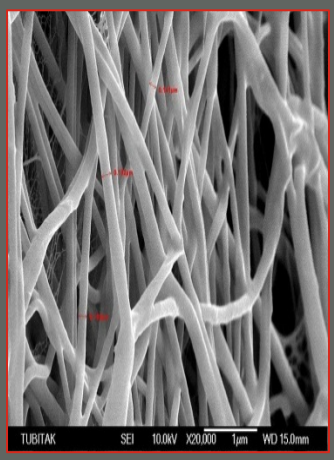

Long-Chain Perfluorinated Chemicals (LCPFCs) Used in Carpets

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Prepared for:
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Long-Chain Perfluorinated Chemicals Used in Carpets

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Executive Summary

Perfluorinated chemicals (PFCs) are substances with special properties that have a variety of industrial applications. PFCs are used in carpets to impart stain, soil, and grease repellant properties (U.S. EPA 2009c; KEMI 2006). During the manufacturing process, PFCs are utilized in the impregnation of carpets or as a chemical finish which endows fabrics with those characteristics. Long-chain perfluorinated chemicals (LCPFCs) are found world-wide in the environment, wildlife, and humans. They are bioaccumulative in wildlife and humans, and are persistent in the environment (Danish Ministry of the Environment 2008).

There are four typical scenarios for chemical application that could lead to the presence of LCPFCs in carpet products. First, LCPFCs could be applied to carpet at a carpet and rug mill during the manufacturing process. Secondly, LCPFCs could be applied to carpet after the manufacturing process at a separate finishing facility. Thirdly, treatment products containing LCPFCs could be applied to carpets by final consumers in the post manufacturing stage. In the described scenarios, LCPFCs could be domestically produced or imported. In addition, domestically produced carpets could be made using imported fabrics that had been treated with LCPFCs. Finally, carpet containing LCPFCs could be imported into the United States as a final product.

The Agency believes that the LCPFC chemical substances included in the proposed rule are no longer being manufactured, processed, or imported for use as part of carpet or for treating carpet (e.g., for use in the carpet aftercare market) in the United States. Partly as a result of the 2010/15 PFOA Stewardship Program, U.S. manufacturers have stopped producing LCPFC-based products used for carpet treatment. Major manufacturers have developed alternative products that are based on short-chain PFCs. However, a few companies continue to sell previously manufactured products that use LCPFCs. It is expected that no LCPFC-based products will be available for sale in the U.S. once the existing inventory is sold out.

In addition to the phase-out of long-chain PFCs in carpet products by domestic manufacturers, EPA believes that imported carpet products do not contain LCPFCs. Only 16 percent of domestically consumed carpets and rugs are imported, while 84 percent of the product is manufactured in the U.S.

Long-chain PFCs may also be imported into the U.S. from countries like China and applied to carpets domestically. The imports data obtained from ITC suggest that no long-chain PFCs for use in carpet treatment are currently imported into the U.S.

Because chemical treatments for carpets are not only applied during the manufacturing process but can also be applied to carpets by the consumers in the post manufacturing stage, exposure to carpet treatment chemicals may occur both during and after the manufacturing process.

This market profile is developed to support the Significant New Use Rule (SNUR) being proposed by EPA for long-chain PFCs used in carpets.

1. Introduction

Perfluorinated chemicals (PFCs) are substances with special properties that have a variety of industrial applications. PFCs are used widely in the textile industry because of their thermo-stability, ability to adapt to a variety of surface characteristics, high chemical stability, and other characteristics (Armeduri and Bouterin 2004). PFCs are used in carpets to impart stain, soil, and grease repellant properties (U.S. EPA 2009c; KEMI 2006). During the manufacturing process, PFCs are utilized in the impregnation of carpets or as a chemical finish which endows fabrics with those characteristics.

Long-chain perfluorinated chemicals (LCPFCs) are found world-wide in the environment, wildlife, and humans. They are bioaccumulative in wildlife and humans, and are persistent in the environment (Danish Ministry of the Environment 2008). To date, significant adverse effects have not been found in the general human population[1]; however, LCPFCs have been linked to a number of health effects, including thyroid disease and reproductive function (Knox, et al., 2011; Melzer, et al., 2010).

Although three broad types of PFCs are used in textiles: fluorotelomers, fluoropolymers, and perfluoroalkyl sulfate (PFAS), we found no evidence of fluoropolymers used in carpet treatment products.

This market profile is developed to support regulatory activities that would limit or eliminate the use of long-chain PFCs (LCPFCs) in carpets. This market profile in support for the Significant New Use Rule (SNUR) being proposed by EPA for LCPFCs used in carpets is structured in the following way:

- Section 2 identifies individual manufacturers of PFCs and provides a description of the carpet manufacturing process.
- Section 3 provides an overview of the carpet manufacturing sector and its economic activity.
- Section 4 defines the role of PFCs in the carpet industry.
- Section 5 lists available alternatives to LCPFC-based carpet treatment products.

[1] Based on review of a number of studies examining health effects of LCPFCs.

2. Carpet Manufacturing

2.1 Introduction

U.S. manufacturers have stopped producing LCPFC-based products used for carpet treatment. The manufacturers have developed alternative products that are based on short-chain PFCs. Specific technologies and products for each of these companies are described in Section 5. However, a few companies continue to sell previously manufactured products that use LCPFCs. It is expected that no LCPFC-based products will be available for sale in the U.S. once the existing inventory is sold out. This section presents a list of companies that manufacture PFC-based products for use in carpets.

During the manufacture of carpets, PFCs may be applied to carpets for oil, stain, grease repellency (U.S. EPA 2009b). It is important to note that chemical treatments for carpets are not only applied during the manufacturing process but can also be applied to carpets by the consumers in the post manufacturing stage (3M Company 1999).

Therefore, exposure to carpet treatment chemicals may occur both during and after the manufacturing process. EPA's ORD reviewed literature and found that there were high levels of PFAC in carpet and carpet treatment products (levels were from 0.04-14,100 ng/g)[2] (U.S. EPA 2009b). This is of particular concern for children since they engage in a variety of activities on carpets for longer periods of time in their earliest years and can be exposed to chemicals in carpets via inhalation. (U.S. EPA 2009b).

2.2 Manufacturers Using PFCs in Carpet Products

EPA is not presenting a list of manufacturers of PFCs used in carpets due to the proprietary nature of these data.

2.3 Manufacturers of Remaining Carpet Products with Long-Chain PFCs

The U.S. manufacturers listed above have stopped producing LCPFC-based products used in carpets. However, a few companies continue to sell previously manufactured products that use LCPFCs. It is expected that no LCPFC-based products will be available for sale in the U.S. once the existing inventory is sold out. Additional details on those companies that are found to continue to offer LCPFC-based products are provided in this section.

2.3.1 Advanced Polymer, Inc., Carlstadt, NJ

Advanced Polymer, Inc. lists a product, APG-5295, in its catalog, which is described as a "Perfluoroalkylacrylate emulsion" by the manufacturer and can be used to carpet protection[3] (product description is dated April 6th 2011). APG-5295 is also described in a product catalog as a "C8-based fluorochemical system."[4] This product in no longer manufactured, although limited stock is still

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2 EPA referenced the research by ORD in their 2009 Long-Chain Perfluorinated Chemicals (PFCs) Action Plan. Therefore, the research and review of the research was completed prior to 2009 (U.S. EPA 2009b).

