EPA United States Environmental Protection Agency

An Alternatives Assessment for the Flame Retardant Decabromodiphenyl Ether (DecaBDE)

Chapter 2

Products and Materials

FINAL REPORT

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2 Products and Materials

Decabromodiphenyl ether (decaBDE) is used for fire safety in a broad range of plastics and polymers with product applications in diverse sectors. Presented below are the categories of materials (Section 2.1) and sectors and products (Section 2.2) for which decaBDE has been or is currently used. Flammability standards relevant for products containing decaBDE are discussed briefly at the end of the chapter (Section 2.3).

2.1 Materials Outlined in the Scope

The materials included in this section are those in which decaBDE is currently or was used in the past across the globe. Additionally, polycarbonate (PC) and polycarbonate-acrylonitrile butadiene styrene (PC-ABS) were included because they can be used with some of the alternative flame retardants. These materials are polymers, made up of chains of repeating monomer units. Table 2-1 displays end-uses by polymer group, each of which may contain several different polymers. A key characteristic of these polymers is whether or not they can be reprocessed and therefore this is touched on in each section. The end-use products and sectors for these materials are discussed in Section 2.2. DecaBDE may not be used in all polymer/end-use application combinations; those relevant to decaBDE are noted in Section 2.2.

Table 2-1: Summary of Polymers and Their End-Use Application

Polymer Group	End-Use Applications								
	Electronics	Wire and Cable	Public Buildings	Construction Materials	Automotive	Aviation	Storage and Distribution Products	Textiles	Waterborne emulsions & coatings
Polyolefins	✓	✓	✓	✓	✓	✓	✓	✓	✓
Styrenics	✓		✓	✓	✓	✓	✓		
Engineering Thermoplastics	✓	✓	✓	✓	✓	✓		✓	✓
Thermosets	✓		✓	✓	✓	✓	✓	✓	✓
Elastomers	✓	✓	✓	✓	✓	✓	✓	✓	✓
Waterborne emulsions and coatings[1]	✓	✓	✓	✓	✓			✓	✓

[1] Includes acrylic, polyvinyl chloride (PVC), ethylene vinyl chloride, and urethane emulsions

Source: Personal communication with members of the partnership

2.1.1 Polyolefins

There are a variety of polyolefins but only three in which decaBDE is commonly used: polypropylene (PP), which has the molecular formula (MF) $(C_3H_6)_n$; polyethylene (PE), which has the MF $(C_2H_4)_n$; and ethylene vinyl acetate (EVA)[7], which is a copolymer of ethylene and vinyl acetate, $(C_2H_4)_m$ $(C_4H_6O_2)_n$ (Mark 2009). Polyolefins are polymers with single carbon bonds, but are derived from hydrocarbons with carbon-carbon double bonds (e.g., ethylene). The basic repeating unit has the MF (C_nH_{2n}). Polyolefins can soften and eventually melt upon heating. As a result, they can be reprocessed which allows them to be remolded repeatedly (Harper and Modern Plastics 2000; Rex 2011). Polyolefin materials can be flexible and are used for applications such as garbage bags, undergarments for wet suits, foam shoes, seat cushions, arm rests, shrink film, and other products (Mark 2009). Additional important polyolefins applications include wire and cable, electrical connectors, battery casings, foamed sheets and pipes for thermal insulations.

2.1.2 Styrenics

Styrenics are based on styrene monomers, also known as vinyl benzene, which consist of a phenyl group attached to a two-carbon chain, $CH_2{=}CH(C_6H_5)$. There are several different types of styrene plastics, two of which can contain decaBDE: high-impact polystyrene (HIPS) and acrylonitrile butadiene styrene (ABS). Polystyrene (PS) and styrene copolymers tend to be brittle, so rubber particles are added to increase impact resistance (Howe-Grant 1997a; Rex 2011). Like polyolefins, styrenics can soften and eventually melt upon heating. As a result, they can also be reprocessed which allows them to be remolded repeatedly (Harper and Modern Plastics 2000; Rex 2011). The following descriptions provide an overview of each material and its general application.

> *HIPS*. HIPS is produced by combining PS with rubber particles, which gives it the mechanical properties that make it suitable for use in durable molded items. Its historical use in television casings is a well-known example (Harper and Modern Plastics 2000).
>
> *ABS*. ABS is a mixture of acrylonitrile, butadiene, and styrene. In general, ABS is widely used in the casing of equipment for telephones, televisions, and computers (Harper and Modern Plastics 2000).

