Project Report

Enhancing Trilateral Understanding of Flame Retardants and Their Use in Manufactured Items

Supply Chain Analysis of Select Flame Retardants Contained in Manufactured Items Used in Indoor Environments

Summary Report – Phase I

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List of Abbreviations and Acronyms

ABS	Acrylonitrile butadiene styrene
AHFA	American Home Furnishings Alliance
BFRs	Brominated flame retardants
CAS	Chemical Abstracts Services
CDR	Chemical Data Reporting
CEC	Commission for Environmental Cooperation
CFRs	Chlorinated flame retardants
DBDPE	1,1'-(Ethane-1,2-diyl)bis[2,3,4,5,6-pentabromobenzene]; or decabromodiphenyl ethane
EPA	United States Environmental Protection Agency
FPF	Flexible polyurethane foam
HBCD	Hexabromocyclododecane
HIPS	High-impact polystyrene
IUR	Inventory Update Reporting
PentaBDE	Pentabromodiphenyl ether
PIP	Phenol, isopropylated, phosphate (3:1)
PUF	Polyurethane foam
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SVHC	Substances of Very High Concern
TB	Technical Bulletin
TBB	2,3,4,5-Tetrabromobenzoic acid 2-ethylhexylester
TBE	1,1'-[Ethane-1,2-diylbis(oxy)]bis[2,4,6- tribromobenzene]; or 1,2-bis(2,4,6-tribromophenoxy) ethane
TBEP	Ethanol, 2-butoxy-, phosphate (3:1)
TCEP	Tris(2-chloroethyl) phosphate
TCP	Phosphoric acid, tris(methylphenyl) ester
TCPP	2-Propanol, 1-chloro-, phosphate
TDCPP	2-Propanol, 1,3-dichloro-, phosphate (3:1)
TEP	Phosphoric acid, triethyl ester
TPP	Triphenyl phosphate
TPU	Thermoplastic polyurethane

Abstract

Flame retardants are chemical compounds that exhibit properties that prevent or delay the development of flames in items manufactured for use in indoor settings. These chemical compounds can either chemically react or physically bind to the components of manufactured items, such as plastics, textiles, and coatings—which pose a risk of spreading flames. This study evaluates the availability of information for 46 flame retardants of interest to the Commission for Environmental Cooperation (CEC) of North America and presents publicly-available supply chain information for 16 targeted flame retardants, including available information on the global and North American drivers of flame retardants, the prevalence of these flame retardants in respective markets, and existing regulations that affect their use in manufactured items. This study also provides a more in-depth view of the North American polyurethane foam industry—from the use of flame retardants in polyurethane foam manufacturing, to incorporation of the foam into manufactured items marketed for commercial and consumer use, and ultimately, to the end-of-life management of the foam, particularly in upholstered furniture.

Introduction

The Commission for Environmental Cooperation (CEC) is an intergovernmental organization created by Canada, Mexico, and the United States (US) under the North American Agreement on Environmental Cooperation (NAAEC). The Commission was established to address regional environmental concerns, help prevent potential trade and environmental conflicts, and promote effective enforcement of environmental law.

The CEC's Council—its governing body—approved a project entitled Enhancing Trilateral Understanding of Flame Retardants and Their Use in Manufactured Items as part of the Operational Plan for 2013-2014 because international and North American communities have recognized that chemicals in products (including flame retardants) can have a significant and adverse effect on the environment and human health. The results will be used to inform future risk management decisions; contribute to the longer-term environmental goal of reducing significant adverse impacts of chemicals of common interest; and reduce people's exposure to these chemicals throughout North America.

Study Objectives

The CEC and the project team (consisting of representative members of Canadian, Mexican, and United States agencies responsible for managing chemicals) identified an initial list of 46 flame retardants of common interest for further study to inform future risk evaluations (see Table 1. Forty-six Flame Retardants of Common Interest).[1] To improve the efficiency of the effort, the study team conducted a preliminary review of readily available information for each specific chemical [this review, summarized in the present report, is phase 1 of the project], with the goal of identifying a subset of chemicals for more-detailed study [in phase 2].

One of the primary objectives of this study was two-fold: to identify products containing these flame retardants and to ascertain the amount of flame retardant in each product. More specifically, the goal was to identify the primary international manufacturers of the 46 chemicals, determine their location (with a particular focus on characterizing markets in Asia), and trace the movement of a subset of 16 of the 46 flame retardants from manufacture, through the supply chain, to final specific manufactured items imported into North America. The final manufactured items containing the flame retardants were to be identified as specifically as possible, including descriptions of the items, their uses, trade names, and North American retailers (focusing on manufactured items in indoor environments; commercial buildings are explicitly outside the scope).

A second primary objective was to contact North American representatives of the polyurethane foam industry and obtain information and perspectives on the current and future use of flame retardants in foam (focusing on foam used in residential upholstered furniture). The goal was to contact at least three flexible polyurethane foam manufacturers, three manufacturers of side B components of rigid polyurethane foam insulation, three manufacturers of rigid spray polyurethane and polyisocyanurate foam insulation, and six product formulators/processors. The purpose was to identify specific end-use manufactured items that contain the flame retardants and would be potential candidates for product testing in the second phase of this project.

A third objective was to gather information on existing regulations and flame retardancy standards that affect the use of flame retardants in different categories of manufactured items.

[1] This table, and others in the report, lists these chemicals by their unique numbers assigned by the Chemical Abstracts Service (CAS) Registry, as well as by common synonyms, and by an internal reference number included to aid in cross-referencing chemicals in other sections of this report.

Publicly available market information and non-confidential data collected from government and industry sources, supplemented with primary data and insights provided by industry representatives throughout the supply chain, were gathered to assist in accomplishing these goals.

Table 1. Forty-six Flame Retardants of Common Interest

Reference Number	CAS Number	Chemical Name
1	13674-84-5[a]; 6145-73-9 (isomeric mixture)	2-Propanol, 1-chloro-, phosphate (TCPP); 1-Propanol, 2-chloro-, phosphate
2	13674-87-8	1,3-Dichloro-2-propanol phosphate (3:1) (TDCPP)
3	26040-51-7	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-bis(2-ethylhexyl) ester (TBPH)
4	84852-53-9	1,1'-(ethane-1,2-diyl)bis[2,3,4,5,6-pentabromobenzene]; Decabromodiphenyl ethane (DBDPE); 1,2-Bis(pentabromophenyl) ethane
5	183658-27-7	2,3,4,5-Tetrabromobenzoic acid 2-ethylhexyl ester (TBB)
6	77-47-4	1,3-Cyclopentadiene, 1,2,3,4,5,5-hexachloro-; Hexachlorocyclopentadiene (HCCPD)
7	78-40-0	Phosphoric acid, triethyl ester; Triethyl phosphate (TEP)
8	78-42-2	Phosphoric acid, tris(2-ethylhexyl) ester; Tris(2-ethylhexyl) phosphate (TEHP)
9	78-51-3	Ethanol, 2-butoxy-, phosphate (3:1); Tris(2-butoxyethyl) phosphate (TBEP)
10	108-78-1	1,3,5-Triazine-2,4,6-triamine (melamine)
11	298-07-7	Phosphoric acid, bis(2-ethylhexyl) ester
12	1330-78-5	Phosphoric acid, tris(methylphenyl) ester; Tricresyl phosphate (TCP)
13	3278-89-5	Allyl 2,4,6-tribromophenyl ether (ATE)
14	13560-89-9	1,4:7,10-Dimethanodibenzo[a,e]cyclooctene, 1,2,3,4,7,8,9,10,13,13,14,14-dodecachloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-dodecahydro-; 1,2,3,4,7,8,9,10,13,13,14,14-dodecachloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-dodecahydro-1,4:7,10-Dimethanodibenzo[a,e]cyclooctene; Dechlorane Plus
15	25155-23-1	Phenol, dimethyl-, phosphate (3:1)
16	26446-73-1	Phosphoric acid, bis(methylphenyl) phenyl ester
17	29761-21-5	Phosphoric acid, isodecyl diphenyl ester
18	32588-76-4	1H-Isoindole-1,3(2H)-dione, 2,2'-(1,2-ethanediyl)bis[4,5,6,7-tetrabromo-; Ethylene bistetrabromo phthalimide (BT-93); (EBTBP)
19	56803-37-3	Phosphoric acid, (1,1-dimethylethyl)phenyl diphenyl ester