3 http://www.advpolymer.com/docs/APG-5295.pdf (Accessed 11/30/2011)

4 Advanced Polymer, Inc. 2011. Product Catalog. Revised June 23, 2011.Available at: http://www.advpolymer.com/docs/PRODUCT_CATALOG.pdf (Accessed 11/30/2011).

available for purchase on a first come first served basis.[5] A company representative indicated that currently C8-based carpet protection products are being replaced with C-6 alternatives.[6]

2.4 Carpet Manufacturing Process

There are two different processes of carpet manufacturing: 1) tufting and 2) weaving. Tufting is a process that uses machines and synthetic materials to manufacture a carpet (WFCA 2011b). The tufting process involves the following steps:

(1) Weaving fibers into a backing material,

(2) Dyeing the carpet[7],

(3) Applying a coating of latex to the primary back and a secondary backing and sending the carpet though a heat press to be squeezed together[8], and

(4) Shearing (WFCA 2011b).

The second carpet manufacturing process, weaving, may be done by hand, looms, or industrial machinery using fibers and yarn (WFCA 2011b). The process involves stretching fibers in one direction, called warps, tight on a frame and weaving yarn through them, and then laying fibers, called wefts, horizontally across the yarn (WFCA 2011b).

Currently, 90 percent of carpets are made with synthetic (i.e., man-made) fibers (WFCA 2011a.). Synthetic fibers are either nylon, polypropylene, and polyester, while the most common natural fibers are wool, silk and bamboo (WFCA 2011a).

2.5 Carpet Treatment

Anti-stain and anti-soil chemicals can be applied to a wide variety of textiles, including fibers, yarns, fabrics, and carpet using the following techniques (Kissa 2001):

- Spraying
- Padding
- Kiss-roll
- Foam application
- Exhaust methods

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5 Personal Communication with a sales representative at Advanced Polymer, Inc. on 12/13/2011.

6 Personal Communication with a sales representative at Advanced Polymer, Inc. on 12/13/2011.

7 Dyeing can occur before the other steps or at the end of the manufacturing process. Carpets that are dyed before the final steps are normally one color; while carpets that are dyed at the end of the process usually have a pattern or style. (WFCA 2011b).

8 At the point in the process, manufacturers can apply an anti-stain treatment (WFCA 2011b).

For carpets, spraying is the most popular technique for applying anti-stain and anti-soil chemicals. In most cases, these chemicals are applied at the last step of the manufacturing process before the carpet is dried (Kissa 2001). However, based on a report by 3M company in 1999, it appears to be possible for anti-stain treatment to occur during fiber manufacturing before these fibers are manufactured into a carpet.

3. Industry Overview

3.1 Sector Definition

3.1.1 Primary Manufacturing: Chemical Manufacturing

Chemical manufacturing is broadly captured under NAICS 325. This three-digit NAICS sector represents an industry involved in the transformation of raw materials (both organic and inorganic) via a chemical process and the formulation of products (U.S. Census Bureau 2011c).

Perfluorinated chemicals could be manufactured under a variety of six-digit NAICS codes, within NAICS 325: Chemical Manufacturing. Based on a review of NAICS code definitions, the following NAICS codes were identified as industries potentially involved in production of perfluorinated chemicals.

NAICS Code	NAICS Description
325120	Industrial Gas Manufacturing*
325188	All Other Basic Inorganic Chemical Manufacturing
325199	All Other Basic Organic Chemical Manufacturing
325211	Plastics Material and Resin Manufacturing
325212	Synthetic Rubber Manufacturing
325991	Custom Compounding of Purchased Resins
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing

*Includes Fluorocarbon gases manufacturing.

3.1.2 Secondary Manufacturing: Carpet Manufacturing and Treatment

Carpet manufacturing and treatment is part of the textile industry, which primarily involves the design or manufacture of clothing as well as the distribution and use of textiles. The textile industry includes fiber production (natural and synthetic), raw weaving, knitting, dyeing, felting, finishing and printing and final make-up into garments (e.g. carpets, fabrics). Natural fibers include animal wools and cellulose products such as cotton and flax, while synthetic fibers include rayon, acrylic, polyester, polyurethane, polyamide and others. Textiles also include leather articles, upholstered household furniture, mattresses, and draperies.

Carpet manufacturing and treatment is represented by NAICS 314110 “Carpet and Rug Mills“ and falls under NAICS 314 (Textile Product Mills) that represents manufacturers that produce textile products, excluding apparel. The processes used in this sector include cutting and sewing of fabric in order to make non-apparel textile products such as woven and tufted carpets (U.S. Census Bureau 2011d).

The Carpet and Rug Mills industry comprises establishments primarily engaged in the following activities (U.S. Census Bureau 2011d):

> (1) Manufacturing woven, tufted, and other carpets and rugs, such as art squares, floor mattings, needlepunch carpeting, and door mats and mattings, from textile materials or from twisted paper, grasses, reeds, sisal, jute, or rags.
>
> (2) Finishing carpets and rugs.

3.2 Economic Activity

Exhibit 3-1 presents the 2007 value of shipments for the 6-digit industry sector "Carpet and Rug Mills" and compares it to the economic activity of NAICS 314 (Textile Product Mills). As shown in the table, the Carpet and Rug Mills sector accounts for almost half of economic activity within NAICS 314.

Exhibit 3-1: Textile Product Mill Sectors: Economic Activity, 2007

NAICS Code	NAICS Description	Value of Shipments ($1,000)	% of Total Product Mill Industry
314110	Carpet and rug mills	$13,054,338	45.5%
314	**Textile Product Mills**	**$28,682,164**	**100.0%**

Source: U.S. Census Bureau 2010

Exhibit 3-2 presents historical data from Census on the number of establishments and value of shipments for the Carpet and Rug Mills sector. A significant industry growth in terms of the value of shipments is observed between 1992 and 2002 and a slight slowdown is exhibited between 2002 and 2007.

Exhibit 3-2: Carpet and Rug Mills: Economic Activity, Historical Data

Year of Data	Number of Establishments	5-Year Percent Change	Value of Shipments ($1,000)	5-Year Percent Change
2007	335	-17.3%	$13,054,338	-6.5%
2002	405	-14.2%	$13,958,654	21.5%
1997	472	5.8%	$11,492,786	16.9%
1992	446	-6.1%	$9,828,300	0.3%
1987	475	-	$9,795,000	-

Sources:

2007 data: U.S. Census Bureau, 2010

2002 data: U.S. Census Bureau, 2005a

1997 data: U.S. Census Bureau, 2005b

1992 and 1987 data: U.S. Census Bureau, 1996 (SIC Based)

Notes: 1992 and 1987 data are SIC-based. SIC 2273 is equivalent to NAICS 314110 (Carpet and Rug Mills).

3.3 NAICS Sectors Potentially Using PFCs in Carpets

It is likely that not all carpet and rug mills manufacture finished products that contain PFCs. Fluorinated telomers are primarily utilized in the impregnation of carpets or as a chemical finish which endows fabrics with stain, soil, or grease repellant characteristics. The focus of this analysis is on the economic activity of the carpet manufacturing sectors that impregnate and chemically finish their carpets at the textile mill level. It is important to note that carpet mill manufacturers may also purchase fabrics for use in carpets that are already treated with PFCs. EPA believes that carpet treatment products containing long-chain PFCs are not manufactured in or imported into the U.S.

Exhibit 3-3 shows product lines under the Carpet and Rug Mills sector, the corresponding number of companies with shipments of $100,000 or greater, and the value of shipments for these products.

Exhibit 3-3: Carpet and Rug Mill Product Lines: Economic Activity, 2007

NAICS Code	NAICS Description	Number of Companies with Shipments of >$100,000	Products Shipments Value ($1,000)	% of Industry Value
314110	Carpet and rug mills	N	$12,910,484	100.0%
31411011	Carpet and rugs, woven	14	$444,004	3.4%
31411031	Carpet and rugs, tufted only or tufted & finished in same plant	73	$11,469,402	88.8%
31411032	Carpet and rugs, finishing only	15	$319,137	2.5%
31411051	Other carpet, rugs, and mats	32	$432,731	3.4%
3141103Y	Carpet and rugs, tufted, nsk	N	$9,626	0.1%
314110W	Carpet and rug mills, nsk, total	N	$235,584	1.8%

Source: U.S. Census Bureau 2009.

