forbo Adhesives Llc	Omaha	NE		
Rubber Products						
2822	Synthetic Rubber	Advanced Elastomer Systems L P	Cantonment	FL		11,560
3021	Rubber and Plastics Footwear	Tingley Rubber Corp.	South Plainfield	NJ		8,379
3052	Rubber and Plastics Hose and Belting	Goodyear Tire & Rubber Co	Marysville	OH		2,235
3052	Rubber and Plastics Hose and Belting	Hbd Industries Inc	Chanute	KS		
3052	Rubber and Plastics Hose and Belting	Eaton Aeroquip Inc	Mtn. Home	AR		
Rubberizing Fabric Products						
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	North American Rubber Thread Co..	Fall River	MA		618
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Tyco Adhesives	Franklin	KY		12,408
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Firestone Building Prods. Co.	Prescott	AR		2,515
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Teknor Apex Co	Pawtucket	RI		1,760
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Polyone Corp.	Dyersburg	TN		1,232
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Carlisle Syntec Inc	Carlisle	PA		587

3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Pawling Corp	Pawling	NY		
3069	Fabricated Rubber Products, NEC (rubberizing fabric)	Carlisle Syntec Inc Plant 7	Greenville	IL		
Plastics Compounding, Extruding and Processing						
3081	Unsupported Plastics Film and Sheets	3m Co Brownwood	Brownwood	TX		1,300
3081	Unsupported Plastics Film and Sheets	Poly-America L.P	Grand Prairie	TX		
3083	Laminated Plastics Plate, Sheet, and Profile Shapes	Hart & Cooley Inc	Sanger	CA		24
3083	Laminated Plastics Plate, Sheet, and Profile Shapes	Atco Rubber Products Inc	Fort Worth	TX		1,010
3083	Laminated Plastics Plate, Sheet, and Profile Shapes	Gil Techs.	Piperton	TN		219
3083	Laminated Plastics Plate, Sheet, and Profile Shapes	Carlisle Syntec Inc	Senatobia	MS	1,202	75
3083	Laminated Plastics Plate, Sheet, and Profile Shapes	Strongwell Corp	Bristol	VA		2,375
3084	Plastics Pipe	3m Co. Chelmsford	Chelmsford	MA	3,924	-
3086	Plastics Foam Products (polystyrene foam products)	Sekisui America Corp Voltek Div	Coldwater	MI		21,473
3087	Custom Compounding of Purchased Plastics Resin	V-Bat Plastic Processing Corp.	Washington	PA		
3087	Custom Compounding of Purchased Plastics Resin	Spartech Polycom Inc Plant 2	Donora	PA	1,500	19,000
3087	Custom Compounding of Purchased Plastics Resin	A. Schulman Inc Specialty Compounding	Sharon Center	OH		5,506
3087	Custom Compounding of Purchased Plastics Resin	Polymer Products Co Inc	Stockertown	PA		4,710
3087	Custom Compounding of Purchased Plastics Resin	Spartech Polycom Inc	Arlington	TX	990	28
3087	Custom Compounding of Purchased Plastics Resin	General Cable Co Inc	Marion	IN		14
3087	Custom Compounding of Purchased Plastics Resin	General Cable Industries Inc	Indianapolis	IN		
3087	Custom Compounding of Purchased Plastics Resin	A Schulman Inc Nashville Plant	Nashville	TN		23,540
3087	Custom Compounding of Purchased Plastics Resin	Gitto Global Corp	Lunenburg	MA		12,409
3087	Custom Compounding of Purchased Plastics Resin	Polyone Corp.	Dyersburg	TN		5,244
3087	Custom Compounding of Purchased Plastics Resin	Plastics Color & Compounding Inc	Dayville	CT	202	4,796
3087	Custom Compounding of Purchased Plastics Resin	Miller Waste Mills (DBA RTP Co)	Winona	MN		1,850
3087	Custom Compounding of Purchased Plastics Resin	Teknor	Henderson	KY		1,300
3087	Custom Compounding of Purchased Plastics Resin	Rtp Co	Indianapolis	IN		1,210
3087	Custom Compounding of Purchased Plastics Resin	Rtp Co.	Fort Worth	TX		1,039
3087	Custom Compounding of Purchased Plastics Resin	Mack Molding Co Inc	Statesville	NC	504	252
3087	Custom Compounding of Purchased Plastics Resin	Alphagary Corp	Leominster	MA	1,033	189
3087	Custom Compounding of Purchased Plastics Resin	Saint-Gobain Aurora-Danner Facility	Aurora	OH		12,765
3087	Custom Compounding of Purchased Plastics Resin	Polyone Corp	Macedonia	OH		5,991
3087	Custom Compounding of Purchased Plastics Resin	Asahi Thermofil Inc	Fowlerville	MI		3,670
3087	Custom Compounding of Purchased Plastics Resin	Spartech Polycom Inc	Donora	PA	96,000	230,000
3087	Custom Compounding of Purchased Plastics Resin	Techmer Pm Llc	Clinton	TN		
3087	Custom Compounding of Purchased Plastics Resin	Epic Resins	Palmyra	WI		
3089	Plastics Product, NEC	Flambeau Plastics Blow Molding Div.	Baraboo	WI	-	1,727
3089	Plastics Product, NEC	Premix	N. Kingsville	OH		6,544
3089	Plastics Product, NEC	Strongwell Chatfield Div.	Chatfield	MN		1,143
3089	Plastics Product, NEC	Bedford Reinforced Plastics Inc.	Bedford	PA		
3089	Plastics Product, NEC	Fibergrate Composite Structures Inc.	Stephenville	TX		
3089	Plastics Product, NEC	Tyco Electronics Corp	Menlo Park	CA		2,355
3089	Plastics Product, NEC	Mack Molding Co	Arlington	VT		700