Table 1. Forty-six Flame Retardants of Common Interest (continued)

Reference Number	CAS Number	Chemical Name
20	68527-01-5	Alkenes, C12-30 α-, bromo chloro
21	68527-02-6	Alkenes, C12-24, chloro
22	68937-41-7	Phenol, isopropylated, phosphate (3:1) (PIP)
23	77098-07-8	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-; 3,4,5,6-Tetrabromo-1,2-benzenedicarboxylic acid, mixed esters with diethylene glycol and propylene glycol; Tetrabromophthalate Diol (TBPA Diol, mixed esters)
24	20566-35-2	2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromobenzenedicarboxylate; 2-(2-hydroxyethoxy)ethyl 2-hydroxypropyl ester; 2-(2-hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate
25	7415-86-3	Bis(2,3-dibromopropyl) phthalate;1,2-Bis(2,3-dibromopropyl) ester; 1,2-Benzenedicarboxylic acid
26	115-96-8	Tris(2-chloroethyl) phosphate (TCEP)
27	25637-99-4; 3194-55-6	Hexabromocyclododecane (HBCD) and related congeners
28	3194-57-8	1,2,5,6-Tetrabromocyclooctane
29	58965-66-5	1,2,4,5-tetrabromo-3,6-bis(pentabromophenoxy)benzene; Tetradecabromo-1,4-diphenoxybenzene
30	61262-53-1	1,1'-[Ethane-1,2-diylbis(oxy)]bis[2,3,4,5,6-pentabromobenzene]; 1,2-bis(2,3,4,5,6-pentabromophenoxy)ethane
31	37853-59-1	1,1'-[Ethane-1,2-diylbis(oxy)]bis[2,4,6-tribromobenzene]; 1,2-bis(2,4,6-tribromophenoxy)ethane (TBE)
32	25713-60-4	2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine
33	35109-60-5	Benzene, 1,3,5-tribromo-2-(2,3-dibromopropoxy)-; 1,3,5-Tribromo-2-(2,3-dibromopropoxy)benzene (DPTE)
34	21645-51-2	Aluminum hydroxide
35	68333-79-9	Polyphosphoric acids, ammonium salts; Ammonium polyphosphate
36	1309-64-4	Antimony trioxide
37	1332-07-6	Zinc borate
38	78-33-1	Phenol, 4-(1,1-dimethylethyl)-, 1,1',1''-phosphate
39	26265-08-7	Phenol, 4,4'-(1-methylethylidene)bis[2,6-dibromo-, polymer with (chloromethyl)oxirane and 4,4'-(1-methylethylidene)bis[phenol] (the reaction product of TBBPA); D.E.R. 538; Sumiepoxy ESB 600

Table 1. Forty-six Flame Retardants of Common Interest (continued)

Reference Number	CAS Number	Chemical Name
40	115-86-6	Triphenyl phosphate
41	38051-10-4	Phosphoric acid, P,P'-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P'P'-tetrakis(2-chloroethyl) ester
42	7782-42-5; 12777-87-6	Expandable graphite
43	26444-49-5	Phosphoric acid, methylphenyl diphenyl ester
44	2781-11-5	Phosphonic acid, P-[[bis(2-hydroxyethyl)amino]methyl]-, diethyl ester
45	184538-58-7	Phosphoric acid, triethyl ester, polymer with oxirane and phosphorus oxide (P2O5)
46	125997-21-9	Resorcinol bis-diphenylphosphate

[a] CAS number 13674-84-5 is TCPP, the primary constituent (>90%) in a mixture of isomers that also contains CAS number 6145-73-9, an isomer that exists in trace amounts. The isomers are not isolated for separate commercial use and are generally marketed as TCPP.

Overall Summary

A detailed search strategy was developed to acquire the information needed to accomplish the three primary goals and inform recommendations of manufactured items likely to contain the flame retardants of interest. Approximately 300 information sources were identified and reviewed. These include, but are not limited to: online market data, peer-reviewed literature, conference proceedings, risk assessment and related reports, experimental studies pertaining to flame retardant testing, market studies, corporate brochures, Internet websites, and government inventories and reporting databases. To supplement information from the literature review, industry, academic, and government experts were identified, and interviews with several of these contacts were conducted to acquire information and insights regarding the markets of interest.

A substantial amount of data and other information were collected that may be useful in evaluating the supply chain for the chemicals of interest, identifying data gaps, and targeting future work. Several factors, however (discussed at the end of this Executive Summary), precluded a full characterization of the supply chains for specific chemicals, as originally intended in order to meet the study objectives. While these factors make it difficult to determine conclusively which specific chemicals of interest are present in which specific brand name products used in North America, the report provides a reasonable basis for identifying products that are likely to contain the flame retardants.

This Executive Summary summarizes the information that was collected and used to characterize the flame retardant supply chain and make reasonable inferences pertaining to manufactured items that may contain the 16 flame retardants of interest.

Approach to Identifying 16 Flame Retardants for Targeted Review

As noted above, the study began with an initial list of 46 flame retardant chemicals. A methodology was developed to rank and evaluate these chemicals, with the chemicals of highest interest then subjected to a more detailed supply chain analysis. The ranking approach was quantitative, assigning each chemical a numerical score for each one of four criteria (or evaluation categories). This enabled a direct comparison of the nature and scope of readily available information that was gathered for each of the 46 flame retardants. The four criteria are as follows:

- Flame Retardants of Highest Interest. Chemicals of greatest common interest to the individual countries were identified and assigned a high ranking.
- Availability of Analytical Methods. Analytical methods to characterize the 46 flame retardants are not common and few accepted methods are known. Therefore, each chemical was evaluated to determine whether test methods are available or are under development for their measurement, and whether laboratories are capable of analyzing for the chemical. Chemicals for which analytical methods exist and laboratory capabilities were known earned a high score.
- Demand for the Flame Retardant. Market information pertaining to the quantity manufactured and associated use patterns of each flame-retardant category was evaluated. Chemicals within the categories with expected high production volumes were assigned a high score.
- Market Penetration and Availability of Information. Preliminary information identifying the potential use patterns in different manufactured items and end markets was evaluated. Chemicals with expected widespread use (and potential for significant consumer exposure) were assigned a high score.

Category scores were summed to provide an overall total score for each of the 46 chemicals. The scores and sub-scores were not used as a strict rationale for selecting the subset for further review; rather they were used to inform the Project Team's deliberation, which led to the selection of the 16 flame retardants to be studied in more detail, as presented in Table 2. Sixteen Flame Retardants Selected for Targeted Review.

