Industry Profile for the Flexible Polyurethane Foam Industry- Generic Scenario for Estimating Occupational Exposures and Environmental Releases -Draft-

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1.0 INTRODUCTION

This document was prepared for U.S. EPA's Design for the Environment Program (DfE). In the past, DfE has worked with and researched industries that use diisocyanates, including the autorefinishing and the polyurethane foam industries, to assess potential sources of emissions and to identify best practices and controls to eliminate or reduce these emissions. Diisocyanates are skin sensitizers and are reported to be the leading cause of occupational asthma. Industries using diisocyanates may pose a health risk to workers or nearby communities if proper personal protective equipment and controls are not used. Diisocyanates are a key ingredient in the manufacturing of flexible polyurethane foam. This document profiles the flexible polyurethane foam industry, its use of diisocyanates, and its use of other chemicals of concern.

The following sections of this document describe the flexible polyurethane foam industry, the manufacturing process of flexible polyurethane foam, the releases and associated occupational exposures from the manufacturing process, related control technologies and personal protective equipment, and regulations governing the use and potential release of diisocyanates in the industry.

2.0
FLEXIBLE POLYURETHANE FOAM INDUSTRY BACKGROUND

The flexible polyurethane foam industry produces many different manufactured products, including products made from slabstock and molded foam. Flexible polyurethane foam applications include:

- Automotive seat cushions and padding
- Mattress foam padding
- Furniture foam padding
- Pillows
- Flooring (carpet underlay)

2.1 SIC-NAICS Classification

The Standard Industrial Classification (SIC) System was developed in the 1930's to categorize industry into numeric groups. Throughout the years the SIC system has been updated and revised with the latest update to the classification occurring in 1987. Many U.S. economic and environmental databases have historically presented and analyzed industry data based on SIC codes.

On April 9, 1997, the Office of Management and Budget (OMB) announced its decision to adopt the North American Industry Classification System (NAICS) to replace the 1987 SIC system. The NAICS codes have at 6 to 10 digits compared to the 4-digit SIC system, thus allowing the NAICS codes to categorize smaller industry segments than the SIC system. The U.S. Census presents economic industry data for industry sectors according to 6-digit NAICS codes and in some cases, provides data for smaller specialized industry segments up to the 10-digit level.

Due to the fairly recent adoption of the NAICS codes, some economic and environmental data sets are only available based on the SIC codes rather than the more current, and more specific, NAICS codes. Therefore, both classification systems were used to obtain data and characterize the foam industry for this report.

The following subsections describe the SIC code and NAICS code industry sectors relevant to the flexible polyurethane foam industry. As discussed below, the NAICS codes more specifically categorize and differentiate the flexible polyurethane foam industry than the SIC codes. Therefore, when possible, information presented by NAICS codes is used in this report. Specifically, economic data such as number of workers, number of facilities, and size of the flexible polyurethane foam industry is available and presented according to NAICS codes. All Toxic Release Inventory (TRI) data presented in this report, however, is reported by SIC codes.

SIC Codes

The relevant SIC code considered in this report for the flexible polyurethane foam industry is SIC code 3086, “Plastics Foam Products”. This category includes facilities that manufacture the following products.

- Cups, foamed plastics
- Cushions, carpet and rug, plastic foam
- Foam plastic products
- Ice chests or coolers, portable, foamed plastics
- Insulation and cushioning, foamed plastics
- Packaging, foamed plastics
- Plates, foamed plastics
- Shipping pads, plastic foam

From the list of categories shown above, flexible polyurethane foam is expected to be included in 1) cushions, carpet and rug, plastic foam; 2) foam plastic products; and 3) insulation and cushioning, foamed plastics. Therefore, flexible polyurethane foam manufacturing is a subset of the SIC 3086 industry sector which encompasses other foaming industries. As a result data obtained for the SIC 3086 industry sector will represent an overestimate of economic and environmental release data for flexible polyurethane foam.