Notes: Sectors where carpet and rug treatment with PFCs takes place are highlighted in grey.

nsk -"not specified by kind"

N - "Not available or not comparable"

Product shipments value is the total value of all products produced and shipped by all producers.

Generally, tufted carpet is treated with some form of stain resisting chemicals, which helps to lengthen the life of the carpet. Of the product line codes listed under the Carpet and Rug Mills sector, carpet and rug treatment with PFCs is likely to take place under the following product line codes:

- 31411031: Carpet and rugs, tufted only or tufted & finished in same plant;
- 31411032: Carpet and rugs, finishing only.

As shown in Exhibit 3-3, most finishing of carpet and rugs occurs at the same plant where the carpet or rug is manufactured (89 percent of industry value) – NAICS 31411031. In some instances (2.5 percent of industry value), carpet finishing takes place separately from the manufacturing process – NAICS 3141103Y. Furthermore, in some instances, fibers are treated *before* they are sent to a mill for manufacturing carpets or rugs (3M Company 1999).

3.4 Exports, Imports, and Domestic Consumption

Exhibit 3-4 presents data on imports and exports for the Carpet and Rug Mills sector. The table also shows the implied domestic consumption, import penetration and export intensity. Exhibit 3-5 presents the economic activity figures for the Carpet and Rug Mills sector.

In 2007, the value of shipments is $13.1 billion, the value of imports is $2.2 billion, and the value of exports is $1.0 billion. According to 2007 Economic Census data and U.S. International Trade Commission (ITC) data, U.S. imports represent 16 percent of domestic consumption and exports represent eight percent of the value of shipments.

The values for the imports and exports are originally reported in HTS codes that are mapped to NAICS codes. The import value represents the cost, insurance, and freight value (C.I.F.), which is the landed value of the products at the first port of arrival in the U.S. (U.S. Census Bureau 2011a). The C.I.F. import value is essentially the sum of the import charges and the customs value (U.S. Census Bureau 2011a). The export value is based on the free alongside ship (F.A.S.) value, which represents the value of exports at the U.S. seaport, airport, or border port of export (U.S. Census Bureau 2011a). This value is based on the transaction price, which includes inland freight, insurance, and other charges, but excludes the cost of loading the merchandise aboard the exporting carrier and the freight, insurance, and any charges or transportation costs beyond the port of exportation (U.S. Census Bureau 2011a). The value of shipments is reported by U.S. Census Bureau data for each NAICS code.

Exhibit 3-4: Carpet and Rug Mills: Imports, Exports, and Implied Domestic Consumption, 2007

NAICS Code	NAICS Description	Products Description	Value of Shipments ($1,000)[1]	Imports ($1,000)[2]	Exports ($1,000)[2]	Implied Domestic Consumption ($1,000)	Import Penetration	Export Intensity
314110	Carpet and rug mills	Carpets and Rugs	$13,054,338	$2,238,584	$1,047,551	$14,245,371	16%	8%

Sources:

[1] U.S. Census Bureau 2010

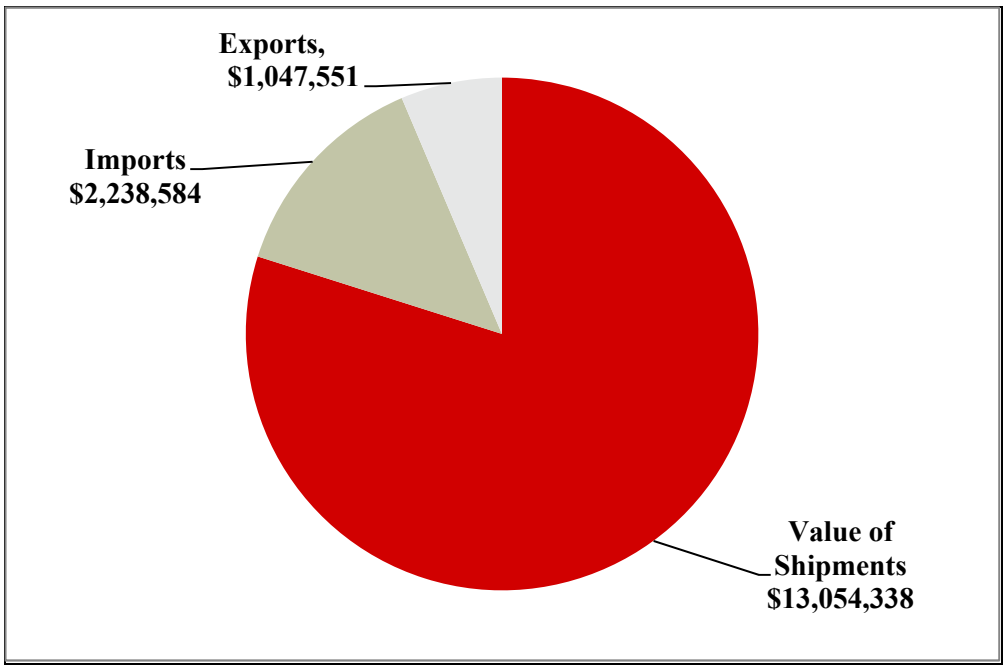
[2] U.S. Census Bureau 2011b

Notes: Imports and exports values are based on products (HTS codes) and not on industry classification (NAICS codes).

Import penetration figures are calculated as a ratio of imports over the value of domestic consumption.

Export intensity figures are calculated as a ratio of exports over the value of shipments.

Exhibit 3-5: Carpet and Rug Mills: Imports, Exports, Value of Shipments ($1,000), 2007



Sources: U.S. Census Bureau 2010; U.S. Census Bureau 2011b

3.4.1 U.S. International Trade Commission Data on Imports, 2000 – 2010

Historical import data on imports for carpets and treated textile fabrics are available from the U.S. International Trade Commission (U.S. ITC). Data on the following HTS codes were accessed via the Interactive Tariff and Trade DataWeb.

HTS Code	Description
57	Carpets and other textile floor coverings
5903*	Textile fabrics impregnated, coated, covered or laminated with plastics

Source: U.S. ITC 2010

*5903 HTS code is not specific to carpets and reflects all textile fabrics impregnated with plastics.

In addition to the phase-out of long-chain PFCs in carpet products by domestic manufacturers, EPA believes that LCPFC chemical substances are not being imported as part of carpet. As presented in Exhibit 3-6, only 16 percent of domestically consumed carpets and rugs are imported from abroad, while 84 percent of the product is manufactured in the U.S.

Long-chain PFCs may be imported into the U.S. from countries like China and applied to carpets domestically. We obtained relevant imports data from ITC and concluded that PFCs for which

imports data are available are not used in carpets.[9] EPA believes that imported carpets do not contain LCPFCs.

Exhibit 3-7 and Exhibit 3-8 present general imports ($1,000,000) for carpets and impregnated fabrics, respectively, for each year, from 2000 to 2010. From 2000 to 2010, carpet imports increased by 19 percent and impregnated fabric imports increased by 107 percent (more than doubled). The following figures present the time trend for these two industry sectors.