2.1.3 Engineering Thermoplastics

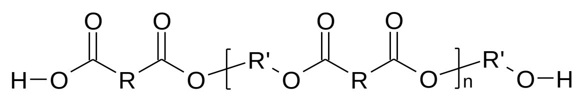
Engineering thermoplastics are materials that are typically not cross-linked, can soften and eventually melt upon heating, and have high levels of mechanical and thermal performance in molded goods when compared to commodity thermoplastics (e.g., PP, PE, HIPS, etc.). As a result, thermoplastics can be reprocessed (Harper and Modern Plastics 2000). This property of thermoplastics allows them to be remolded repeatedly. There are several types of engineering thermoplastics in which decaBDE can be used, including polyester, polyamide (PA), PC, and

[7] EVA is a copolymer of ethylene (an olefin) and vinyl acetate, therefore it is considered to be a polyolefin. However, EVA also has elastomeric properties. For this reason, this report classifies EVA as both a polyolefin and an elastomer. For further discussion on EVA, see Section 2.1.5 on elastomers.

polyethylene ether – high-impact polystyrene (PPE-HIPS). The following descriptions provide an overview of each material and their general applications.

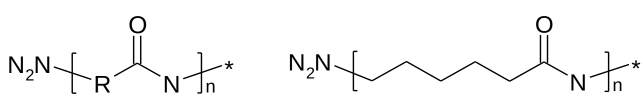
Polyesters. Polyesters (see Figure 2-1) are a broad class of thermoplastics characterized by an ester linkage. Within this class, decaBDE can be used in polybutylene terephthalate (PBT) and polyethylene terephthalate (PET). The only structural difference between PBT and PET is the presence of four methylene repeat units in each PBT repeat unit rather than the two present in each PET repeat unit. PBT has numerous automotive applications such as the exterior as well as connectors for under-the-hood electronic controls. Another major use of PBT is in glass-reinforced grades that are often in switches and connectors for electrical equipment. PET has many commercial applications in injection moldings, blow-molded bottles, and films (Harper and Modern Plastics 2000). Polyesters are also used in commercial and domestic carpeting and textile fibers.

Figure 2-1: Chemical Structure of Polyester



PAs. PAs (see Figure 2-2), also referred to as nylons, are characterized by amide groups along the polymer backbones. There are several types of PAs, the majority of which are used in injection molding applications in information technologies and the transportation industry, mostly for automobiles. PAs are used in automobile exteriors (e.g., wheel covers and handles), interiors (e.g., chair and seat belt mechanisms and light housings), under-the-hood applications, and commercial and domestic carpeting and textile fibers (Howe-Grant 1997d). Glass-reinforced grades also use PAs in electrical switches and connectors.

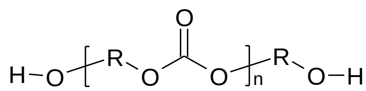
Figure 2-2: Chemical Structure of PA and Nylon



PA Nylon

PCs. PCs (see Figure 2-3) contain a carbonate group and have an excellent combination of mechanical properties, which make them ideal for a variety of applications. PC is a good choice for applications requiring higher use temperatures, lower flammability, and greater impact strength, assuming that the application can afford the higher cost of PC. They are commonly used to manufacture roofing panels, windows for aircraft, trains, and schools, and to make automotive components, such as headlamps and bumpers. Additionally, PC is used to make plastic bottles, CDs & DVDs, electrical equipment, especially connectors, and motorcycle and football helmets. PC is also commonly blended with other materials, such as ABS, to achieve lower cost and improved properties (Howe-Grant 1997e). For example, sometimes PC is added to polymers to impart improved thermal deflection properties. PC-ABS blends are used for equipment housing and structural parts that require high levels of stiffness, gloss, and impact resistance (Weil and Levchik 2009).

Figure 2-3: Chemical Structure of PC



PPE-HIPS. PPE-HIPS, a polymer blend, imparts a higher heat resistance compared to PS. PPE-HIPS is commonly used for dishwashers, washing machines, hair dryers, cameras, instrument housings, and in television accessories (Harper and Modern Plastics 2000).