NAICS Codes

The NAICS code for urethane foam product manufacturing (NAICS 326150) is more specific than the SIC 3086. This NAICS code encompasses only manufacturers of rigid and flexible urethane foam. The NAICS Bridge (a comparison of the NAICS and SIC codes) indicates that NAICS 326150 industry sector comprises 57 percent of the facilities covered under SIC 3086.

2.2 Industry Size

An analysis of the 1997 Manufacturers Census for NAICS 326150 provides details of the industry sector using 10-digit NAICS Codes (18). Table 2-1 presents the shipping value of the sub-industries in NAICS 326150. While these data are somewhat outdated, the qualitative and relative magnitude of the shipments values from 1997 within the NAICS 326150 may be used as an indicator of current and relevant size of the sub-sectors of NAICS 326150. The 2002 Census reports are expected to have more detailed and more recent data. They will be published over a two year period spanning early 2004 through 2006.

Based on the description assigned to each sub-industry in NAICS 326150, the data presented in Table 2-1 were reorganized to reflect the two categories of products that may be expected from each sub-industry: flexible polyurethane foam and rigid polyurethane foam. A third category was added ("Undetermined") to identify those sub-industries for which a determination of the product-type could not be made based on the NAICS description. Table 2-2 presents the results of this analysis. In general, polyurethane foams used in transportation, furniture, mattresses, and carpets were assumed to be predominantly flexible foam, based on known uses of polyurethane foam for these industries. Polyurethane foams used in construction and electronic wiring were assumed to be predominantly rigid foam, based on known uses of rigid foams used for roofing and insulation.

According to the Table 2-2 analysis, flexible foam manufacturing comprised at least 58 percent of the NAICS 326150 industry by shipment value and at least 45 percent of the industry by total facilities in 1997. Of this portion of the Urethane and Other Foam Products industry, "polyurethane foam formed and slabstock for pillows, seating, and cushioning" represents the largest share of shipment value, at 25 percent of total flexible foam shipments. Table 2-3 presents the 10-digit NAICS 326150 that represent the flexible polyurethane foam industry and their percent of the total NAICS 326150 sector.

Table 2-1

1997 Manufacturing Industry Series: Shipping Value Data for NAICS 326150: Urethane and other (nonpolystyrene) Foams

NAICS CODES FOR URETHANE FOAMS					Number companies with >$99,999	Shipments Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Description		6-Digit	7-Digit	8-Digit	10-Digit
326150				Urethane and foam products other than polystyrene	N	$6,196,664			
	3261501			Transportation polyurethane foam products	N		$1,260,730		
		32615011		Transportation polyurethane foam products	N			$1,260,730	
			3261501101	Transportation polyurethane foam products, molded seating	15				$460,348
			3261501102	Transportation polyurethane foam products, cut slabstock for seating and trim	20				$98,494
			3261501103	Transportation polyurethane foam products, other molded including headrest, armrest, etc.	30				$595,685
			3261501Y	Transportation polyurethane foam products, nsk	N				$106,203
	3261502			Packaging polyurethane foam products	N		$342,491		
		32615021		Packaging polyurethane foam products	N			$342,491	

Table 2-1 (continued)

1997 Manufacturing Industry Series: Shipping Value Data for NAICS 326150:

Urethane and other (nonpolystyrene) Foams

NAICS CODES FOR URETHANE FOAMS					Number companies with >$99,999	Shipments Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Description		6-Digit	7-Digit	8-Digit	10-Digit
			3261502116	Polyurethane foam protective shipping pads and shaped cushioning (peanuts,disks,etc)	46				$97,964
			3261502196	Other polyurethane foam packaging products	33				$244,527
			3261502Y	Packaging polyurethane, nsk	N		$13,534		
	3261503			Building and construction polyurethane foam products	N		$481,221		
		32615031		Building and construction polyurethane foam products	N			$477,424	
			3261503116	Building and construction polyurethane foam insulation (including pipe and block)	24				$287,933
			3261503196	Other building and construction polyurethane foam products	19				$189,491
		3261503Y		Building and construction polyurethane foam, nsk	N			$3,797	
	3261504			Furniture and furnishings polyurethane foam products	N		$2,224,120		