3089	Plastics Product, NEC	Wollin Products Inc (Aka Titan Plastics Group)	Clyde	OH	-	-
Mineral Wool						
3296	Mineral Wool	Armstrong World Industries Inc	Pensacola	FL		5,600
3296	Mineral Wool	Armstrong World Industries	Hilliard	OH		2,016
3296	Mineral Wool	Cta Acoustics Inc	Corbin	KY		2,421
3296	Mineral Wool	Armstrong World Industries	Marietta	PA		1,797
Wire and Cable						
3357	Drawing and Insulating of Nonferrous Wire	American Insulated Wire Corp	Attleboro	MA		2,700
3357	Drawing and Insulating of Nonferrous Wire	Judd Wire Inc	Turners Falls	MA		
3357	Drawing and Insulating of Nonferrous Wire	General Cable Corp	Willimantic	CT		49,564
3357	Drawing and Insulating of Nonferrous Wire	Rockbestos-Surprenant Cable Corp	East Granby	CT		12,142
3357	Drawing and Insulating of Nonferrous Wire	Aetna Insulated Wire	Virginia Beach	VA		8,471
3357	Drawing and Insulating of Nonferrous Wire	Biw Cable Systems Inc	North Dighton	MA		3,994
3357	Drawing and Insulating of Nonferrous Wire	Belden Electronics Div Richmond Plant	Richmond	IN	-	1,550
3357	Drawing and Insulating of Nonferrous Wire	Rockbestos-Surprenant Cable Corp	Clinton	MA		94
3357	Drawing and Insulating of Nonferrous Wire	Tyco Thermal Controls Llc	Redwood City	CA		60,000
3357	Drawing and Insulating of Nonferrous Wire	General Cable Industries Inc	Du Quoin	IL		8,757
3643	Current-Carrying Wiring Devices	Volex Inc	Clinton	AR		1,717
3643	Current-Carrying Wiring Devices	Woods Inds. Inc.	Carmel	IN		
TV Manufacturing						
3651	Household Audio and Video Equipment	Matsushita Kotobuki Electronics	Vancouver	WA	189,979	
Miscellaneous						
3444	Sheet Metal Work	Hart & Cooley Inc	Olive Branch	MS		
3679	Electronic Components, NEC (antennas)	Northfield Acquisition Co	Northfield	MN		1,907
3699	Electrical Machinery, Equipment and Supplies	Nelson Heat Tracing Systems	East Granby	CT		1,197
3714	Motor Vehicle Parts and Accessories	Xlo Macedonia Plant	Macedonia	OH		14,000
3585	Air-Conditioning and Warm Air Heating Equipment	Goodman Co. L.P.	Fayetteville	TN		
3585	Air-Conditioning and Warm Air Heating Equipment	Hart & Cooley Inc.	Jackson	TN		
4953	Refuse Systems (hazardous waste treatment and disposal)	Chemical Waste Management	Sulphur	LA		280,000
2899	Chemical Preparations, NEC	Apex Chemical Corp	Spartanburg	SC		
2843	Surface Active Agents, Finishing Agents, Sulfonated Oils, etc.	Kao Specialites Americas Llc	High Point	NC		-
2851	Paints, Varnishes, Lacquers, Enamels and Allied Products	International Paint Inc	Union	NJ		886
2869	Industrial Organic Chemicals, NEC (aliphatics)	Haywood Co	Brownsville	TN		280