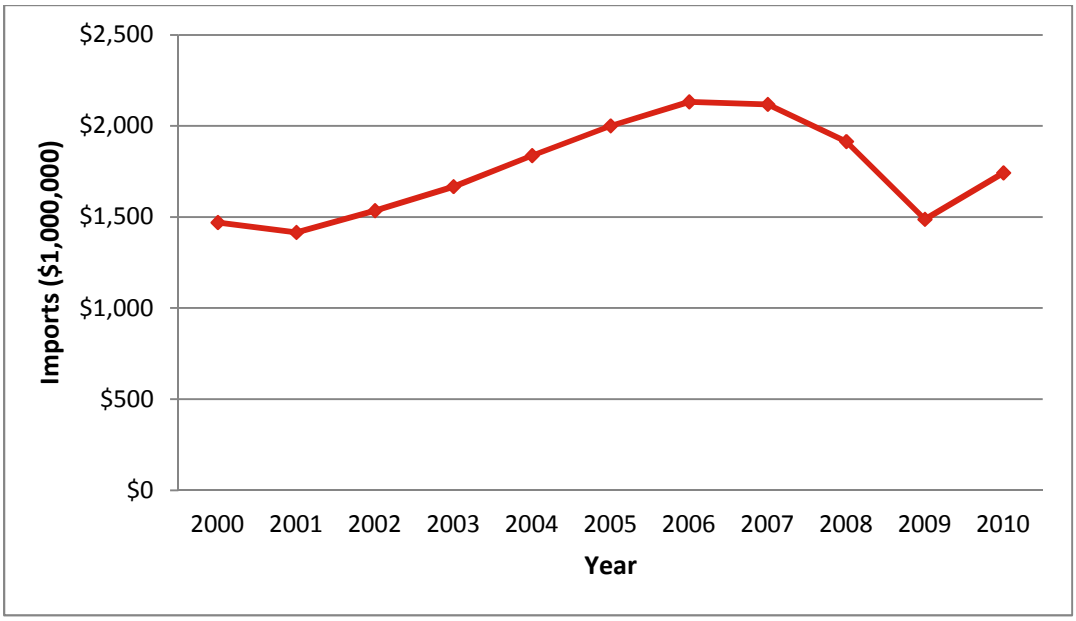
[9] As a result of our conversation with an ITC representative.

Exhibit 3-6: Carpet and Impregnated Fabrics: U.S. Imports, ($1,000,000)

Material	HTS Code	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	% Change (2000-2010)
Carpet	57	$1,469	$1,415	$1,535	$1,667	$1,838	$2,000	$2,133	$2,118	$1,914	$1,487	$1,742	**19%**
Impregnated Fabrics	5903	$281	$257	$318	$374	$427	$465	$521	$538	$525	$422	$581	**107%**

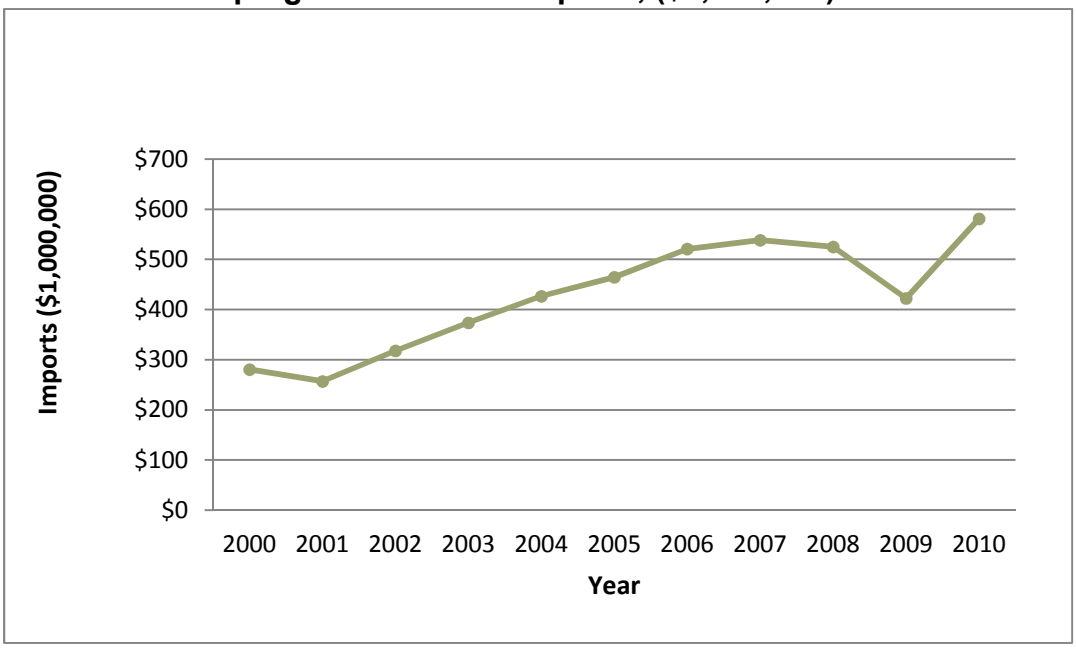
Source: U.S. ITC 2011

Exhibit 3-7: Carpet Imports, ($1,000,000)



Source: U.S. ITC 2011

Exhibit 3-8: Impregnated Fabrics Imports, ($1,000,000)



Source: U.S. ITC 2011

4. Role of PFCs in Carpet Manufacturing

Two broad types of fluorochemicals are used in carpets: fluorotelomers (described in Section 4.1) and perfluoroalkyl sulfate, PFAS (described in Section 4.2). According to 2006 data, carpet and carpet care products are the second largest group of consumer products manufactured using fluorotelomers, after apparel (U.S. EPA 2009b). Fluorotelomers are not manufactured using PFOA, but may degrade to form PFOA (U.S. EPA 2009b). Fluorotelomers are essentially polymers with a functional group on the end of the carbon chain (Danish Ministry of the Environment 2008). On the other hand, PFAS is a generic grouping term that encompasses any fully fluorinated carbon chain length sulfonate, including perfluorooctane sulfonate (PFOS) (OECD, 2007).

To date no evidence of fluoropolymers used in carpet treatment has been found.[10]

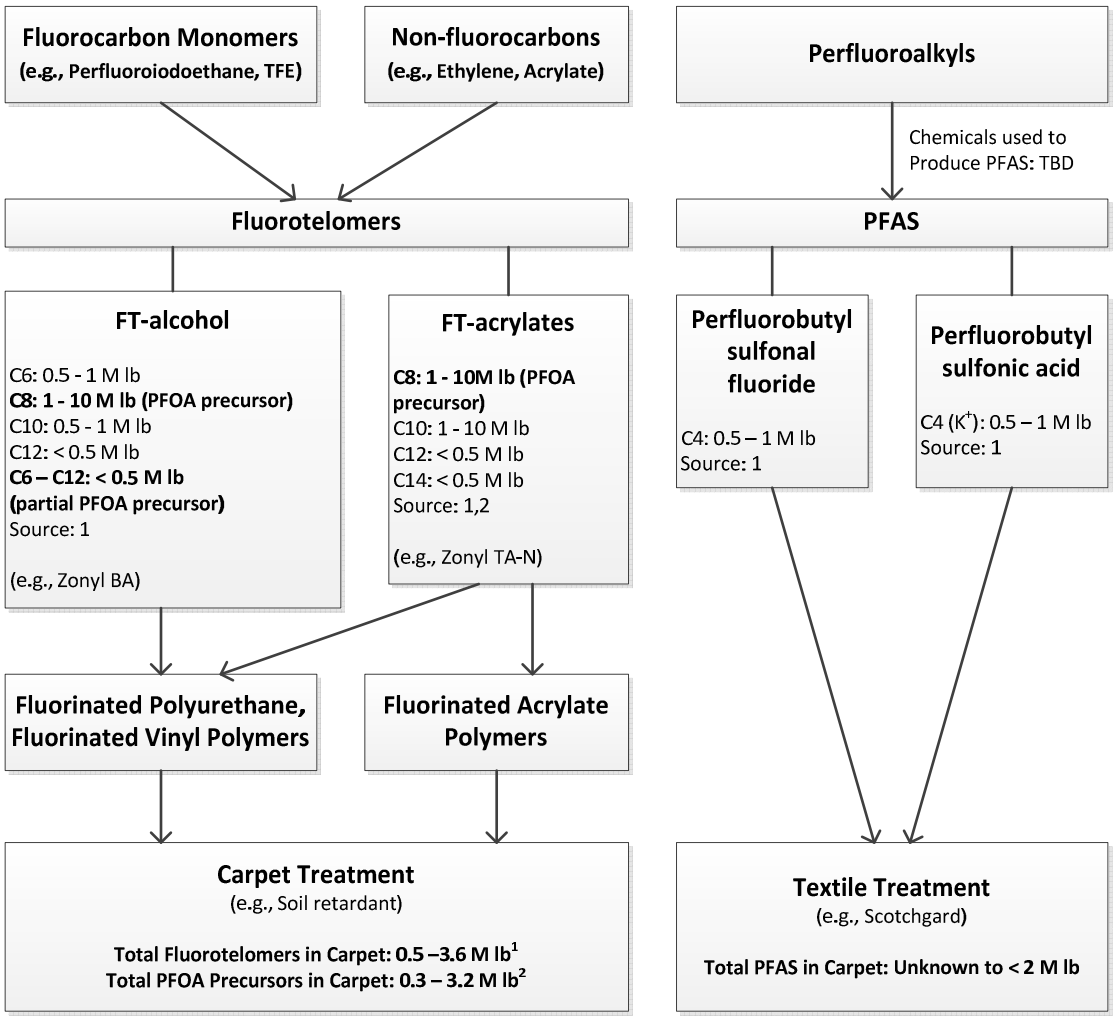
The flowchart below presents the broad categories of PFCs used in carpet treatments, their subcategories, and estimated production volumes of those chemicals. PFOA's presence in each chemical category was also identified.