Table 2-1 (continued)

1997 Manufacturing Industry Series: Shipping Value Data for NAICS 326150:

Urethane and other (nonpolystyrene) Foams

NAICS CODES FOR URETHANE FOAMS					Number companies with >$99,999	Shipments Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Description		6-Digit	7-Digit	8-Digit	10-Digit
		32615041		Polyurethane foam formed and slabstock for pillows, seating, and cushioning	N			$886,141	
			3261504110	Polyurethane foam formed and slabstock for pillows, seating, and cushioning	36				$886,141
		32615042		Other polyurethane foam furniture and furnishings products	N			$1,085,685	
			3261504215	Polyurethane foam carpet underlay, carpet and rug cushions, prime	12				$350,011
			3261504216	Polyurethane foam carpet underlay, carpet and rug cushions, bonded	11				$289,127
			3261504227	Polyurethane foam mattress cores (uncovered only)	11				$60,325
			3261504228	Polyurethane foam topper pads and quilting rolls	12				$77,134
			3261504237	Other furniture and furnishings polyurethane foam products	17				$309,088
		3261504Y		Furniture and furnishings polyurethane foam, nsk	N			$252,294	
	3261505			Consumer and institutional	N		$192,780		

Table 2-1 (continued)

1997 Manufacturing Industry Series: Shipping Value Data for NAICS 326150:

Urethane and other (nonpolystyrene) Foams

NAICS CODES FOR URETHANE FOAMS					Number companies with >$99,999	Shipments Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Description		6-Digit	7-Digit	8-Digit	10-Digit
				polyurethane foam products					
		32615051		Consumer and institutional polyurethane foam products	N			$192,780	
			3261505100	Consumer and institutional polyurethane foam products	37				$192,780
	3261506			Miscellaneous polyurethane foam products, nec	N		$332,533		
		32615061		Miscellaneous polyurethane foam products, nec	N			$325,919	
			3261506116	Electrical and electronic polyurethane foam products	32				$182,207
			3261506196	Other polyurethane foam products, including medical, clothing, fillers, diapers, etc.	23				$143,712
		3261506Y		Miscellaneous polyurethane foam products, nec, nsk	N			$6,614	
	3261509			Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.	N		$968,036		

Table 2-1 (continued)

1997 Manufacturing Industry Series: Shipping Value Data for NAICS 326150:

Urethane and other (nonpolystyrene) Foams

NAICS CODES FOR URETHANE FOAMS					Number companies with >$99,999	Shipments Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Description		6-Digit	7-Digit	8-Digit	10-Digit
		32615091		Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.	N			$968,036	
			3261509100	Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.	84				$968,036
	326150W	326150W		Polyurethane and other foam products, nsk, total	N		$381,219		

N = not provided.
nec = Not elsewhere classified.
nsk = Not specified by kind.

Table 2-2

NAICS Sub-Industry Categorized by Assumed Product

1997 Manufacturing Industry Census

NAICS CODES FOR URETHANE FOAMS		Shipments Value per NAICS ($1000)		
		Flexible Foam	Rigid Foam	Undetermined
3261501101	Transportation polyurethane foam products, molded seating	460,348		
3261501102	Transportation polyurethane foam products, cut slabstock for seating and trim	98,494		
3261501103	Transportation polyurethane foam products, other molded including headrest, armrest, etc.	595,685		
3261501Y	Transportation polyurethane foam products, nsk	106,203		
3261502116	Polyurethane foam protective shipping pads and shaped cushioning (peanuts, disks, etc.)	97,964		
3261502196	Other polyurethane foam packaging products			244,527
3261502Y	Packaging polyurethane, nsk			13,534
3261503116	Building and construction polyurethane foam insulation (including pipe and block)		287,933	
3261503196	Other building and construction polyurethane foam products		189,491	
3261503Y	Building and construction polyurethane foam, nsk		3,797	
3261504110	Polyurethane foam formed and slabstock for pillows, seating, and cushioning	886,141		
3261504215	Polyurethane foam carpet underlay, carpet and rug cushions, prime	350,011		
3261504216	Polyurethane foam carpet underlay, carpet and rug cushions, bonded	289,127		
3261504227	Polyurethane foam mattress cores (uncovered only)	60,325		