2.1.4 Thermosets

Thermosets (also referred to as 'thermoset plastics') undergo an irreversible chemical cross-linking reaction upon curing. Unlike styrenics, polyolefins and thermoplastics, thermosets cannot be reprocessed once they cure/polymerize; they are insoluble in most solvents and can only be broken up by breaking chemical bonds (Mark 2009). While the inability to reprocess thermosets presents some drawbacks, it also gives thermoset plastics enhanced properties that are maintained in extreme conditions (Harper and Modern Plastics 2000). There are several types of thermosets in which decaBDE can be used, including unsaturated polyesters (UPEs), epoxies, and melamine-based resins. The following descriptions provide an overview of each material and their general applications.

UPE. UPEs are produced from maleic anhydrides and alcohols, and are used to produce molding compounds. UPEs contain an unsaturated diacid (typically maleic acid or fumaric acid) which can be cross-linked during the curing process; additionally a reactive solvent/monomer is also added before curing (American Composites Manufacturers Association 2004). Other acids and alcohols are added for desired chemical properties. Typical applications include automotive and building components, commercial connectors, and various household articles (Harper and Modern Plastics 2000; Troitzsch 2004).

Epoxies. Epoxies are co-polymers formed from the reaction of two chemicals: a resin that consists of a short chain polymer with epoxy groupings at either end and a hardening or cross linking agent. The reaction forms a three-dimensional lattice. These epoxies have excellent adhesion properties as well as chemical and heat resistance. As a result, they can be used in thermal insulation as well as in electronics (Mark 2009). Epoxies are used broadly, from high-performance military to commodity commercial applications, such as connectors, relays, printed circuit boards, switches, coils, aircraft skins, and satellite parts (Harper and Modern Plastics 2000).

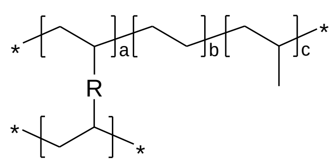
Melamine-Based Resins. Melamine-based resins are a type of amino resin made by combining melamine ($C_3H_6N_6$) with formaldehyde (CH_2O). Melamine-based resins are used as textile-finishing materials to provide wash-and-wear properties to cellulosic fabrics (Howe-Grant 1997b).

2.1.5 Elastomers

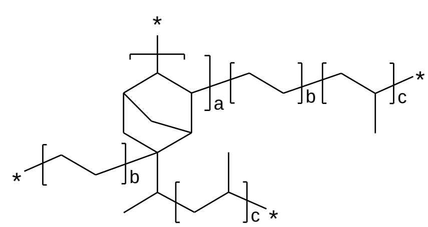
Elastomers are rubberlike materials that can recover their original shape after being stretched or compressed (Howe-Grant 1997c). There are three types of elastomers in which decaBDE can be used: (1) ethylene propylene diene monomer (EPDM) rubber, (2) thermoplastic polyurethanes (TPUs), and (3) EVA[8]. The following descriptions provide an overview of each material and their general applications.

EPDM. EPDM (see Figure 2-4) is a copolymer of ethylene, propylene, and a diene, and is mainly used in automotive applications as radiator hoses and seals; in building and construction as roofing membranes and pond liners; in cable and wire as insulation and jacketing; and in appliances as molded components (Howe-Grant 1997c; Ciesielski 2000).

Figure 2-4: Chemical Structure of EPDM Polymer



EPDM



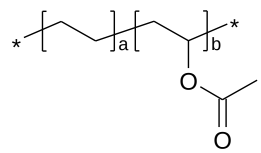
Common Example of EPDM.
Note: “a” is small compared to “b” and “c”.

TPUs. TPUs contain carbamate groups, also referred to as urethane groups, in their backbone structure (Howe-Grant 1997f). The mechanical properties of TPUs fall between rubber polymers and thermoplastics, and they are made into products through injection or extrusion. TPUs have a variety of uses in automobiles, as well as in medical equipment, wire and cable, and other applications (Randall 2010).

[8] EVA is a copolymer of ethylene (an olefin) and vinyl acetate, therefore it is considered to be a polyolefin. However, EVA also has elastomeric properties. For this reason, this report classifies EVA as both a polyolefin and an elastomer.

EVA. EVA (see Figure 2-5) is typically used in 'hot-melt' formulations. EVA based hot-melts have various applications, such as packaging, bookbinding and labeling (SpecialChem 2011).