The following abbreviations are used in the flowchart:

- FT: Fluorotelomer
- TFE: Tetrafluoro ethylene
- PFAS: Perfluoroalkyl sulfonate
- PFOA: Perfluorooctanoic acid

[10] As a result of a conversation with an ITC representative, we believe that none of the imports data on PFCs available through ITC are applicable to carpets.

Exhibit 4-1: PFCs in Carpet



[1] Represents sum of minimum and maximum of production volume range for fluorotelomers (3 – 23.5 M lb) times 15.5% for Carpet (US EPA, Pie Chart).

[2] Represents sum of minimum and maximum of production volume range for PFOA precursors, incl. partial (2 – 20.5 M lb) times 15.5% for Carpet (US EPA, Pie Chart).

4.1 Fluorotelomers in Carpets

Worldwide, repellents account for 4.1 percent of finishing products for textile applications; Fluorocarbons make up 59 percent of the repellents category, with paraffins (39 percent) and silicones (two percent) comprising the remaining portion (Schindler and Hauser 2004). Fluorotelomers are used in the textile market because of their thermo-stability, ability to adapt to a variety of surface

characteristics, low refractive indexes, low dielectric constants, and high chemical stability (Armeduri and Bouterin 2004). Fluorotelomers are used as soil retardants and stain repellents in carpets (Kissa, 2001).

Fluorotelomers are used to treat textiles which cannot be laundered, including carpets, by preventing or reducing the adhesion of liquid or solid contaminants to the textile fibers. Fluorotelomer carpet treatments are incorporated in polymers including *fluorinated polyurethanes*, *fluorinated vinyl polymers* (Kissa, 2001) and *fluorinated acrylate and methacrylate polymers* (Scheirs, 1998). These fluorinated polymers have a non-fluorinated backbone with fluorinated alkyl chains which provide the desired physical characteristics. Fluorinated polyurethanes are noted to be tough but resilient and can withstand foot traffic on carpets (Kissa, 2001). Fluoroacrylate and fluoromethacrylate polymers are used primarily for fibers and textiles (Drobny 2009), however, at least one company markets fluorinated acrylate polymers for use in carpets.[11] Exhibit 4-2 summarizes the fluorotelomers identified as ingredients in carpet treatments.

Exhibit 4-2: Fluorotelomers and Chemicals Containing Fluorotelomers Used in Polyurethane Resin

Chemical Formula	Chemical Description	Source
$F(CF2)_nOH$ n = 6–12	Perfluoroalkyl alcohol	Kissa, 2001
$F(CF_2)_nCH_2CH_2OH$ n = 6-14	Perfluoroalkylethyl alcohol	Kissa, 2001
$F(CF_2)_nCH_2CH_2OC(=O)NH(CH_2)_x$- n is unspecified	Perfluoroalkyl carbamic acid esters	Kissa, 2001
$F(CF_2)_8SO_2N(CH_3)CH_2CH_2OH$	*n*-Ethyl(perfluorooctane) sulfonamidoethyl alcohol	Kissa, 2001
$F(CF_2)_nSO_2CH(CH_3)CH_2OC(=O)C(CH_3)=CH_2$	Perfluoroalkylethyl methacrylate	Kissa, 2001
$F(CF_2)_nSO_2CH(CH_3)CH_2OC(=O)CCH_3=CH_2$ n is unspecified	Perfluoroalkylsulfonyl ethylmethacrylate	Kissa, 2001
$F(CF_2)_nCH_2CH_2C(=O)OCH=CH_2$ n is unspecified n = 6-12	Perfluoroalkylethyl acrylate	Kissa, 2001 Kissa, 2001
NA	Fluorinated acrylic resins	Scheirs, 1998
NA	Fluoroalkylethyl phosphates	Danish, 2008

Sources: Page 150 of Scheirs, 1998; Pages 565 - 568 of Kissa, 2001, Table 2.1, page 24 of Danish Ministry of Environment, 2008.

[11] Mason Chemical, e.g., Masurf® FS-810 Fluoroaliphatic Polyacrylate Oligomer Fluorosurfactant. http://www.masonsurfactants.com/Products/Masurf_FS_810.htm.

Exhibit 4-3 presents 2006 IUR production data for fluorotelomers used in polyurethane resin[12].

Exhibit 4-3: Fluorotelomers Used in Polyurethane Resin with 2006 IUR Production Data

CAS Number	Description	R_F Length	2006 IUR Production (lb)
Perfluoroalkylethyl Alcohol			
647-42-7	1-Octanol, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-	6	> 500K - 1M
678-39-7	1-Decanol, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluoro-	8	> 1M - 10M
865-86-1	1-Dodecanol, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-heneicosafluoro-	10	> 500K - 1M
39239-77-5	1-Tetradecanol, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,13,13,14,14,14-pentacosafluoro-	12	< 500K
68391-08-2	Alcohols, C8-14, γ-ω-perfluoro	6-12	< 500K
Perfluoroalkylethyl Acrylate			
17741-60-5	2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-heneicosafluorododecyl ester	10	> 1M - 10M
27905-45-9	2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl ester	8	> 1M - 10M
34362-49-7	2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,13,13,14, 14,15,15,16,16,16-nonacosafluorohexadecyl ester	14	< 500K
34395-24-9	2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,13,13,14,14,14-pentacosafluorotetradecyl ester	12	< 500K

Source: OECD 2007, U.S. EPA 2011a

[12] The 2006 IUR required reporting for chemicals manufactured or imported in quantities above a 25,000 lb site-specific production threshold. Thus, it is possible that fluorotelomers may be produced in quantities below this threshold and then used in carpets treatment products that are not included in the 2006 IUR dataset.

4.2 PFAS in Carpets

Perfluoroalkyl sulfonate (PFAS)[13] based compounds are used for treating textiles, fabrics and carpet, most notably under the trade name Scotchgard, owned by 3M. Scotchgard upholstery and fabric protectors are designed to repel spills and make clean-ups easier. It is also used to protect rugs and carpets against soiling and restore their original look. Prior to 2003, Scotchgard formulation was based on perfluorooctane sulfonate (PFOS) compounds, which contain *eight* perfluorinated carbons (considered a long-chain PFC). After 2003, 3M reformulated its Scotchgard product to be based on perfluorobutane sulfonate (PFBS) compounds containing *four* perfluorinated carbons (considered a short-chain alternative PFC) (Renner 2006).