Table 2-2 (continued)

NAICS Sub-Industry Categorized by Assumed Product

1997 Manufacturing Industry Census

NAICS CODES FOR URETHANE FOAMS		Shipments Value per NAICS ($1000)		
		Flexible Foam	Rigid Foam	Undetermined
3261504228	Polyurethane foam topper pads and quilting rolls	77,134		
3261504237	Other furniture and furnishings polyurethane foam products	309,088		
3261504Y	Furniture and furnishings polyurethane foam, nsk	252,294		
3261505100	Consumer and institutional polyurethane foam products			192,780
3261506116	Electrical and electronic polyurethane foam products		182,207	
3261506196	Other polyurethane foam products, including medical, clothing, fillers, diapers, etc.			143,712
3261506Y	Miscellaneous Polyurethane foam products, nec			6,614
3261509100	Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.			968,036
326150W	Polyurethane and other foam products, nsk, total			381,219
TOTAL SHIPMENT VALUE		3,582,814	663,428	1,950,422
PERCENT SHIPMENT VALUE OF TOTAL		58%	11%	31%

nec = Not elsewhere classified.
nsk = Not specified by kind.

Table 2-3

Distribution of Flexible Foam Sub- Industry

Based on 1997 Shipment Value

NAICS CODES FOR URETHANE FOAMS		**%**
3261504110	Polyurethane foam formed and slabstock for pillows, seating, and cushioning	25%
3261501103	Transportation polyurethane foam products, other molded including headrest, armrest, etc.	17%
3261501101	Transportation polyurethane foam products, molded seating	13%
3261504215	Polyurethane foam carpet underlay, carpet and rug cushions, prime	10%
3261504237	Other furniture and furnishings polyurethane foam products	9%
3261504216	Polyurethane foam carpet underlay, carpet and rug cushions, bonded	8%
3261504Y	Furniture and furnishings polyurethane foam, nsk	7%
3261501Y	Transportation polyurethane foam products, nsk	3%
3261501102	Transportation polyurethane foam products, cut slabstock for seating and trim	3%
3261502116	Polyurethane foam protective shipping pads and shaped cushioning (peanuts, disks, etc.)	3%
3261504228	Polyurethane foam topper pads and quilting rolls	2%
3261504227	Polyurethane foam mattress cores (uncovered only)	2%

nsk = Not specified by kind.

2.3 Number of Manufacturing Facilities

This report presents several sources of information to determine the number of flexible polyurethane foam manufacturing facilities. According to industry contacts made in 2002, slabstock polyurethane foam is produced at 65 locations (25 companies) in the United States (10). Another source estimated that there were 78 slabstock plants and 49 molded foam plants in 1993 in the United States (11). According to the 2001 County Business Patterns, there are 610 establishments under NAICS 326150 (23). From above (see Table 2-2), it is estimated that 58 percent of the NAICS 326150 industry sector is flexible polyurethane foam; therefore, approximately 353 establishments may be flexible polyurethane foam establishments. The most recent data from industry contacts is used to make release estimates in Section 4.0.

Table 2-4 presents the distribution of establishments by employment size class for facilities under the NAICS 326150 (23). More detailed information for the sub-industries in this classification were not available from the 2001 County Business Patterns; therefore, Table 2-4 presents data at the 6-digit NAICS level and thus includes flexible, rigid, and other undetermined urethane foams facilities.