Table 2. Sixteen Flame Retardants Selected for Targeted Review

Reference No.	FR Group (or Category)	CAS Number	Chemical Name
1	Chlorinated Phosphorus	13674-84-5[a]; 6145-73-9	2-Propanol, 1-chloro-, phosphate (TCPP) and 1-Propanol, 2-chloro-, phosphate
2	Chlorinated Phosphorus	13674-87-8	1,3-Dichloro-2-propanol phosphate (3:1) (TDCPP)
3	Brominated	26040-51-7	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-bis(2-ethylhexyl) ester (TBPH)
4	Brominated	84852-53-9	1,1'-(ethane-1,2-diyl)bis(2,3,4,5,6-pentabromobenzene); Decabromodiphenyl ethane (DBDPE)
5	Brominated	183658-27-7	2,3,4,5-Tetrabromobenzoic acid 2- ethylhexyl ester (TBB)
7	Phosphorus	78-40-0	Phosphoric acid, triethyl ester; Triethyl phosphate (TEP)
9	Phosphorus	78-51-3	Ethanol, 2-butoxy-, phosphate (3:1) ; Tris(2-butoxyethyl) phosphate (TBEP)
12	Phosphorus	1330-78-5	Phosphoric acid, tris(methylphenyl) ester; Tricresyl phosphate (TCP)

Table 2. Sixteen Flame Retardants Selected for Targeted Review (continued)

Reference No.	FR Group (or Category)	CAS Number	Chemical Name
16	Phosphorus	26446-73-1	Phosphoric acid, bis(methylphenyl) phenyl ester
22	Phosphorus	68937-41-7	Phenol, isopropylated, phosphate (3:1) (PIP)
23	Brominated	77098-07-8	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-; 3,4,5,6-Tetrabromo-1,2-benzenedicarboxylic acid, mixed esters with diethylene glycol and propylene glycol; Tetrabromophthalate Diol (TBPA Diol)
24	Brominated	20566-35-2	2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromobenzenedicarboxylate; 2-(2-hydroxyethoxy)ethyl 2-hydroxypropyl ester (HEEHP-TEBP)
26	Phosphorus	115-96-8	Tris(2-chloroethyl) phosphate (TCEP)
27	Brominated	25637-99-4 3194-55-6	Hexabromocyclododecane (HBCD) and related congeners
31	Brominated	37853-59-1	1,1'-[1,2-Ethanediylbis(oxy)]bis[2,4,6- tribromobenzene] or 1,2-bis (2,4,6- Tribromophenoxy) ethane (TBE)
40	Phosphorus	115-86-6	Triphenyl phosphate (TPP)

[a] CAS number 13674-84-5 is TCPP, the primary constituent (>90%) in a mixture of isomers that also contains CAS number 6145-73-9, an isomer that exists in trace amounts. The isomers are not isolated for separate commercial use and are generally marketed as TCPP.

An in-depth review of the data sources was conducted for each of these 16 chemicals, encompassing publicly available information on production and use, applications in intermediate goods and manufactured items, respective product concentrations, and trade flows. To understand in more detail the impacts of global imports into North America, contacts were made with global manufacturing firms with production facilities in the Asia-Pacific region, which represents a large share of global flame retardant demand. North American trade associations and individual companies involved in various stages of the supply chain were also engaged, including flame retardant manufacturers, polyurethane manufacturers, foam manufacturers, and manufacturers of residential upholstered furniture.

Key Findings

Information from approximately 300 resources was collected and compiled for use in the study. This includes information pertaining to flame retardant use in general, global flame retardant markets, and market flows. A general conclusion of this review was that market data on individual chemicals are very limited, precluding a complete characterization at the chemical-specific level. However, aggregated data representing categories of flame retardants (which include the chemicals of interest) are often reported. Data at the category level are useful because they can inform analyses of the specific chemicals of interest, and may also be useful in future efforts. Key findings from the review are summarized in this section.

Summary of North American Production and Import Data

The Freedonia Group estimates demand for all classes of flame retardants in North America at 443,500 tonnes in 2011 (Freedonia 2013). The largest share of flame retardant demand is in alumina trihydrate, followed by boron, phosphorous, and brominated compounds.

Canada's demand is approximately 37,000 tonnes (Freedonia 2013). However, publicly available data quantifying the current production, import, and demand volume in Canada at the chemical-specific level could not be identified. The consensus opinion of industry representatives contacted for this study, however, is that Canadian manufacture of the 16 chemicals of interest is very limited. Representatives of the three largest global flame retardant manufacturers with operations in North America stated that they were not aware that any of these 16 flame retardant chemicals were being manufactured in Canada. However, most of these chemicals are expected to be found in both intermediate and finished goods sold in Canada.

Overall, Mexican demand for flame retardants in 2011 was estimated at 36,000 tonnes (Freedonia 2013). Domestic manufacturing of flame retardants in Mexico is very limited, however, and most use is via import of raw materials. Only one company, Chemtura Corporation México S. de R.L. de C.V., was identified as a possible manufacturer of flame retardants in Mexico. Similarly to the situation in Canada, industry contacts from the larger global flame retardant manufacturing companies confirmed that the flame retardants of interest are not manufactured in Mexico by their companies, and they are also not aware of any smaller manufacturers producing them. Table 3. presents data collected on Mexican imports of selected flame retardants of interest.

US demand for flame retardants totaled 370,000 tonnes in 2011 (Freedonia 2013). In contrast to Canada and Mexico, data for individual chemicals are publicly available in the US These data can be found in the US Chemical Data Reporting (CDR) program and its predecessor, the Inventory Update Reporting (IUR) program.[2]

[2] Confidentiality claims sometimes limit the level of detail that can be released through these programs, particularly for chemicals that are manufactured or imported by a small number of reporting entities. For example, production and import volumes may be aggregated and reported as a range, rather than as specific volumes for individual chemicals.

Table 3. Flame Retardants Imported into Mexico, 2009–2013

Reference No.	CAS Number	Number of Import Sites Identified	Imports by Year (tonnes)				
			2013	2012	2011	2010	2009
40	115-86-6	11	70	1	3	<1	<1
12	1330-78-5	12	<1	<1	<1	<1	1
1	13674-84-5	5	240	160	82	40	20
24	20566-35-2	1	<1	0	0	0	0
27	25637-99-4	3	19	<1	0	0	36
7	78-40-0	7	5	0	0	3	0
9	78-51-3	19	35	56	52	50	123
4	84852-53-9	3	9	40	32	4	0

Source: Ministry of Economy 2014

According to the 2006 IUR, 11 of the 16 chemicals of interest were manufactured in or imported into the US in 2005. The maximum number of sites manufacturing or importing each chemical was four, and four of the chemicals were associated with only two sites. The highest volume ranges for these chemicals is between 4,540 and 22,700 tonnes, and half the chemicals fall within this range. Volumes for the remaining chemicals are all below 4,540 tonnes (EPA 2014b).

Data submitted under the more recent (2012) CDR show that 15 of the 16 chemicals of interest were manufactured or imported in 2011. Of these, three were only manufactured, eight were manufactured and imported, two were only imported, and it was not known whether the remaining two were manufactured or imported (due to confidentiality claims). The publicly accessible CDR includes the aggregated volume by chemical, across all reporting entities, as long as such data are not protected by the submitters as confidential business information (CBI). A summary of 2012 CDR data is presented in Table 4.