Figure 2-5: Chemical Structure of EVA



2.1.6 Waterborne Emulsions and Coatings

There are three types of waterborne emulsions and coatings in which decaBDE can be used: acrylic, PVC and ethylene vinyl chloride, and urethane. The following descriptions provide an overview of each material and their general applications.

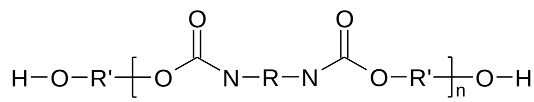
Acrylic. Acrylic emulsions are aqueous, anionic, emulsion-polymerized dispersions of acrylate copolymers. According to a manufacturer website, acrylic emulsions are used for their heat sealability, resistance to heat and light discoloration, good initial color and clarity, and overall durability (Lubrizol 2011). Acrylic emulsions may fade over time, depending on the quality of the colorants or pigments used (Jones 2004; Friddle 2011). Acrylic emulsions span a wide range of polymer and end-use properties. While acrylic emulsions are frequently used in nonwoven and paper saturation applications, many are equally applicable for paint and coatings applications. These formulations can be molded into very soft, flexible coatings or very hard, stiff coatings (Friddle 2011).

PVC and Ethylene Vinyl Chloride. Vinyl chloride emulsions are aqueous anionic dispersions of vinyl chloride and copolymers. These emulsions are primarily designed for coating, impregnation and saturation of fibrous materials such as paper, nonwovens and textiles. Their heat reactive nature poses excellent adhesion to various substrates, and they are commonly used in wall covering and resilient flooring (Friddle 2011).

Vinyl chloride polymers are used in textile coatings, nonwovens, paper, paints, and graphic arts applications. Ethylene vinyl chloride polymers are used in a variety of adhesive applications, such as paper packaging, wood bonding, furniture, book binding, wall and ceiling coverings, flooring, consumer glues, and film laminates (Friddle 2011).

Urethane. Polyurethanes (see Figure 2-6) are the most well-known polymers used to make foams, though they can also be elastomers. Polyurethane materials are commonly formulated as paints or finishing coats to protect or seal wood and textiles (Friddle 2011).

Figure 2-6: Chemical Structure of Polyurethane



2.2 Uses of decaBDE

The purpose of this section is to highlight the various uses of decaBDE. The profile of industries and products using decaBDE has changed in recent years, mainly due to changing international and state-based regulations. Segmentation of decaBDE uses by weight in the U.S. is suggested to be 26 percent for textiles, 26 percent for automotive/transportation, 26 percent for building and construction, 13 percent for electrical and electronic equipment, and 9 percent for other uses (Levchik 2010). This data does not include imports of manufactured goods into the U.S. At the time of publication of this report, this data was the most conclusive information located in light of the shifting landscape of decaBDE uses in certain industries and products. For information on exposure to flame retardants due to the use of these products, see Chapter 5. The uses of decaBDE outlined in this chapter are global uses, however, in regards to any regulatory statutes which require the use of flame retardants in this report, these are more U.S. based unless otherwise stated.

Many electronics manufacturers have moved away from using decaBDE in HIPS, especially in Europe, where the Restriction of Hazardous Substances (RoHS) Directive has banned the use of decaBDE in electronics with certain exemptions (Council of the European Union 2003; Washington State Department of Health 2008; Council of the European Union 2011). A use profile of decaBDE for the years prior to RoHS was not available when this report was compiled. However, in 2003 it was estimated that 80 percent of decaBDE was used in electronics (which included television enclosures, central processing unit housing and wire and cable) and 10 to 20 percent of decaBDE was used in textiles (which included upholstered furniture and automotive upholstery) (Hardy 2003). Additionally, although HIPS containing decaBDE was once used in office machines such as printers, copiers, and fax machines, these products are now made using other types of plastics that do not contain decaBDE (Pure Strategies Inc. for Maine Department of Environmental Protection 2010). To the best of our knowledge decaBDE was not used in mattresses or polyurethane foam for furniture, but can be used in textile back-coatings for furniture (Trainer 2010). For further information on flame retardants for polyurethane foam, refer to the *Profiles of Chemical Flame-Retardant Alternatives for Low-Density Polyurethane Foam* report (U.S. EPA 2005).