Table 2-4

Classification of Establishments by Employment Size Class for NAICS 326150

			Total Employment Size Class			
NAICS	**Industry**	**Establishments**	**1-19**	**20-99**	**100-499**	**>499**
326150	Urethane and Foam Products Other than polystyrene	610	229	276	102	3
			38%	45%	17%	<0.5%

A total of 35,635 employees are reported in the NAICS 326150 (23). From the analysis presented in Section 2.1, it may be assumed that the flexible foam industry comprises 58 percent of the NAICS 326150 by shipment value. If the representation of employees and facilities parallels the percent shipment value, an average of 58 employees per facility (35,635 employees ÷ 610 establishments) is estimated.

2.4 Geographic Distribution

EPA's Toxic Release Inventory (TRI) collects geographic information for all facilities reporting releases. The TRI data, however, are collected by SIC code rather than the

NAICS code. Since the SIC code 3086 for flexible foam groups all foamed plastics together, the geographic data contained in TRI does not distinguish between flexible polyurethane foam facilities and facilities manufacturing other foam products. Despite this limitation, the TRI data represents the only identified source of geographic data available for this analysis and thus are assumed to be representative of the flexible polyurethane foam industry for the purpose of this report. The distribution of the 224 facilities reporting TRI releases under SIC 3086, Foamed Plastics in 2001, is presented as Figure 2-1.

The TRI data are further limited due to reporting thresholds associated with the Superfund Amendments and Reauthorization Act (SARA) Title III Section 313. Facilities are required to report releases of TRI chemicals only if they manufacture or process the chemical in excess of 25,000 pounds per year or if they "otherwise use" the chemical (e.g., as a solvent) in excess of 10,000 pounds per year.[1] Therefore, TRI data may not include releases associated with very small facilities.

In order to provide a more focused analysis of the geographic distribution of flexible foam manufacturing facilities, the top producing flexible foam companies in 1998 are listed in Table 2-5 (17). These eight companies were identified from a market analysis on flexible polyurethane foam published by Morgan, Lewis, Githens & Ahn, Inc. (17).

The eight companies listed in Table 2-5 operate 58 facilities that reported TRI releases under SIC 3086 in 2001. These facilities represented 35 percent of all TRI releases reported under SIC 3086 and 24 percent of the total number of facilities that reported to TRI under SIC 3086. The eight corporations represented about 70 percent of the flexible foam market in 1998 as shown in Table 2-5 (17). The geographic distribution of these facilities is presented in Figure 2-1. This distribution indicates that most of the flexible foam manufacturing occurs in the eastern third of the United States.

[1] Note: There are exceptions to these thresholds for 20 chemicals designated to be persistent, bioaccumulative, and toxic. These chemicals have significantly smaller thresholds. However, diisocyanates and other commonly used chemicals in polyurethane foam manufacturing are not designated as persistent, bioaccumulative, and toxic.

Table 2-5

Top U.S. Producers of Flexible Polyurethane Foam

Corporation	Percent of Market
Foamex	≈25%
Carpenter Co.	≈17%
Flexible Foam Products	≈9%
Hickory Springs	≈8%
Woodbridge	≈7%
British Vita (Crest Foam)	≈5%
Future Foam	≈4%
Leggett & Platt	≈4%

Source: Morgan Lewis Githens & Ahn.

Figure 2-2 presents the population density surrounding the top 10 TRI dischargers among the top U.S. producers of flexible polyurethane foam shown in Table 2-5.