Table 4. Flame Retardant Volumes Manufactured and/or Imported into the United States, 2011

Reference No.	Short Name	CAS Number	Manufacture and/or Import	Number of Sites Identified	2011 Volume (tonnes)
3	TBPH	26040-51-7	Manufacture	>2	454–4,554
4	DBDPE	84852-53-9	Manufacture and Import	>4	22,700–45,454
5	TBB	183658-27-7	Manufacture	Unknown	CBI
7	TEP	78-40-0	Manufacture and Import	7	4,800
9	TBEP	78-51-3	Manufacture and Import	6	454–4,554
40	triphenyl phosphate	115-86-6	Manufacture and Import	>6	4,900
22	PIP	68937-41-7	Manufacture and Import	>3	6,775
12	TCP	1330-78-5	Manufacture and Import	>3	454–4,554

1	TCPP	13674-84-5 6145-73-9	Manufacture and Import	10	24,800
23	-	77098-07-8	Manufacture	1	CBI
27	HBCD	25637-99-4 3194-55-6	Manufacture and Import	>3	CBI
26	TCEP	115-96-8	Import only	1	CBI
16	-	26446-73-1	Import only	1	CBI
2	TDCPP	13674-87-8	Unknown	>2	4,545–22,700
24	-	20566-35-2	Unknown	>2	454–4,554

Source: EPA 2014b.

Note: Non-confidential volume ranges are based on the aggregate of all reported manufactured and imported volumes.

Summary of the Asian Market

The report includes a detailed look at the Asian market and China, in particular. According to The Freedonia Group, the Asia/Pacific region accounts for a combined 38 percent of global flame retardant demand. Within the region, China has the largest, fastest growing, and most dynamic market. Japan and South Korea are the other important markets within Asia (Freedonia 2013).

Contacts with trade associations, global manufacturers, and others familiar with the Asia/Pacific flame retardants chemical market were helpful in identifying leading producers within each of the broader flame retardant categories. With this information, it was possible to locate some suppliers of individual chemicals using sources such as public websites advertising commodity chemicals for sale. Although this was insufficient to characterize overall production and export activity levels for these chemicals, substantial additional information is presented in the full report. There is also supporting documentation that can be used to understand the Asian market and identify categories of flame retardants that are most prevalent in production and use. This information can help to infer use patterns of specific flame retardants within the categories and suggest which manufactured items incorporate them. The paragraphs below summarize market data for China, Japan, and South Korea.

China is a leading producer of both chlorinated and antimony-based flame retardants, and exports antimony-based materials, in particular, globally (Freedonia 2013). Production of brominated and phosphorous flame retardants in China is also on the rise. While markets in other parts of the world are dominated by large global producers, production in China appears to be more fragmented. Public data sources as well as industry contacts indicate there are many small to medium-size manufacturers that often specialize in the production and/or distribution of a small number of flame retardants on an as-needed, made-to-order basis to local customers. These customers incorporate flame retardants into intermediate goods and manufactured items that may be sold domestically or exported.

Japan produces much of what it needs for domestic use and also exports some of its output to China and other Asia/Pacific markets (Freedonia 2013). Exceptions are the brominated compounds, which are imported from the large global producers, and antimony trioxide, which is often acquired from China.

South Korea has a limited domestic manufacturing industry and relies on imports to meet demand from its key electronics and automotive sectors (Freedonia 2013). Antimony and chlorinated flame retardants (CFRs) are imported from Japan and China, while demand for brominated flame retardants (BFRs), used in electronics, is largely met through imports from the US.

Industry contacts noted that because flammability regulations and standards are not chemical specific, economic considerations dominate the selection and use of specific flame retardant chemicals in end products. Producers of manufactured items are not typically aware of which specific chemicals are incorporated into products, as they are more concerned about compliance with applicable standards. North American industry contacts also noted that importers of end products do not typically evaluate or even know which flame retardant chemicals are in such products.[3] In summary, because of product substitutability, a fragmented market structure, and limited regulatory oversight, there are no systems in Asia to identify and track exports of specific chemicals or their subsequent incorporation into products. Further, chemical-specific information pertaining to the manufacture, sale, and use of flame retardants is considered highly confidential in Asia and no public inventories to identify production and use volumes in Asia were identified.

Intermediate Goods and Manufactured Items Expected to Contain Flame Retardants of Interest

Publicly available data sources in Canada, Mexico, and the US were used to identify the types of intermediate goods and manufactured items likely to contain specific flame retardants of interest. The information collected was supplemented by data from published studies that involved testing of intermediate goods and manufactured items to determine the presence and concentration of the chemicals.

Table 5 identifies specific types of intermediate goods either known to or likely to contain one or more of the 16 flame retardants of interest. This summary is based on market reports acquired for the study; reviews of publicly available data from North American chemical inventories and customs databases; technical papers and studies that identify the presence of flame retardants in products; and input from industry contacts and other experts.

As shown, most chemicals of interest are associated with more than one intermediate good (from two to as many as eight), and most categories of intermediate goods are known to contain or may potentially contain more than one chemical of interest (from five to eleven). This does not necessarily imply that individual items, if analyzed, would contain more than one of the chemicals. Rather, it reflects the fact that some of the chemicals of interest are functionally similar, and the selection of which to use (if any) within a category may be based on economics, availability, performance characteristics, or other factors.

[3] Exceptions may include those associated with California Proposition 65, which may require disclosure of specific ingredients in products. Three flame retardants of interest are subject to Proposition 65 notification requirements.

Table 5. Known or Suspected Use of Selected Flame Retardants of Interest in Intermediate Goods in North America

	CAS Number																
Intermediate Good	**triphenyl phosphate 115-86-6 (Ref. No. 40)**	**TCEP 115-96-8 (Ref. No. 26)**	**TCP 1330-78-5 (Ref. No. 12)**	**TCPP and isomer 13674-84-5 and 6145-73-9 (Ref. No. 1)**	**TDCPP 13674-87-8 (Ref. No. 2)**	**TBB 183658-27-7 (Ref No. 5)**	**20566-35-2 (Ref. No. 24)**	**26446-73-1 (Ref No. 16)**	**HBCD and related congeners 3194-55-6 -and 25637-99-4 (Ref. No. 27)**	**TBE 37853-59-1 (Ref. No. 31)**	**PIP 68937-41-7 (Ref. No. 22)**	**77098-07-8 (Ref. No. 23)**	**TBPH 26040-51-7 (Ref. No. 3)**	**TEP 78-40-0 (Ref. No. 7)**	**TBEP 78-51-3 (Ref. No. 9)**	**DBDPE 84852-53-9 (Ref. No. 4)**	**References**
Rigid Plastic	X	X	X	X	X				X	X				X	X	X	2, 3, 4, 8, 14, 15
Flexible PUF	X	X	X	X	X	X	X	X			X	X	X			X	1, 2, 3, 4, 5, 6, 7, 10, 11
Textiles	X	X		X	X				X				X			X	2, 3, 4, 6, 7
Flexible Plastic/Rubber	X		X	X							X		X			X	2, 3, 14, 15
Polyvinyl chloride (PVC)		X	X	X							X		X	X		X	12, 14, 15,16
Resin		X		X							X		X	X	X	X	4, 6, 7
Rigid PUF		X	X	X	X	X	X	X	X		X	X					1, 2, 3, 4, 5, 6, 7, 10, 11
Spray Foam		X	X	X	X	X	X	X			X						1, 2, 3, 4, 5, 6, 7, 10, 11

Sources:
1. Stapleton, H., et al. 2011.
2. Chen, S., et al. 2009.
3.Kajiwara, N. et al. 2011.
4. Arcadis 2011.
5. EPA 2014a.
6. Stapleton, H., et al. 2009.
7. Stapleton, H., et al. 2012.
8. Chemtura 2010.
9. BIPRO 2011.
10. NLM 2014
11. European Union 2008.
12. ECHC 2012
13. ILS 2005.
14. Sino 2014.
15. UK Environment Agency 2009a.
16. UK Environment Agency 2009b.