It is important to note that based on the literature reviewed and the IUR data, we have not found any evidence that PFAS is currently used elsewhere in textile treatment, aside from PFBS in Scotchgard. Exhibit 4-4 presents 2002 and 2006 IUR production data for all PFAS based compounds. The specific PFAS compounds used in textiles and carpet are not known. In the 2002 IUR, 24 PFAS compounds were reported, with perfluorinated carbon chain lengths ranging from four to ten (OECD 2007). In 2006, only two PFAS compounds were reported, both of which are PFBS with perfluorinated carbon chain length of four (short-chain). Notably, the reformulation of Scotchgard in 2003 to short-chain PFC-based product corresponds with the lack of reported data on long-chain PFAS chemicals in the 2006 IUR data. All chemicals listed in Exhibit 4-4 were reported to IUR by 3M only.

Exhibit 4-4: PFAS Compounds with 2002, or 2006[14] IUR Production Volume

CAS Number	Description	Rf Length	IUR Production (lbs)	
			2002	2006
1763-23-1	1-Octanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-	8	10K - 500K	No Reports
29117-08-6	Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(heptadecafluorooctyl)sulfonyl] amino]ethyl]-ω-hydroxy-	8	10K - 500K	No Reports
67584–42–3	Cyclohexanesulfonic acid, decafluoro(pentafluoroethyl)-, potassium salt	8	10K - 500K	No Reports

[13] Perfluoroalkylsulfonates (PFAS) refers to the group of perfluorinated chemicals of any carbon chain length terminated with a sulfonate (-SO3-) functional group. The two PFAS compounds described in this section are perfluoro*butyl*solfuonate (PFBS; italics added to identify the infix describing carbon chain length), which contains four perfluorinated carbons, and perfluoro*octyl*sulfonate (PFOS; italics added to identify the infix describing carbon chain length), which contains eight perfluorinated carbons.

[14] 2006 is the latest year for which IUR data are available.

CAS Number	Description	Rf Length	IUR Production (lbs)	
			2002	2006
68867-62-9	2-Propenoic acid, 2-methyl-, 2-[ethyl[(heptadecafluorooctyl)sulfonyl] amino]ethylester, telomer with 2-[ethyl[(nonafluorobutyl)sulfonyl]amino]ethyl 2-methyl-2-propenoate, 2-[ethyl[(pentadecafluoroheptyl)sulfonyl]amino]ethyl 2-methyl-2-propenoate, 2-[ethyl[(tridecafluorohexyl)sulfonyl]amino]ethyl 2-methyl-2-propenoate, 2-[ethyl[(undecafluoropentyl)sulfonyl]amino]ethyl 2-methyl-2-propenoate, 1-octanethiol and α-(1-oxo-2-propenyl)-ω-methoxypoly(oxy-1,2-ethanediyl)	4-8	10K - 500K	No Reports
68958-61-2	Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(heptadecafluorooctyl)sulfonyl] amino]ethyl]-ω-methoxy-	8	10K - 500K	No Reports
306974–45–8	Sulfonic acids, C6-8-alkane, perfluoro, compds. with polyethylene-polypropyleneglycol bis(2-aminopropyl) ether	6-8	10K - 500K	No Reports
307–35–7	1-Octanesulfonyl fluoride, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-	8	10K - 500K	No Reports
375-72-4	1-Butanesulfonyl fluoride, 1,1,2,2,3,3,4,4,4-nonafluoro-	4	10K - 500K	>500K - 1M
376–14–7	2-Propenoic acid, 2-methyl-, 2-[ethyl[(heptadecafluorooctyl)sulfonyl]amino] ethylester	8	10K - 500K	No Reports
383–07–3	2-Propenoic acid, 2-[butyl[(heptadecafluorooctyl)sulfonyl]amino]ethyl ester	8	10K - 500K	No Reports
1691-99-2	1-Octanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-N-(2-hydroxyethyl)-	8	10K - 500K	No Reports
1869-77-8	Glycine, N-ethyl-N-[(heptadecafluorooctyl)sulfonyl]-, ethyl ester	8	10K - 500K	No Reports
2263-09-4	1-Octanesulfonamide, N-butyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-N-(2-hydroxyethyl)	8	10K - 500K	No Reports
2795-39-3	1-Octanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-,potassium salt	8	10K - 500K	No Reports
4151-50-2	1-Octanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-	8	10K - 500K	No Reports
13417-01-1	1-Octanesulfonamide, N-[3-(dimethylamino)propyl]-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-	8	10K - 500K	No Reports
29420-49-3	1-Butanesulfonic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, potassium salt	4	10K - 500K	< 500K

CAS Number	Description	Rf Length	IUR Production (lbs)	
			2002	2006
31506-32-8	1-Octanesulfonamide, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-N-methyl-	8	10K - 500K	No Reports
34454-97-2	1-Butanesulfonamide, 1,1,2,2,3,3,4,4,4-nonafluoro-N-(2-hydroxyethyl)-N-methyl-	4	10K - 500K	No Reports
50598-28-2	1-Hexanesulfonamide, N-[3-(dimethylamino)propyl]-1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-	6	10K - 500K	No Reports
56773-42-3	Ethanaminium, N,N,N-triethyl-, salt with 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonic acid (1:1)	8	10K - 500K	No Reports
67906-42-7	1-Decanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heneicosafluoro-, ammonium salt	10	10K - 500K	No Reports
68156-06-9	Cyclohexanesulfonyl fluoride, decafluoro(pentafluoroethyl)-	8	10K - 500K	No Reports
307-35-7	Perfluoro-1-octanesulfonyl fluoride	8	10K - 500K	No Reports

Source: OECD 2007, U.S. Environmental Protection Agency (U.S. EPA) 2011a, b.

Note: Grey highlights indicate chemicals with production data for 2006.

5. Availability of Alternatives

Short chain fluorotelomers are being used as substitutes for long chain fluorotelomers in products such as textile, carpet and paper additives uses, and tile surface treatments. As of April 2010, EPA received a total of more than 75 PMN notices for short chain fluorotelomers (U.S. EPA 2010). Furthermore, through the end of 2008, over 100 alternatives of various types have been received and reviewed by EPA (U.S. EPA 2009a).

It is important to note that while fluorotelomers, such as substances with an alkyl chain length of C6 or less, have been used as substitutes for PFOS in a variety of products, telomerization results in various telomers of different chain lengths, even if the majority has less than six carbons (Danish Ministry of the Environment 2008). Thus, impurities could be found in the short chain products.

Below is a list of alternatives developed by major manufacturers of PFC-based carpet products. Note that for Clariant, AGC, and BASF, some of the alternatives may not be used on carpets – the manufacturer websites do not always provide sufficient information on specific product uses.

5.1 Clariant

Clariant developed a product series, called Nuva® N, which uses short-chain (C6) chemistry. One product, called Nuva® N2116 liq, is a PFOA-free[15] repellent for synthetic fibers and nonwovens, and can be used on a variety of textiles.[16] Another PFOA-free repellent product, called Nuva® N2114 liq, is used in a variety of textiles including, but not limited to, sunshades, umbrellas, shoes, bedding, mattress protectors, military uniforms, and sportswear.[17] Nuva® N5151 liq is a PFOA-free, soil and stain repellent product for foam applications which can be used on carpets.[18]

5.2 DuPont

DuPont developed an alternative to PFOA-based fluorotelomer products in a step toward reaching PFOA elimination targets under EPA's PFOA Stewardship Program (DuPont 2011). A new line of surface protection products, Capstone™, based on short-chain chemistry (short-chain molecules that cannot break down to PFOA in the environment), is an alternative to fluorotelomer-based products such as Zonyl®. Capstone® repellents and surfactants are based on short-chain technology consisting

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[15] It is important to note that when a fluoropolymer is called PFOA-free, it means that the PFOA content is below the limit of detection.