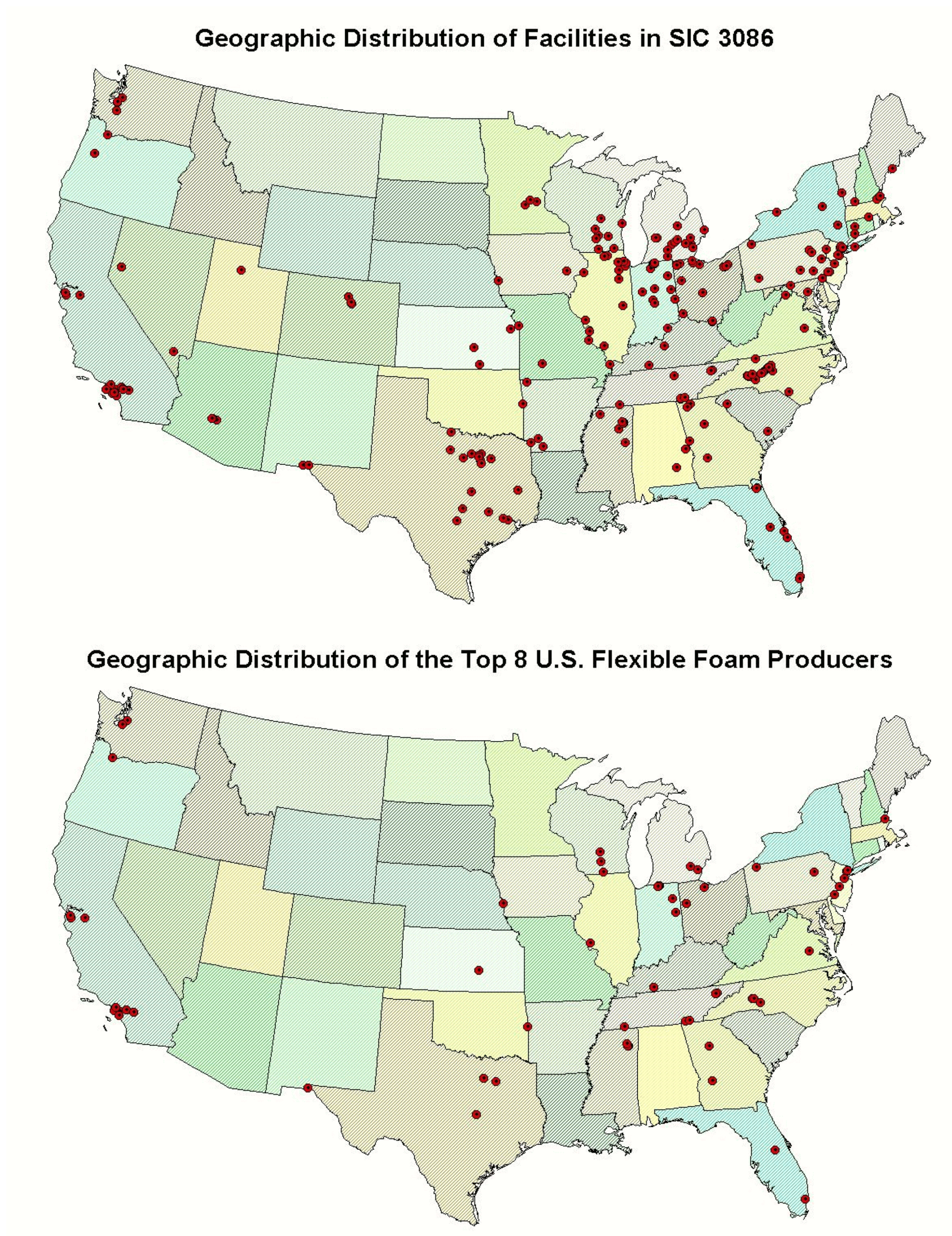
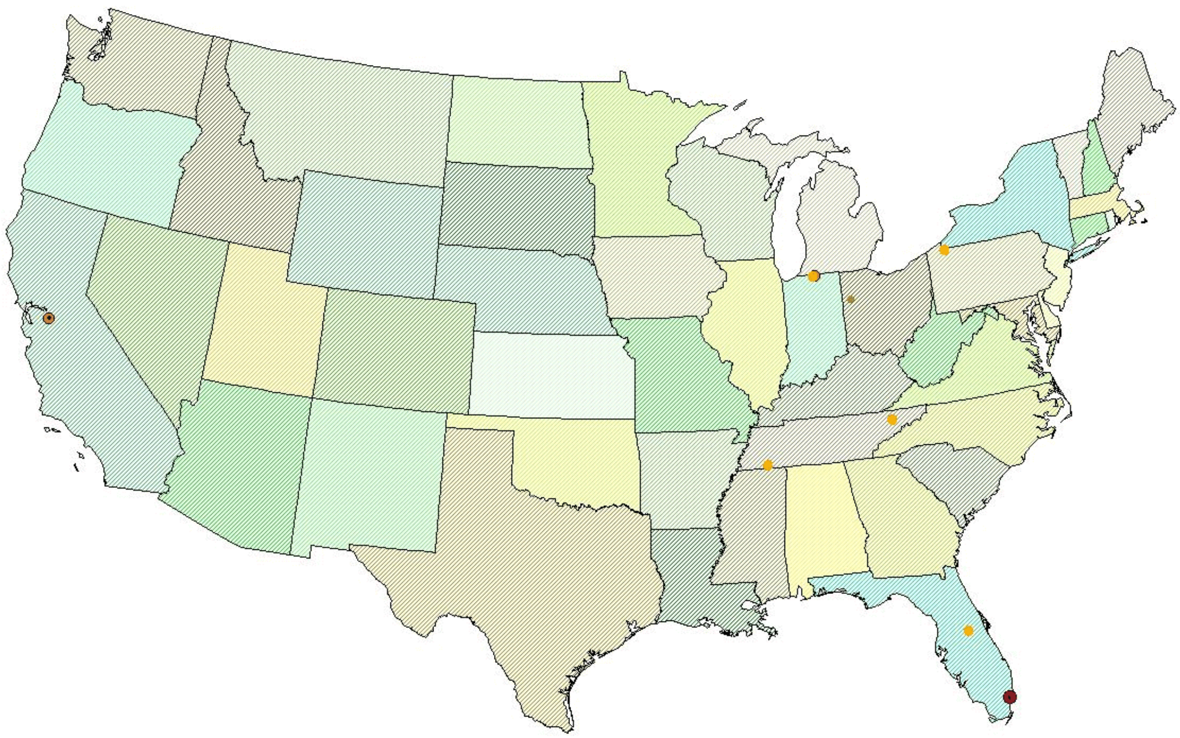