[a] CAS number 13674-84-5 is TCPP, the primary constituent (>90%) in a mixture of isomers that also contains CAS number 6145-73-9, an isomer that exists in trace amounts. The isomers are not isolated for separate commercial use and are generally marketed as TCPP.

As with intermediate goods, the results of similar literature and data reviews conducted for manufactured items, and a set of tentative conclusions drawn from them, were shared with industry and academic stakeholders knowledgeable about flame retardant use in North America. Table 6 presents a summary of the manufactured items in which each of the 16 flame retardants are either known to be, or likely to be, incorporated.

Table 6. Known or Suspected Use of Selected Flame Retardants of Interest in Manufactured Items in North America

	CAS Number															
Manufactured Item	**TCPP and isomer 13674-84-5 and 6145-73-9[a] (Ref. No. 1)**	**TDCPP 13674-87-8 (Ref. No. 2)**	**DBDPE 84852-53-9 (Ref. No. 4)**	**TBB 183658-27-7 (Ref. No. 5)**	**TBPH 26040-51-7 (Ref. No. 3)**	**TEP 78-40-0(Ref. No. 7)**	**TBEP 78-51-3 (Ref. No. 9)**	**TCP 1330-78-5 (Ref. No. 12)**	**26446-73-1(Ref. No. 16)**	**PIP 68937-41-7(Ref. No. 22)**	**77098-07-8 (Ref. No. 23)**	**20566-35-2 (Ref. No. 24)**	**TCEP 115-96-8 (Ref. No. 26)**	**HBCD and congeners 25637-99-4 and 3194-55-6 (Ref. No. 27)**	**TBE 37853-59-1 (Ref. No. 31)**	**Triphenyl phosphate 115-86-6 (Ref. No. 40)**
Furnishings	X	X	X	X	X			X	X	X		X	X			X
Wire and Cable		X	X		X			X		X						X
Electrical and Electronic Products	X	X	X		X	X	X	X					X	X	X	X
Construction Materials	X			X	X	X		X	X	X	X	X	X	X	X	X
Automotive		X	X			X	X	X	X				X	X	X	X
Textiles, Coatings, Adhesives	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X

[a] CAS number 13674-84-5 is TCPP, the primary constituent (>90%) in a mixture of isomers that also contains CAS number 6145-73-9, an isomer that exists in trace amounts. The isomers are not isolated for separate commercial use and are generally marketed as TCPP.

As shown, with the exception of 1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-, mixed esters with diethylene glycol and propylene glycol (CAS No. 77098-07-8), most chemicals of interest are associated with from two to as many as six manufactured items, and most categories of manufactured items are known to contain or may potentially contain from five to fourteen chemicals of interest. As with the similar analysis pertaining to intermediate goods, this does not necessarily imply that individual products, if analyzed, would contain more than one chemical of interest. Use of specific chemicals within a product category may be based on economics, availability, performance characteristics, or other factors.

Table 7 separately identifies intermediate goods and manufactured items known to contain one or more of the 16 chemicals of interest, based on at least one citable source.

Table 7. Manufactured Items Potentially Containing Selected Flame Retardants

Ref. No.	CAS No.	Chemical Name	Intermediate Goods and Manufactured Items
1	13674-84-5 and 6145-73-9a	2-Propanol, 1-chloro-, phosphate (TCPP) and 1-Propanol, 2-chloro-, phosphate (isomer of TCPP)	PUF: upholstery, bedding, nursing pillow, changing pad, car seat, portable crib, glider rocker, portable mattress, footstool, headrest from chair, chair, ottoman. Rigid PUF: building insulation and refrigerator casings. Wallpaper. Can also be used in isocyanurate PUF, PVC, EVA and phenolics, and epoxy resin.
2	13674-87-8	1,3-Dichloro-2-propanol phosphate (3:1) (TDCPP)	PUF: car seat head supports, car seat insets, high chair pad headrests, baby walkers, baby carriers, changing pads, sleeping wedges, bassinet mattresses, car seats, portable crib mattresses, infant bath slings, booster seats, nursing pillows, couches, chairs, sofa beds. Textiles, specifically tent fabric. Wallpaper. LCD TV components; laptop components.
3	26040-51-7	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-bis(2-ethylhexyl) ester (TBPH)	PUF: couches, car seats, changing table pads, portable mattresses, rockng chair, furniture. PVC: imitation leather. Ethylene propylene diene terpolymer (EPDM): wire and cable. Rubber and plastic products, including thermoplastic polyurethane (TPU), styrene butadiene rubber (SBR), and neoprene. Sealants/adhesives, building and construction. Electrical and electronic products. Textiles; carpet backing, coated fabrics, wall coverings.

Table 7. Manufactured Items Potentially Containing Selected Flame Retardants (FR) (continued)

4	84852-53-9	1,1'-(ethane-1,2-diyl)bis(2,3,4,5,6-pentabromobenzene); Decabromodiphenyl ethane (DBDPE, DBE-209); 1,2-Bis(pentabromophenyl) ethane	PUF: car seats, changing table pads, portable mattress, rocking chairs, couches, and stuffed toys. Rubber and plastics. An industry contact noted it is currently the most abundant FR used in High-Impact Polystyrene (HIPS). Other rubber and plastics include polyethylene (PE), polypropylene (PP), and acrylonitrile butadiene styrene (ABS), engineered thermoplastics, polyolefins, TPU, UPE, epoxy, polybutylene terephthalate (PBT), and PVC/nitrile. Coatings. Textiles, including tent fabric. Car interiors. Electrical components, such as computers, TVs, and electrical appliances.
5	183658-27-7	2,3,4,5-Tetrabromobenzoic acid 2-ethylhexylester (TBB)	PUF: car seats, changing table pads, portable mattresses, couches, rocking chairs.
7	78-40-0	Phosphoric acid, triethyl ester; Triethyl phosphate (TEP)	PUF: insulation board. PVC. Also used as a plasticizer or additive for cellulose, polyester and polyurethane. Wallpaper. Electrical and electronic components (TVs, laptops). Intermediate in manufacturing of phosphonate esters and vinyl phosphates.
9	78-51-3	Ethanol, 2-butoxy-, phosphate (3:1) ; Tris(2-butoxyethyl) phosphate (TBEP)	Plasticizer for resins and elastomers. Floor finishes and waxes. Anti–foam agent (note: this may not be a flame retardant use).
12	1330-78-5	Phosphoric acid, tris(methylphenyl) ester; Tricresyl phosphate (TCP)	PUF: couches. PVC. Rubber products. Adhesives. Pigment dispersions. Wire and cable insulation. Automotive interiors. Electronics such as TVs and laptops. Textiles such as wallpaper, artificial leather, vinyl moisture barriers, and furniture upholstery, conveyor belts (for mining) and vinyl films. Also used as a hydraulic fluid, in photographic film, and as a lubricant additive (note: this may not be a flame retardant use).