10 Appendix B. Textile Fire Safety Regulations

The following subsections list the main fire safety standards affecting products used in the mattress, upholstered furniture and drapery industries. In addition to these key standards, there are other textile-related standards. These standards are not reviewed in detail since they are similar to those in the following sections, apply to specific sub sectors not covered in this report, or have become largely obsolete and replaced by more current standards.

Table 19: Other Textile Fire Protection Standards

American Society of Testing and Materials - ASTM E-84 tunnel test
City of Boston Fire Department
State of Massachusetts
Federal Aviation Administration
City of New York / New Jersey Board of Standards and Appeals
Port Authority of New York and New Jersey

10.1 Mattresses

There are two main types of standards to prevent mattress fires: prevention against cigarette type ignition and prevention from open-flame ignition. The older cigarette federal cigarette-ignition test known as 16 CFR 1632 is largely responsible for a near elimination of fire deaths due to cigarette-ignited mattresses. The new CA TB 603 standard was written to prevent fire deaths from open-flame ignition sources – the source of nearly two-thirds of U.S. mattress fires according to the U.S. CPSC (ISPA 2005). In December 2004, the CPSC announced its intent to propose a national fire safety standard for mattresses, which is likely to follow CA TB 603.

Table 20: State and Federal Mattress Fire Regulations and Standards

Standard	Applicability	Description
CFR 1632 January 2000	Federal flammability standard for mattresses and mattress pads	Cigarette type test for ignition resistance. Sets requirements for testing of prototype designs of mattresses and mattress pads before their sale or introduction in commerce. The standard is based on CA TB 106.
CA TB 121 April 1980	Mattresses for Use in High Risk Occupancies	Regulation for facilities including, but are not limited to, jails, prisons, penal institutions, correctional facilities, juvenile detention centers, nursing homes, and health care facilities. This test procedure is not intended to be used for the evaluation of residential mattresses. There are similar requirements in Massachusetts set by the Boston Fire Department.
CA TB 129 October 1992	Mattresses used in public buildings	The public occupancies include, but are not limited to health care facilities, old age convalescent and board and care homes, college dormitories and residence halls. This test method is cited in the Boston Fire Prevention Code.

CA TB 603 January 2005	Residential mattress/box spring beds	This regulation is based on a 30-minute open-flame fire test. TB 603 will include, but is not limited to, futons, hybrid flotation and airbed ensembles, sofa sleepers, cribs and bunk beds, roll-a-way, and hide-a-beds. So-called “renovated” or recovered used bedding would also be subject to these requirements.

10.2 Upholstered Furniture

There are currently no federal flame retardant standards for the U.S. upholstery industry. The CPSC is currently working on a national flammability performance standard and hopes to develop a draft rule in 2005. The Upholstered Furniture Action Council developed voluntary standards that are used by many in the industry. California has developed a number of standards that are referenced in building codes throughout the country for public places, commercial offices, and high-risk settings.

Table 21: California Upholstered Furniture Fire Regulations

Standard	Applicability	Description
Upholstered Furniture Action Council (UFAC) 1983	Cigarette testing of upholstered furniture fabric	Component standard. Roughly 85% of the industry meets this standard, 80% of furniture production resists cigarette ignition (CPSC Monitor 2004).
CA TB 116 January 1980	Cigarette testing of upholstered furniture fabric	Component standard. All upholstered furniture sold in CA must pass this flame test. This test is generally not used by jurisdictions outside of CA.
CA TB 133 1984	Seating furniture for use in public occupancies	Composite standard. A full-scale flame test for furniture manufactured for use in public buildings in CA. TB 133 was developed in May to address the specific fire problems of furnishings in public (not residential) buildings. Many states including IL, MA, NC and OH have adopted TB 133.
CA TB 117 Updated March 2000	Filling materials used in upholstered furniture	Component standard. Furniture that meets the TB 117 standard is less likely to ignite rapidly, and if ignited, less likely to burn quickly or to sustain burning. Many leading upholstered furniture products sold nationwide meet this CA standard. Some states, including MN, require TB 117 instead of TB 133.