2.2.1 Electrical and Electronic Equipment

Box 2-1 DecaBDE is, or has been, used in the following electric and electronic applications:

- Housings and internal components of TVs
- Mobile phones and fax machines
- Audio and video equipment
- Remote controls
- Communications cables
- Capacitor films
- Building cables
- Wire and cable, e.g., heat shrinkable tubes
- Connectors in electrical and electronic equipment
- Circuit breakers
- Coils of bobbins (i.e., for use in transformers)
- Printing and photocopy machine components – e.g., plastic housing for toner cartridges
- Scanner components

Source: Bromine Science and Environmental Forum 2007

Historically, most decaBDE was used in electrical and electronic equipment in plastic casings, wire and cable and small electrical components to meet fire safety standards (see Table 2-2). The main use of decaBDE was in the front and back panels of televisions made of HIPS (Levchik 2010). Additionally, decaBDE was often used in electronic connectors made from glass-filled PBT or nylons (Levchik 2010). With the European RoHS Directive, many global companies have phased out decaBDE in these uses.

Despite this transition, decaBDE is still used in a variety of electronic equipment including household appliances and tools such as vacuum cleaners (in both the casings and internal components) and washing machines (internal components only) because the markets for these products are more domestic than global and European Union regulations have not impacted the use of decaBDE in these products as significantly (Levchik 2010). In these appliances, the housings are typically made from PP, HIPS or ABS.

Another use of decaBDE is in small electrical parts, such as light sockets or decorative lights (e.g., Christmas lights), and wires and cables. These products are usually made from high density PE, PP or PPE (Levchik 2010). DecaBDE is also used in the plastics PBT and PA, which are found in electrical, automotive, and plumbing parts such as housings, switches and other small inner parts of larger electrical equipment (Weil and Levchik 2009). DecaBDE is also commonly used in electrical components of cars and airplanes, which will be discussed in Section 2.2.4.

2.2.2 Textiles

Another major use of decaBDE is in textiles. Flame retardants are applied to textiles in order to meet required flammability standards (see Table 2-2). They are often applied to the back of a fabric as part of a coating that also contains antimony trioxide in an acrylic or EVA copolymer (Pure Strategies Inc. for the Lowell Center for Sustainable Production 2005).

Box 2-2 DecaBDE is or has been used in the following textile applications:

- Transportation
  - Public transit busses
  - Trains
  - Airplanes
  - Ships
- Public occupancy spaces
  - Draperies of theatres, hotels, conference rooms, student dormitories
- High-risk occupancy areas
  - Furniture of nursing homes, hospitals, prisons, hotels
- Military
  - Tarps
  - Tents
  - Protective clothing

Source: Bromine Science and Environmental Forum 2007

The uses of decaBDE in textiles for the automotive and aviation sectors are discussed in more detail in Section 2.2.4. DecaBDE is not used in consumer clothing (e.g., children's pajamas) (Pure Strategies Inc. for the Lowell Center for Sustainable Production 2005) or in residential carpet (Levchik 2010). Residential carpet is mainly flame retarded by addition of aluminium hydroxide to the back coating. Children's pajamas often meet flammability standards without the use of flame retardants. This is because children's pajamas need to pass the Consumer Product Safety Commission (CPSC) ignition test (three seconds of flame exposure), which can be passed by synthetic fabrics without addition of any flame retardant (Levchik 2010).

Box 2-3 DecaBDE is used in the following building and construction applications:

- Pipes
- Lamp holders
- Stadium seats
- Reinforced plastics
- Switches and connectors
- Facing laminates for insulation panel
- Film for use under the roof and to protect building areas
- Electrical ducts and fittings
- Components in analytical equipment in industrial
- Medical laboratories
- Air ducts for ventilation systems
- Pillars for telephone and communication cables

Source: Bromine Science and Environmental Forum 2007

2.2.3 Building and Construction

DecaBDE is used in wall and roof panels, which are typically made from UPE glass composites; floor tiles; and commercial grade carpeting. DecaBDE is also used in insulation materials, foamed polyolefins, and in roofing materials such as membranes and films for use under roofs to protect building areas. DecaBDE can also be found in ducting elements such as the duct covering or insulation.