[16] Clariant Textile Chemicals: Nuva® N2116 liq. 2011. Available at: http://www.textiles.clariant.com/C12571C400483A78/vwWebPagesByID/8A961FBAA5272607C12575D00048F470 (Accessed October 3, 2011).

[17] Clariant Textile Chemicals: Nuva® N2114 liq. 2011. Available at: http://www.textiles.clariant.com/C12571C400483A78/vwWebPagesByID/ABCE5BDE71BE7555C12572AC0049E92D (Accessed October 3, 2011).

[18] Clariant Textile Chemicals: Nuva® N5151 liq. 2011. Available at: http://www.textiles.clariant.com/C12571C400483A78/vwWebPagesByID/506A4218AA031289C12575D00048FF30 (Accessed October 3, 2011).

of six or fewer fluorinated carbons, bound to a "delivery system" such as a polymer or surfactant. DuPont Capstone™ products for textile finishes provide a step-change reduction in trace impurities below the limit of detection, designed to offer the same or better performance than their predecessors without compromising fluorine efficiency. Capstone™ products also meet the goals of the U.S. EPA 2010/15 PFOA Stewardship Program targets for PFOA and precursors.

For the vast majority of textiles applications, including mills and finishers, DuPont™ Capstone™ products are the key ingredient in fabric finishes for apparel, home furnishings and other textiles that will be sold to mills by Huntsman under the Huntsman trade name Oleophobol® CP.

DuPont™ Capstone® products are commercially available in home furnishings, firefighting foam, fluorosurfactants, paper packaging, textiles, stone and tile, and leather end uses. DuPont's goal is to transition the majority of the textiles business to short-chain chemistry by the end of 2010.[19]

DuPont has developed LX Platform of fluorotelomer-based products that includes DuPont™ Teflon®, Zonyl® and Foraperle® technologies.[20] LX Platform products meet high performance and value requirements, while removing nearly all trace levels of PFOA and direct precursors to PFOA. The LX Products are among the world's first commercial fluorotelomer products to meet the EPA's PFOA and direct precursor reduction criteria (including the reduction of higher homologue acids and direct precursors).[21] Because the LX Platform products were developed using technology to remove unintended levels of PFOA and direct precursors, they are intended to be drop-in replacements for the existing DuPont products that do not require new equipment or investments, causing no disruption or delay in the manufacturing process.

DuPont claims that this new manufacturing process will remove greater than 97 percent of all trace levels of PFOA, its homologues and direct precursors from the LX Platform Products. DuPont also states that telomer chemistry, on which LX Platform Products are based, is not made with PFOA, nor is PFOA added during the manufacture of DuPont telomer-based products. However, PFOA is found at trace levels in some fluorotelomer products as an unintended byproduct of the manufacturing process. DuPont believes that no one can substantiate statements that fluorotelomer products are "PFOA Free" or have "Zero PFOA" even if test results are below the limit of detection. DuPont believes such a claim must be made with scientific accuracy, and analytical methods continue to advance to ever-lower detection limits.[22] DuPont states that their LX Platform Products are listed on global regulatory clearances, such as the U.S. (TSCA), Europe (EINECS), Canada (DSL) and Japan (ENCS).[23]

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19 http://www2.dupont.com/Capstone/en_US/uses_apps/textiles/textiles.html

20 DuPont. 2011. Textiles and Carpet Care. Available at: http://www2.dupont.com/Zonyl_Foraperle/en_US/uses_apps/carpet_pgs/textiles.html (Accessed 11/28/2011).

21 http://www2.dupont.com/Zonyl_Foraperle/en_US/products/lx.html

22 http://www2.dupont.com/Capstone/en_US/prod_steward/claims_you_can_trust.html

23 DuPont. 2011. Textiles and Carpet Care. Available at: http://www2.dupont.com/Zonyl_Foraperle/en_US/uses_apps/carpet_pgs/textiles.html (Accessed 11/28/2011).

While DuPont is not using long chain PFCs in its products, fluorinated telomers may break down into long chain PFCs as unintended byproducts of the manufacturing process.

5.3 AGC Chemicals Americas (Asahi)

AGC Chemicals Americas, Inc., a subsidiary of the Asahi Glass Company of Japan, produces fluorotelomers and flouropolymers (e.g., PTFE, and carboxylate) that are used heavily in textiles. AGC Chemicals Americas manufactures a fluoropolymer, known as their Fluon® PTFE (Polytetrafluoroethylene) Resins.[24] This resin is manufactured in three forms: as an aqueous dispersion, a coagulated dispersion, or as granular powders. Fluon® PTFE can be used to make textile membranes. Aqueous dispersions of Fluon® PTFE can be used to make coatings for woven fabrics.[25]

AGC has developed a stain resistant and water and oil repellent PFC product, Guard E-SERIES.[26] This product does not contain PFOA or long-chain PFCs and their precursors. Instead, this product has six carbons, which is considered a short chain PFC. These PFCs are applied to textiles because the product imparts stain resistance and water and oil repellency, while still maintaining the texture, breathability and color of the textile. The Guard E-SERIES essentially keeps textile products, such as fabric and leather, looking new for longer. Furthermore, this product can also be used in applications such as food wrapping materials, trays, cooking paper, water repellent tents, paper, and board.

5.4 Daikin Industries

Daikin Industries, Ltd and its subsidiaries are attempting to stop manufacturing, selling, and using PFOA C8 telomer-based water and oil repellent products by the end of 2012. Daikin specifically uses PFOA as a polymerization aid for the manufacture of some of its fluoropolymers and fluoroelastomers. They are planning on manufacturing alternatives with processing aids that are not PFOA, by 2012. They have also developed a short chain, C6, alternative for their water/ oil repellent C8 fluorotelomer products. Daikin has already begun the process of replacing these products (Daikin Industries Ltd 2011b).

Daikin Industries, Ltd has jointly developed a product with Dow Corning Corporation called UNIDYNE Multi-Series™.[27] UNIDYNE Multi-Series™ products are made from C6. Specifically,

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[24] AGC Chemicals Americas Inc. 2011a. "Fluon® PTFE Resins." Available at: http://www.agcchem.com/products/fluoropolymer-resins-compounds/fluon-ptfe-resins (Accessed September 29, 2011).

[25] AGC Chemicals Americas Inc. 2011b. “Coagulated Dispersion Polymers.” Available at: http://www.agcchem.com/docs/fluon-technical-data/2011/03/16/Fluon®%20Coagulated%20Dispersion%20Polymers.pdf?Status=Master (Accessed September 29, 2011).

[26] AGC Chemicals Americas, Inc (AGC). “Asahi Guard E-SERIES.” Available at: http://www.agcchem.com/products/specialty-chemicals/asahi-guard-e-series (Accessed September 28, 2011).

[27] Daikin Industries Ltd. 2011. "Activities for Environmental Issues of UNIDYNE™ " Available at: http://www.daikin.com/chm/pro/kasei/unidyne_multi/feature/env.html (Accessed September 30, 2011).

these products use ifluoro-silicone hybrid technology.[28] Exhibit 5-1 provides a list of these products and their features.

Exhibit 5-1: UNIDYNE Multi-Series™ Water and Oil Repellent Products

Product Name	Features
TG-5601	Soft-hand feel; high wash durability
TG-5541	Soft-hand feel; high water repellency
TG-5543	Soft-hand feel; high wash durability
TG-5502	High water bearing pressure; high alcohol resistance
TG-8111	Oil and grease resistance to paper products

Source: Daiken Industries Ltd. 2012.

Note: TG-5601, TG-5541, and TG-5543 were jointly developed with Dow Corning Corporation.