Table 7. Manufactured Items Potentially Containing Selected Flame Retardants (FR) (continued)

16	26446-73-1	Phosphoric acid, bis(methylphenyl) phenyl ester	Flexible PUF: foam seating and bedding products.
22	68937-41-7	Phenol, isopropylated, phosphate (3:1) (PIP)	PVC, TPU, Epoxy resins, flexible PUF [specific end products not identified].
23	77098-07-8	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-; 3,4,5,6-Tetrabromo-1,2-benzenedicarboxylic acid, mixed esters with diethylene glycol and propylene glycol; Tetrabromophthalate Diol (TBPA Diol)	Rigid and flexible PUF and isocyanurate foam [specific end products not identified].
24	20566-35-2	2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromobenzenedicarboxylate; 2-(2-hydroxyethoxy)ethyl 2-hydroxypropyl ester	Rigid PUF; RIM, elastomers; coatings adhesive and fibers as PHT4-DIOL [specific end products not identified].
26	115-96-8	Tris(2-chloroethyl) phosphate (TCEP)	PUF: portable cribs, nursing pillows, baby carriers, car seats, sleeping wedges, changing table pads, nursing bath slings, couches, automotive cushioning, upholstered furniture, and roofing insulation. PVC. Coatings and adhesives, including cellulose and polyester resins. Textiles, including back coatings for carpets.
31	37853-59-1	1,1'-[1,2-Ethanediylbis(oxy)] bis[2,4,6-tribromobenzene] or 1,2-bis (2,4,6-Tribromophenoxy) ethane (TBE)	Plastics: ABS, polycarbonate, and HIPS (additively integrated into the matrix). Hard and soft plastic toys. Electric and electronic equipment. Construction materials (sealant around window frames, other consumer adhesives).

Table 7. Manufactured Items Potentially Containing Selected Flame Retardants (FR) (continued)

27	25637-99-4 and 3194-55-6	Hexabromocyclododecane (HBCD) and related congeners	Plastics: XPS/EPS, HIPS, latex. PUF: insulation board. Paints and coatings. Wallpaper. Textiles (upholstery). Textile front coatings, predominantly in Europe (not North America) (note industry contact indicated this is a historical use). Printed wiring boards, electrical and electronic components (TVs, laptops) (identified in electronic waste, though conflicting sources indicate HBCD is not used in electronic casings for TV sets and computers. This may account for citations of use in older sources while recent sources indicate no or declining use).
40	115-86-6	Triphenyl Phosphate (TPP)	PUF: car seats, portable crib mattresses, rocking chairs (gliders), couches. Rigid PUF: insulation board or panels. PVC. Engineering thermoplastics, such as polyphenylene-HIPS and ABS-polycarbonate blends. Also used in cellulose nitrate films, coatings, triacetate film and sheet. Textiles (tent fabric and artificial leather). Electrical and electronic components (TVs, laptops, printed wiring board); wire and cable.

Note: Information used to compile this table came from a wide variety of resources, including a list compiled by the Project Team prior to initiation of the study.

[a] CAS number 13674-84-5 is TCPP, the primary constituent (>90%) in a mixture of isomers that also contains CAS number 6145-73-9, an isomer that exists in trace amounts. The isomers are not isolated for separate commercial use and are generally marketed as TCPP.

Impacts of Regulations and Industry Standards

Generally, regulations and standards requiring flame retardancy do not mandate or prescribe the use of specific flame retardants or concentrations, or, for that matter, any use of chemical flame retardants if flame retardancy can be demonstrated through alternate methods, such as barrier technologies or use of inherently flame retarding materials.4 Rather, regulations define performance standards that products must meet. Factors that may influence the selection of flame retardants include compatibility between the flame retardant and the product; the technological feasibility of incorporating the flame retardant; requirements to use specific testing methods to demonstrate compliance with regulations or standards; user specifications; and economic feasibility. Two significant standards that reportedly are driving current and potential future use of flame retardants are California Technical Bulletin 117 (and recent modifications) and the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). Impacts of each are discussed below.

California Technical Bulletin 117

California Technical Bulletin 117 (CA TB117), promulgated in 1975 and enforced by the State of California, has been an important factor driving the use of flame retardants in furniture, in California and elsewhere, for many years. Because of the size of the California market and the logistics of production, inventory control, and distribution, many manufacturers complying with CA TB117 for products they sell in California (or that could eventually be sold in California) choose to make their entire product line compliant. Reviews of the literature concluded that data are insufficient to estimate the quantity or percentage of upholstered furniture in North America that is TB117-compliant, but some industry experts who were contacted speculated that as much as 70 percent of the furniture annually purchased within North America meets TB117 specifications.

Recent revisions to the test methods prescribed by CA TB117-2013 may significantly affect the need for flame-retarded foam in the future. The nature of the smolder test associated with TB117-2013 shifts the burden of compliance from foam producers to fabric suppliers. Unlike the flame test required by TB-117, which exposes foam to the ignition source, the revised TB117-2013 exposes the textile covering. It is widely speculated that due to these changes, furniture manufacturers may no longer need to rely on flame retardants to comply with this standard, although the revised standard will not prohibit their use. Heightened concerns from consumer and environmental groups over the use of flame retardants (especially in furniture) may also influence their decision making. The revised standard went into effect January 1, 2015; however, manufacturers were allowed to begin selling furniture that has passed the test as “TB117-2013 compliant” as early as January 1, 2014.

Contacts were made with representatives of flexible foam manufacturers and trade associations associated with foam production and end-use upholstery manufacturing to discuss effects of the 2013 modification. The consensus opinion among these stakeholders is that the revisions to CA TB117 are likely to result in a general reduction in both the concentration of flame retardants in foam and the percent of foam in upholstery that includes any flame retardants. There was speculation that up to 90 percent of end-use upholstery manufacturers may move completely away from adding chemical flame retardants to upholstery foam.

[4] “Inherently flame-retardant” products may include materials that have built-in flame resistance, negating the need for chemicals. Examples include some wool fabrics and graphite.

REACH

The European Union's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation has the potential to have a significant impact on the flame retardant supply chain and to influence flame retardant chemical use decisions globally. Under REACH, substances determined by the EU to have serious and often irreversible effects on human health and the environment can be identified as substances of very high concern (SVHCs). If a substance is identified as an SVHC, it is added to the Candidate List for potential inclusion in the SVHC authorization list. Chemicals added to the SVHC authorization list may be subsequently banned, preventing their use, marketing, or importation into the EU after a specified date.

Currently, two of the 16 flame retardants of interest have been designated as SVHCs:

- Hexabromocyclododecane (HBCD) and related congeners (CAS Nos. 25637-99-4/3194-55-6)
- Tris(2-chlorethyl) phosphate (TCEP) (CAS No. 115-96-8)

Representatives of the North American Flame Retardant Association (NAFRA) and the Phosphorus, Inorganic and Nitrogen Flame Retardants Association (PINFRA) were contacted and asked to provide their perspectives on REACH and its potential impact. These stakeholders agreed that identification as an SVHC could immediately impact a manufacturer's ability to produce or import a listed product to the European Union. Additionally, there is concern within the industry that such a designation under REACH could lead local and federal regulatory agencies in countries outside of the European Union to take a closer look into the production and use of these chemicals, and may also draw attention from various non-government organizations (NGOs). As a result, companies are expected to factor SVHC classifications immediately into their business plans.