10.3 Draperies

The most significant regulation concerning draperies is the National Fire Protection Agency (NFPA) 701standard. It is a vigorous test to evaluate a material’s ignition resistance and potential to propagate flame beyond the area exposed to an ignition source.

Table 22: Drapery Related FR Regulations

Standard	Applicability	Description
National Fire Protection Agency (NFPA) 701	Draperies in buildings where codes require the NFPA 701 standard	This standard applies not only to draperies but also to theater curtains, hospital privacy curtains, textile wall hangings, table skirts, and other applications. It is a widely used standard for international and national building codes.

10.4 Other Standards

While this section presents the chief fire performance standards for textiles that use decaBDE in the U.S., there are many other textile fire-related standards for other applications. These include standards for high-performance apparel (fire fighter turn out gear and race car suits), carpets and rugs, and bed clothing (such as comforters and pillows). None of these applications appear to be major users of decaBDE.

11 Appendix D: Textile Flame Retardant Chemicals

Table 23: Commercially Available Textile Halogen-free Flame Retardants Chemicals

Flame Retardant: Manufacturer	*Fiber*	*Applications*	*FR Type*	*Characteristics*
Fire Retard KK: Manufacturers Chemical	100% cotton, rayon, cotton/polyester blends, other cotton/synthetic blends	Drapery, decorative fabrics	organic phosphate	• Semi-durable • Does not cause color change, • 25-35% solutions padded on • 60-70 cents per pound • Used as "drop in" decaBDE replacement
Fire Retard 102-52A: Manufacturers Chemical	PVA, acrylic and vinyl acrylic polymer emulsions	Backcoating Textiles	Organic phosphate	• Semi-durable • Does not cause color change in most applications
Fire Retard 66: Manufacturers Chemical	Polyester	Drapery, upholstery, automotive products, backcoatings	Phosphate ester blend	• Curing and rinsing rec. after application
AFLAMMIT® P CONC: Thor	Cotton, cellulose fibers		Organic phosphorus compound	• Durable to washing • applied using special equipment with gaseous ammonia
AFLAMMIT® PE CONC: Thor	Polyester		Organic phosphorus compound	• Durable halogen-free flame retardant for polyester • applied by padding
AFLAMMIT® SAP: Thor	Cotton, Cellulose fibers		Organic phosphorus compound	• Durable flame retardant • Applied using special equipment with gaseous ammonia
AFLAMMIT® ZAL: Thor	Wool		Zirconium acetate solution	• For low smoke flame retardant finishing of **wool** by an exhaust process (Zirpro treatment)

AFLAMMIT® ZR: Thor	Wool		Potassium hexafluoro zirconate and zirconium acetate (ZAL)	• Flame retardant for **wool** used in the Zirpro process (IWS) with AFLAMMIT® ZAL for low smoke emission
AFLAMMAN IST/PCS: Thor			Based on phosphorous and nitrogen compounds	• Intumescent flame retardant liquid form • Used alone or in coating systems
AFLAMMIT INS: Thor			phosphorous and nitrogen compounds	• Intumescent Flame retardant • Pad and coating systems • Halogen-free
FLAMMENTIN® CIF: : Thor	cellulose for interliner fabrics		Organic phosphorus/nitrogen compound	• semi durable
FLAMMENTIN® FMB: : Thor			Phosphorus nitrogen compound	• meets the requirements of cigarette burn test after water soak
FLAMMENTIN® UCR-N: : Thor	cellulose fibers		Inorganic phosphorus compound	• meet cigarette burn test after water soak
AMGARD® CU: Rhodia	polyester	backcoating applications	Cyclic phosphonate ester	• Flame retardant for fabrics and latex binder applications. High performance at reduced loadings in many systems.
AMGARD® 37* : Rhodia	many fabrics, especially polyester and coatings		Organic phosphonate blend	• Minimal effect on fabric hand. Durable or nondurable, depending on application.
AMGARD® NT D-1* : Rhodia	plastics, synthetics and a wide range of other uses		cyclic phosphonate ester	• Non-durable flame retardant for.
AMGARD™ RD1 : Rhodia	variety of fabrics		Phosphonic acid	• Non-hygroscopic, low-fogging flame retardant. Compatible with binders. Non-durable.