5.5 Solvay Solexis

In 2009, Solvay Solexis announced that it had developed an alternative to PFOA that will be used in its products. Specifically, the PFOA-free Fluorolink products were developed for textile and leather good surface treatment in which the PFPE structure delivers reduction of surface energy, water and oil repellency, and stain and soil resistance. The Fluorolink products are based on a perfluoropolyether structure (rather than perfluoroalkyl) which contains functional groups that are able to facilitate interactions with the targeted substrate.

The Fluorolink products can be used on natural and synthetic fibers, washable fabrics like domestic and industrial clothing, and furniture fabrics requiring stain and soil release properties. Additionally, Fluorolink products can be used for upholstery, wall coverings, and rugs that require durable stain release or rainwear, awnings, or sportswear that require highly durable water repellency[29].

5.6 BASF

BASF has developed the Lurotex Duo Systems for stain repellent and stain release to protect textiles from soiling and staining. The technology is made up of a Lurotex fluorocarbon finish based on advanced C6 technology compared to the current C8 technology which allows for an undetectable amount of PFOA.

The Lurotex products can be used in consumer apparel like rainwear, business wear, casual wear or corporate wear. They can also be used in home textiles like upholstery, tablecloths, drapes, mattress

[28] Daikin Industries Ltd. 2011. "Water and Oil Repellents." Available at: http://www.daikin.com/chm/products/fiber/index.html (Accessed September 30, 2011).

[29] Solvay Solexis, 2009. "Textiles and Leather." Available at: http://www.solvaysolexis.asia/marketsapps/specificmarket/marketapplication/0,,40542-2-0,00.htm. (Accessed October 3, 2011).

covers, and bed linen. Additionally, the Lurotex alternative technology can be used in technical textiles like awnings, parasols, tents, luggage, and transportation fabrics.[30]

5.7 Advanced Polymer Inc.

Advanced Polymer has a line of short-chain PFC and PFOA-free technologies used in textiles called AdvaPel. AdvaPel-712 is a C6 based, non-PFOA contributing, waterborne, cationic, fluoropolymer emulsion system designed to impart oil, water and soil repellency to apparel, carpeting and automotive fabrics. AdvaPel-734 is a water-based, air dry, fluorochemical finishing agent that imparts water, oil and soil repellency to textiles, upholstery and carpeting. AdvaPel -734 is a non-C8 based fluoroalkyl compound and is considered PFOA-free.[31]

5.8 3M

As aforementioned in Section 4.2, prior to 2003, 3M produced a product containing PFOS called Scotchgard™, which protected textiles from stains and soil. 3M began a voluntary phase out of PFOS- and PFOA-based products on May 16, 2000 (Hakes and Jariwala 2010). 3M's new Scotchgard™ product contains PFBS (Perfluorobutane Sulfonate), which has a 4 carbon chain, as opposed to the 8 carbon chain present in PFOS (EWG 2011). These products can be used as oil and water repellents coatings for apparel, carpets, furniture, and leather (Hakes and Jariwala 2010).

5.9 Other Alternatives

A research paper (Lindemann 2007) evaluating commercially available PFOA-free repellent finishes was developed at North Carolina State University in 2007. A list of alternative finishes was developed and a number of products were selected for evaluation. Results of the work indicated that none of the commercially available alternatives tested performed at the same level as the traditional PFOA-containing products. Short-chain PFCs showed the highest level of performance. These were the only products which were able to provide oil repellency. Silicone and hydrocarbon wax products were also evaluated and showed varying levels of performance.

The two primary non PFC-based alternatives for fluorocarbon finishes are (1) hydrocarbon hydrophobes and (2) polysiloxane based finishing options. Paraffin wax containing repellents are the oldest and least expensive water repellent finishing option for textiles. Paraffin wax containing repellents (hydrocarbon wax) are both inexpensive and PFOA free. They are applied as aluminum or zirconium soaps. Several other waxes have been developed, but there have been significant issues that have affected the viability of these options in the textile industry. For example, DuPont created Chrome complexes, a wax based finish, which unfortunately had a blue/green color to it. Two other waxes, Pyridinium complexes and N-methylol compounds, may release formaldehyde, a possible carcinogen.

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30 BASF, 2010. "Lurotex®Duo Systems for stain repellent and stain release." Available at: http://www.performancechemicals.basf.com/ev-wcms-in/internet/en_GB/portal/show-content_tc/content/EV/EV8/textile_processing/lurotex/lurotex. (Accessed October 3, 2011).

31 http://www.advpolymer.com/index.php/products/chemistry/fluoropolymers/

Polysiloxane based finishes are water repellent, but may also be a better alternative than Paraffin wax because they are considered more durable, have a better tear strength, improved sewability, and impart a softer feel to the material (referred to as soft hand).[32] One of the benefits of polysiloxanes is that they do not lose their water repellency after being washed, which tends to be the case for fluorocarbon finishes.[33] However, one of the disadvantages to polysiloxanes is that repellency can decrease with over-application, or even be lost if the layer of polysiloxane layer is cracked.[34] Furthermore, neither hydrocarbon waxes nor polysiloxanes have the property of oil repellency.[35]

Lindemann (2007) also evaluated other alternatives in the early stages of development. The following three methods are being researched and developed (as of 2007), and could be viable alternatives for finishing in the future. Plasma aided textile finishing is a "dry" process, instead of "wet" finishing process, which would get rid of waste water and the fabric drying processes. Another benefit of this alternative is that it does not affect fabric properties. One study, by Zhang, et al. compared plasma finishing with a fluorocarbon and Scotchgard™ and found that the plasma treatment worked well in a variety of areas, including softness, whiteness of the samples, water vapor permeability, and abrasion resistance.[36]

Another possible method looks at surface roughness, which increases wetting properties because of the increased surface area.[37] In one research study, the researchers created an ultra-hydrophobic surface on a microfiber polyester fabric, based on the findings on surface roughness.[38] Several other studies have been conducted that look into the relationship between the texture of a surface and water repellency.

Finally, fluorinated polysiloxanes may also become an alternative. One study, by Shao, et al., looked at a perfluoroalkly-containing multi-epoxy compound (PFME) and found that the chemical was oil repellent and had moderate durable press properties.[39]

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32 In Lindemann 2007 this information comes from: Schindler, W. D.; Hauser, P. J.; Textile Institute in Chemical Finishing of textiles; Crc; Woodhead: Boca Raton; Cambridge, England, 2004, pp 213.

33 In Lindemann 2007 this information comes from: Lee, M.; Nishi, K.; Jeong, D. S.; Tokuyama, T.; Itazu, T.; Miyaji, Y.; Wakida, T. Sen'i Gakkaishi 2005, 61, 309.

34 This can occur during washing.

35 In Lindemann 2007 this information comes from: Kissa, E. In Fluorinated surfactants and repellents; Surfactant Science Series; Marcel Dekker: New York, 2001; Vol. 97, pp 615. and Schindler, W. D.; Hauser, P. J.; Textile Institute in Chemical Finishing of textiles; CRC; Woodhead: Boca Raton; Cambridge, England, 2004, pp 213.

36 In Lindemann 2007 this information comes from: Zhang, J.; France, P.; Radomyselskiy, A.; Datta, S.; Zhao, J. A.; van Ooij, W. J Appl Polym Sci 2003, 88, 1473.

37 In Lindemann 2007 this information comes from: Bico, J.; Marzolin, C.; Quere, D. Europhys. Lett. 1999, 47, 220.

38 In Lindemann 2007 this information comes from: Gao, L. C.; McCarthy, T. J. Langmuir 2006, 22, 5998.

39 In *Lindemann 2007* this information comes from: *Shao, H.; Sun, J. Y.; Meng, W. D.; Qing, F. L. Text. Res. J. 2004, 74, 851.*

5.10 Conclusions

As a result of our research on alternative technologies and products used for carpet treatment, we found that major manufacturers of PFC-based carpet products currently offer alternative products that use short-chain PFCs. Additional research is needed to assess performance of those alternative products in comparison to LCPFC-based products.

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