North American Polyurethane Foam Manufacturing—Industry Input

Industry representatives associated with flexible and rigid polyurethane foam manufacturing and subsequent use provided information and their perspectives on the type and concentration of flame retardants used in foams, how regulations may affect the future use of flame retardants, the trends in the use of flame retardants, and imports.

Flexible polyurethane foam (FPF or flexible PUF) is used in various common manufactured items including (but not limited to) upholstered furniture and trim, vehicle interiors, mattresses, packaging, and carpet cushions). FPF from one manufacturer can be customized for use in many manufactured items, and some larger manufacturers have reportedly developed foam for over 150 different products (UNIDO 2012). The exact number of FPF manufacturers in North America is unknown, but industry contacts speculated there could be several hundred to almost 1,000. It was noted that the market includes many smaller manufacturers throughout each North American country.

Industry stakeholders contacted for the study commented that the use of specific flame retardants, as well as the concentration used in the manufacture of polyurethane foams, can vary from lot to lot. This is in part because the type and amount of flame retardant used in a given batch is often based on ambient conditions, such as temperature, pressure, and humidity. Operators and technicians often determine the appropriate flame retardant and concentration to use in a batch based on experience, with the goal of minimizing any detrimental effects on the product.

In addition to variations in flame retardant concentrations, input from the American Home Furnishings Alliance (AHFA) and foam manufacturers suggest that end-use manufacturers are often unaware of the specific flame retardants used in their products, and may not know the type or category (e.g., phosphorus-based or otherwise) (AHFA 2014).

To protect proprietary information and because of the variability in company policies about measuring the concentration of flame retardants in FPF, industry contacts declined to provide specific chemicals used or their concentrations. Although specific concentrations were not disclosed, the respondents noted that the percentage of flame retardants in FPFs tends to be higher for lower density foams.

Manufacturers similarly declined to identify any specific flame retardants being considered for future use. However, both manufacturers and trade association representatives confirmed that the commercial mixture of pentaBDE is one flame retardant no longer in use, as North American production and use has been phased out. Similarly, CFRs generally were highlighted as a category being phased out when possible. While these specific flame retardants have been replaced with others, respondents noted that this has not had substantial impact on the concentrations of flame retardants in foam. Respondents also noted that flame retardant concentrations in FPF generally range from zero to 15 percent.

Use of Flame Retardants in PUF for Residential Upholstered Furniture

One of the primary uses for FPF is in the home furnishings industry. Flexible PUF is used in manufacturing bulk foam cushioning material, which is then sent to cushion cutters who trim the cushions to end-user specifications. These trimmed cushions are then sent to end-use manufacturers for incorporation into the final product. Residential upholstered furniture is assembled with pre-cut polyurethane foams and upholstery components that are likely to contain flame retardants. As described previously, it is difficult, if not impossible; to identify specific flame retardants in specific manufactured items without testing (primarily due to variability in use during production of intermediate goods, and due to assertions of confidentiality).

Trends

During the production of upholstered furniture, the manufacturer specifies the type of foam desired, which directs the production of FPF. These specifications are often based on the furniture manufacturer's need to comply with CA TB117; however, as noted above, changes associated with CA TB117-2013 are expected to have a major impact on the industry. There has been speculation that up to 90 percent of upholstered furniture companies may move away from using flame retardants in the foam (although some stakeholders caution this may be tempered if companies are reluctant to stop using flame retardants due to public perception and potential liability concerns).

Confirming input from foam manufacturers, a representative from AHFA noted that the use of specific flame retardants has changed as certain chemicals have been phased out (such as pentaBDE and TDCPP). At the same time, however, there has been no discernible change in flame retardant concentrations in the foams. It was speculated that flame retardants may be found in lower density foams in concentrations up to five percent, while higher density foams may typically have lower flame retardant concentrations, if they use flame retardants at all.

Imports

Industry representatives estimated that approximately 30 percent of residential upholstered furniture is imported from overseas, predominantly from China. The percentage is relatively higher for labor intensive upholstery products, such as leather sofas, because inexpensive labor costs offset shipping expenses. This gives countries with lower labor costs, like China, a competitive advantage in highly labor-intensive products. Both AHFA and major manufacturers of flame retardants speculated that more flame retardants are imported into North America already incorporated into manufactured items than are imported as raw materials.

End-of-Life

The service life of upholstered furniture varies by product. Couches have a service life of approximately 30 years (AHFA 2014), while an upholstered chair is expected to have a much shorter life span. When a piece of furniture has reached the end of its service life, it is generally disposed of as municipal solid waste that is either landfilled or incinerated (PFA 2014).

A majority of disposed furniture continues to end up in landfills. Based on conversations with industry, although furniture may also be recycled under state or local programs, industrial recycling and recovery processes for upholstered furniture are atypical (AHFA 2014; PFA 2014). On an industrial level, it is generally more expensive to reupholster furniture than to start from new because of labor costs. Consumers, however, may extend the service life of furniture by reupholstering it themselves or by donating it to charities that redistribute items to other homes. Upholstered furniture has also been diverted from landfills, repurposed, and sold commercially, but these activities reportedly occur on a small scale (no quantifiable data were identified). For recycling facilities that receive upholstered furniture, facility staff would sort the pieces based on their reuse potential and send reusable furniture to donation centers. For non-reusable furniture, recycling facilities most likely incinerate the product for energy recovery purposes as an end-of-life practice.

The lack of a market for recycled foams from upholstered furniture is likely attributable to the difficulty of removing foam from furniture that has reached the end of its service life (CalRecycle 2002; PFA 2014). For this reason, foam recycling activities in Canada, Mexico, and the US tend to occur during furniture manufacturing rather than at the end-of-life stage. Recycled scrap foams are generated either by flexible foam fabricators, who supply upholstered furniture manufacturers with pre-cut or pre-trimmed foams meeting the manufacturers' specifications, or by cutting/trimming operations conducted on site by the upholstered furniture manufacturers themselves (EPA 2005; UNIDO 2012). "Scrap foam" in this context can be characterized as trimmings, waste, and off-spec foam generated during industrial manufacturing operations. The foam fabricators are expected to generate the greatest proportion of these scrap foams, as most upholstered furniture manufacturers purchase and incorporate pre-cut or pre-trimmed foams into their products (PFA 2014). Scrap foam originating within the US or imported from other countries such as Canada, Mexico, and China, is directed to the US carpet cushion manufacturing industry (UNIDO 2012). No quantitative data regarding the volume of recycled foam were identified.

Flame Retardant Levels Found in Aged, Upholstered Furniture

A limited number of studies with the goal of identifying the flame retardants present in aged upholstered furniture and their concentrations have been conducted. Research at Duke University has sought to identify and quantify flame retardant content in upholstered furniture manufactured in different time periods and with varying service life in residential homes.

In one study, Duke researchers collected and analyzed 102 samples of polyurethane foam from residential couches purchased by US consumers between 1985 and 2010 (Stapleton, et al. 2012). Table 8 summarizes the average concentrations of the flame retardants of interest. Results corroborate statements from industry stakeholders that flame retardant concentrations can vary by foam, and that concentrations may not be dependent on the specific flame retardant itself.