2.2.4 Transportation

In automobiles, decaBDE is added to plastics used to house and insulate electrical and electronic equipment under the hood. There are no broad federal fire safety standards or regulations for these applications; safety standards are established by each manufacturer. Interior materials, such as cushioning and fabric must meet the Federal Motor Vehicle Safety Standard (FMVSS) No. 302 (U.S. Department of Transportation and National Highway Traffic Safety Administration 1972; Levchik 2010). DecaBDE may also be used in parts of the heating, ventilation, and air conditioning system close to or in contact with electrical parts (Levchik 2010).

In aircraft, decaBDE is used in electrical and electronic equipment (Levchik 2010), and interior components. Materials used on aircraft must meet Federal Aviation Administration (FAA) Technical Standard Orders (FAA 2010).

DecaBDE was likely also used in electronic parts for trains, ships, and elsewhere in the transportation industry for which there was not direct stakeholder representation in the partnership.

Box 2-4: DecaBDE is used in the following aviation and automotive applications

Aviation uses:

- Electrical wiring and cables
- Interior components
- Electric & electronic equipment
  - Navigation and telecommunications equipment
  - Computers and computer devices
  - Audio and video equipment
  - Electrical connectors
  - Galley appliances
  - Housings and internal components of entertainment units
  - Remote controls
  - Communications cables
  - Capacitor films
  - Cables
  - Circuit breakers
  - Cartridges and connectors
  - Air ducts for ventilation systems
  - Electrical ducts and fittings
  - Switches and connectors

Automotive uses:

- Electrical & electronic equipment
  - Battery cases
  - Battery trays
  - Engine controls
  - Electrical connectors
  - Components of radio, disk, GPS and computer systems
- Reinforced plastics
  - Instrument panels
  - Interior trim
- Under hood and internal parts
  - Terminal/fuse block
  - Higher amperage wire and cable jacketing (ignition wires)
- Fabric back coating
  - Rear deck
  - Upholstery
  - Sun visor
  - Head rest
  - Trim panel

Source: Bromine Science and Environmental Forum 2006; Baker 2011

2.2.5 Storage and Distribution Products

There are approximately three billion shipping pallets in use in the U.S., of which over 900 million are plastic (Pure Strategies Inc. for Maine Department of Environmental Protection 2010). According to the National Fire Protection Association (NFPA), plastic pallets that have not been treated with flame retardants are considered a greater fire hazard than wooden pallets. Plastic pallets are typically made of polyolefins, which are very combustible if they are not flame retarded.

Additionally, the International Fire Code (IFC), a widely adopted fire code but separate from the NFPA, requires plastic pallets be protected by an approved specialized engineered fire protection system unless they meet Underwriters Laboratory (UL) 2335 standards (see Table 2-2). Even though wood ignites at a lower temperature than plastic, once a fire begins, plastic burns at a higher temperature, and thus releases more heat (Pure Strategies Inc. for Maine Department of Environmental Protection 2010). NFPA 13 and IFC provide the basis for all state and local fire prevention laws and regulations governing warehouse construction and management throughout the country (Pure Strategies Inc. for Maine Department of Environmental Protection 2010).

To comply with fire standard NFPA 13, plastic pallets must comply with one of the two following options: (1) users must implement systems such as pallet storage management practices (e.g., how high the pallets are stacked and how close together stacks of pallets are) or sprinkler systems in warehouses that make it as safe as wooden pallets to use non-flame retarded plastic pallets, or (2) the pallets must pass tests consistent with American National Standards Institute/Factory Mutual (FM) 4996 (see Table 2-2) that demonstrate that the fire hazard of the plastic pallet or other material handling product is less than or equal to the fire hazard of a wooden pallet (FM Approvals 2013). In order to meet the fire code specifications, flame retardants, often decaBDE, are integrated into plastic pallets to reduce the pallet’s fire hazard (Levchik 2010; Pure Strategies Inc. for Maine Department of Environmental Protection 2010).

2.3 Flammability Tests

DecaBDE is used as a flame retardant in certain products in the U.S. either because of state or federal fire safety standards or for insurance purposes. Rather than specifying what flame retardants should be used, such standards specify the performance standards a product must meet under fire stress (Posner and Boras 2005). The stringency of the standard varies depending on the application (e.g., flammability requirements established for aircraft are much more stringent than those for clothing). Furthermore, decaBDE is sometimes added to products even without manufacturer requirements due to concerns for brand image and market pressure (Illinois Environmental Protection Agency 2007). Flammability standards may be developed by a variety of entities, including regulatory agencies such as the CPSC, or companies such as UL.