PROBAN®: Rhodia	Cotton, cotton rich fabrics & blends	Protective wear, bedding, furnishing, sleepwear	Phosphorus based; blend of tetrakis (hydroxyl methyl) phosphonium chloride (THPC) & urea	• Durability is achieved by the formation of a cross-linked inert polymer within the fiber • Durability washing under laboratory test and industrial wash conditions shows that, with the correct application of PROBAN®, the fabrics flame retardant properties will last for the expected life of the article. • No chemical reaction with the fiber so base fabrics are largely unaffected • Woven or knitted fabrics can be treated
Flamestab® NOR™ 116: Ciba Specialty Chemicals	Polyolefin		monomeric N-alkoxy hindered amine	• Provides flame retardancy to polyolefin fibers, nonwovens and films in concentrations as low as 1%.
PYROSAN® SYN: Noveon Textile Chems	100% Polyester, acrylic			• Durable flame retardant • Halogen-free • Can be incorporated in backcoatings • Used to help meet NFPA 701 • Can be applied via pad or dry cure;
Flamestab NOR 116FF: Ciba Specialty Chemicals	polypropylene		1,3-Propanediamine, N,N"-1,2-ethanediylbis-, reaction products with cyclohexane and peroxidized N-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products	• Can pass NFPA 701 vertical burn as well as a level of UV stability • Can be made non-halogenated

Flovan® CGN: Ciba Specialty Chemicals	Wool, cellulose, polyester, polypropylene and polyethylene fibers	Automotive and decorative fabrics		
Pyromescent: Amitech	Polyester, cotton and blends	Mattresses	Phosphorous	• Contains small amount of halogen (chlorine) that can be removed for customers that need it. • Keeps flame from spreading & creates char • When coated fabric placed between batting and PU foam, product can pass TB 603. • Costs $3-4 per pound
Pyrozoyl 6P: Amitech	polyester	Airline blankets, auto industry, outdoor industrial fabrics	Phosphorous/ halogen (no penta, octa or deca) with chlorinated solvent	• Exhausted (in dye bath) on polyester • Durable to 50 industrial launderings • Costs $3 per pound
Pyrozyl M73: Amitech	Polyester, cotton and blends	Apparel, mattress fabrics	phosphorous	• Durable to 50 industrial launderings • Applied by padding on • Costs $4 per pound
Pyrozyl G-20: Amitech	Cotton, rayon	Decorative and apparel fabrics	Borate based	• Non-durable • Ten times the cost of decaBDE approach
GLO-TARD BG: Glo-Tex	100% polyester	Drapery, upholstery and automotive fabrics	Phosphonate	• When thermosolled, will yield durability to laundering • not recommended for application to apparel fabrics
GUARDEX FR-P115: Glo-Tex	100% cotton, 100% polyester and blends		polyphosphate	• Durable to dry cleaning, enables fabrics to meet requirements of NFPA 701 and other "vertical flammability tests" • non-corrosive, easy to apply with standard padding or spraying, cure at 300ºF or lower to prevent yellowing
GUARDEX FR-235: Glo-Tex	100% cotton, 100% polyester and blends		Phosphate solution	• Durable to dry cleaning • enables fabrics to meet requirements of NFPA 701 and other "vertical flammability tests" • easy to apply with standard padding or spraying

FYRO-BAN BFA: Glo-Tex	woven, knit and nonwoven fabrics constructed of cellulose or cellulose/ synthetic fiber blends	manufacture of upholstered furniture & mattresses	intumescent	• The product is an aqueous dispersion and does not contain bromine, chlorine or antimony compounds.
FYRO-BAN CB: Glo-Tex	Woven, knit and nonwoven fabrics made of cellulose or cellulose/ polyester blends	upholstered furniture and mattresses	intumescent	• The product is an aqueous flame-retardant barrier *free of Chlorine or Antimony compounds.* • can be applied to fabrics by spray or pad method

Sources: Manufacturers websites and MSDS sheets