Table 8. Flame Retardant Concentrations Measured in Polyurethane Foams Found in Aged, Upholstered Furniture

Flame Retardant	No. of Samples	Average Concentration (mg/g)	Number of Detected Samples Purchased (% of Total Samples)	
			Prior to 2005	2005 or Later
TDCPP	42	44.87	10 (24%)	32 (52%)
FM 550a	13	19.76	2 (5%)	11 (18%)
V6/TCEPb	1	41.77	0	1 (2%)
TDCPP and PentaBDEc	2	22.64	2 (5%)	0
TDCPP and FM 550b	2	19.06	0	2 (3%)
Total Samples	102	-	41	61

Abbreviations:

FM 550 - Firemaster 550 (a mixture of TBPH and TBB)

PentaBDE - Pentabromodiphenyl ether

V6 - 2,2-bis(chloromethyl)trimethylene bis(bis(2-chloroethyl)phosphate)

a Measurement reflects the sum of TBB, TPP, and TBPH concentrations.

b Distribution of flame retardant concentrations was not specified.

c PentaBDE shown for completeness. It is outside the scope of this study.

Source: Stapleton et al. 2012.

Gaps Analysis (Factors Preventing Complete Chemical-specific Characterization)

A detailed approach for acquiring data and information to characterize the supply chain and complete other project objectives was developed. This approach included a literature search, reviews of North American government inventories and databases, acquisition and reviews of market studies, and identification of and subsequent correspondence with expert stakeholders in government, academia, and industry. Throughout the course of the project, a variety of challenges arose that prevented the study team from completing the study objectives. The primary challenges are presented below.

Confidentiality Concerns

The flame retardant manufacturing industry and corresponding intermediate goods manufacturing sectors are highly competitive industries. Because of this, concerns over release of information that may affect a company's competitive advantage was the most significant barrier for acquiring information for the study.

It was anticipated that for business reasons companies may be reluctant to share specific production and use volumes. However, it was not anticipated that most companies would also decline to identify the chemicals used and the distribution of their products to downstream industry sectors and their customers.

This reluctance is reportedly, in part, because standards and regulations are performance-based and do not require the use of specific chemicals (or even the use of any chemical flame retardants). Because of this, companies are free to base decisions regarding the use of specific flame retardants on corporate experience. In some intermediate goods manufacturing sectors (such as polyurethane foam) companies base decisions on years of research and experience. Therefore, not only are they reluctant to identify the use rate of flame retardants, they are often wary of identifying the specific chemicals used, the typical concentrations (even broad ranges), and downstream customers because sharing that information may inform competitors and compromise a competitive advantage that has been gained by years of research and experience.

Fragmented Asian Market

Another significant barrier for determining the chemical-specific foreign supply chain is the fragmented structure of the flame retardant market in Asia. The study team's review of public information and market reports, and feedback from industry contacts, confirmed that the flame retardant manufacturing and use industry throughout Asia consists of many small chemical manufacturers and distributors, and also small intermediate goods manufacturers. It was not feasible to identify and contact enough companies to acquire appropriate information, and the study team did not identify any chemical tracking systems or industry surveys that contained production or use data. This makes it challenging, if not impossible, to track the manufacture and use of specific flame retardants in manufactured items on a national or global scale.

These small chemical manufacturing companies typically make small batches of chemicals on an as-needed basis to meet customer requests. Similarly, intermediate goods manufacturers make products on an as-needed basis for incorporation into final manufactured items. The number of these smaller companies is unknown and global flame retardant manufacturers are not aware of inventories or resources to help determine which specific companies manufacture which specific chemicals. Further, these industry representatives commented that, due to their relatively small business size, these companies change ownership or go out of business frequently. This information was corroborated by reviews of proprietary market reports and information available on public Internet sites.

Lack of Chemical Tracking Systems in Asia

North American governments require reporting of chemicals under various regulations to country-specific inventories. Detailed information is often considered confidential and cannot be released for studies such as this. However, some useful publicly available information is available and can be used to identify manufacturers, processors, and users of specific chemicals in the respected jurisdictions along with production and import volumes. Examples are the Canadian Domestic Substances List Inventory Update and the US Chemical Data Reporting (CDR) program. Even if information is considered confidential, it may be available for internal use by the country environmental and health organizations. Unfortunately, comparable publicly available inventories in Asia (specifically China, Japan, and South Korea) were reviewed and do not contain information that is useful for this study. Most of the chemicals of interest are included on the inventories in these countries. However, no data are available to identify companies; production, import, and use volumes; or use patterns.

Lack of Specificity in North American Commerce Databases

Commerce databases in Canada, Mexico, and the US track the general types of goods imported to each country (raw materials, intermediate goods, and manufactured items). However, publicly available data pertaining to import volumes of specific flame retardants are limited (no nonconfidential information was identified regarding Canadian imports of the 16 chemicals of interest and only limited information on Mexican and US imports was found).

Similarly, North American trade databases do not generally include information pertaining to chemicals present in intermediate goods and manufactured items. In general, these databases lack the specificity needed to conclusively determine the presence of specific chemicals in the imported goods. For example, Harmonized Systems codes are typically used to identify products and raw materials that are traded internationally. However, they are aggregated into broader chemical groups for the flame retardants of interest, (e.g., BFRs, CFRs). Because of this, inferences can be drawn as to goods imported from Asia and elsewhere that may contain the flame retardants, but no definitive conclusions can be made.

Options for Use of Specific Flame Retardants due to Effect on Product Quality

The quality of some intermediate goods and manufactured items can be adversely affected by the use of specific flame retardants in the concentrations used in the manufacturing process. Because flame retardancy standards and regulations are performance-based, industry is free to use any chemical or mixture of chemicals (or non-chemical systems) to ensure compliance. This results in flexibility and also significant variability in the selection of specific flame retardants. Companies manufacturing similar products base flame retardant choices on economic considerations and experience regarding effects on performance. For example, industry contacts indicated that a number of chemical and non-chemical options are available to meet compliance standards. However, high loadings of some flame retardants can have detrimental effects on the product. Companies therefore make selections by comparing the cost associated with purchase and use of the specific flame retardants and the potential for detrimental effects. Because of this, different companies may use different flame retardants even when manufacturing the same type of intermediate goods. It is therefore challenging to conclusively identify specific chemicals that are used in intermediate goods unless the individual company is willing to share the information. Even if so, the company may have multiple customers for the end product manufacturing and the end product manufacturer may acquire intermediate goods from multiple suppliers, increasing the uncertainty of chemical use in the manufactured items.

Options for Use of Specific Flame Retardants due to Performance-based Standards

Most flame retardancy standards and regulations are performance-based. Therefore, manufacturers and distributors of manufactured items are often more concerned with compliance than with the chemicals used (if any) to meet the standards. When acquiring intermediate goods for assembly into manufactured items, the end use manufacturers do not typically require their suppliers to provide detailed information pertaining to neither the specific chemicals used nor their concentration; and testing of intermediate goods is not typically conducted. Two industry contacts confirmed this and stated very few end product manufacturers are aware of the chemicals in their products (one estimated less than 10%). Therefore, even if manufacturers of finished goods would be willing to share information, they may not be able to identify specific flame retardants that are used. Exceptions are large, global companies with established policies to ban or phase out the use of certain flame retardants in products. However, even with these companies, the policies are often based on categories of flame retardants, such that it is challenging to determine the specific chemicals used (and impossible with resources available for this study). For example, a company policy may be in place to phase out BFRs; however, it may not specify what flame retardants are used in lieu of those chemicals.

A Note from the CEC Pertaining to Phase 2 of the Project, Enhancing Trilateral Understanding of Flame Retardants and Their Use in Manufactured Items

In phase 2 of the project, a selection of products and methodology from this phase 1 study will be subjected to laboratory testing and the results presented in a separate report to be released at the conclusion of project work.

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