Table 2-2 provides a brief overview of the flammability tests required for a variety of products in which decaBDE is used. This list is not comprehensive but does address many of the standards which lead to the use of decaBDE in the sectors discussed above.

Table 2-2: Summary of Flammability Tests Relevant to decaBDE Uses.

Test	Sectors and Products that Use Test	Description
UL 94	**Electrical and Electronic Equipment:** electronic enclosures	Assesses resistance to ignition from small internal (short circuit) or external (candle) ignition source. Small scale ignition resistance test.
UL 746 pt C	**Electrical and Electronic Equipment:** plastics in electronics and electrical parts	Based on UL 94.
NFPA 701	**Textiles:** public occupancy spaces: e.g., draperies of theatres, hotels, conference rooms, student dormitories	Assesses the propagation of a flame beyond the area exposed to the ignition source. A burner flame is applied for 45 seconds. To pass the test an average weight loss for ten specimens must be less than forty percent and fallen fragments should not burn more than two seconds.
California Technical Bulletin 133	**Textiles:** high risk occupancy areas: e.g., furniture of nursing homes, hospitals, prisons, hotels	Uses a full scale piece of furniture or mock up. Designed as a screening test. The fabric is exposed to a 1.5 inch methane flame for twelve seconds. Drips, burn time and char lengths are monitored along with temperature, mass lost, smoke and carbon monoxide.
FM 4880	**Building and Construction:** public occupancy decorative wall and roof panels	Uses 750 lbs. of wood crib. The test ends when the flame reaches the structural limits or the crib stops burning. Tested material must not support self-propagating fire reaching structural limits.
American Society for Testing and Materials (ASTM) E-84	**Building and Construction:** insulation materials, foamed polyolefins, membranes, films sheets, ducting elements, ducts covering and insulation	Assesses the flame spread and smoke index. The tested material is mounted on the ceiling of the tunnel. Two gas burners are applied for ten minutes. The flame spread index and smoke index are calculated in relation to the flame spread and smoke density of red oak panels and concrete.
ASTM E648-10e1	**Building and Construction:** public occupancy floor tiles and carpeting	Measures the critical radiant flux, which is the minimum heat flux needed for materials to propagate the flame. The burning distance is converted to a critical radiant flux through the known flux distribution along the length of the test sample.
FMVSS 302	**Automotive and Aviation:** car seats, headliners, carpets, door panels, dash panels	Assesses flame spread from cigarettes and matches in the passenger compartment. A 1.5 inch flame is applied for fifteen seconds and flame travel and its speed on a horizontal specimen is recorded.
14 Code of Federal Regulations (CFR) Part 25 regulations: Sections 25.853, 25.855, 25.856, 25.869, Appendix F	**Aviation:** flooring, sidewalls, baggage compartment, insulation, ducting, interior parts, wiring	Materials and parts must successfully pass test(s) in order to show compliance. Nine different tests are specified in the CFR and some materials/parts must pass multiple tests. Variations of configurations require individual testing. For specific details on the flammability tests see Appendix F of 14 CFR Part 25.

Test	Sectors and Products that Use Test	Description
UL 2335	**Shipping Pallets**	Assesses the performance of plastic pallets under fire stress. The goal of this test is to match the performance of plastic pallets to wood pallets. Six pallet stacks are ignited in the middle. The time to activate the first and last sprinkler, the number of sprinklers activated and the temperature at the ceiling are all recorded. Sprinklers are mounted above the stacks and are activated at 165^{o}F. To pass the test no more than six sprinklers can be activated.
FM 4996	**Shipping Pallets**	This standard sets fire performance requirements for plastic pallets so that they can be assigned a classification as equivalent to wood pallets in an effort to determine the demand on a sprinkler system in the event of a fire. The test consists of eight stacks of pallets placed in a specified arrangement. Ignition is provided by four igniters placed at the center of the array. Water is applied to the test array by a simulated sprinkler. A calorimeter and water application apparatus determine the quantities of water need to supress and control the fire. The performance criteria require that the fire must be controlled when a water application density of 0.15 gallons per minute/ft^2 is applied and that the controlled fire will not continue to grow within the 10 minute test frame. If the pallets tested meet or exceed the performance criteria, it is designated "equivalent to wood."

Source: FM Approvals 2013; Levchik 2010; Baker 2011

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