Figure 2-1. Geographic Distribution of Foam Manufacturers

Population Densities Surrounding the Top 10 TRI Dischargers Among the Top 8 U.S. Flexible Foam Producers



LEGEND

Population Density (persons per sq. mile)

- 0-150
- 150-1,500
- 1,500-4,000
- 4,000-7,500

Top 10 TRI Dischargers Among Top 8 Producers

1. Foamex (Milan, TN)	4,401,064 lbs
2. Foamex (Corry, PA)	3,738,651 lbs
3. Carpenter (Elkhart, IN)	3,214,265 lbs
4. Foamex (Elkhart, IN)	1,815,824 lbs
5. Flexible Foam Products (Spencerville, OH)	1,648,698 lbs
6. Foamex (Morristown, TN)	1,343,736 lbs
7. Flexible Foam Products (Miami, FL)	1,326,096 lbs
8. Foamex (Orlando, FL)	1,060,749 lbs
9. Carpenter (Lathrop, CA)	753,440 lbs
10. Flexible Foam Products (Elkhart, IN)	586,358 lbs

Figure 2-2. Population Density Surrounding Top U.S. Flexible Polyurethane Foam Manufacturers

3.0 FLEXIBLE POLYURETHANE FOAM MANUFACTURING PROCESS DESCRIPTION

Flexible polyurethane foam is produced as high-density and low-density foam. Most U.S. flexible foam manufacturers produce low-density foam (1.4 pounds per cubic foot (pcf) to 1.6 pcf) and less than 10 percent manufacture higher density foam (21). Different products require high-density vs. low-density foam. For example, automakers are increasingly using high-density foam for seats; rather than low-density foam, partially because high density foam is more recyclable because it is more durable.

Both high-density and low-density flexible polyurethane foam can be divided into two categories: slabstock foam and molded foam. Table 3-1 presents the flexible polyurethane foam market production for each industry use. As shown in Table 3-1, 77 percent of flexible polyurethane foam production is slabstock (24).

Table 3-1

Flexible Polyurethane Foam Consumption Per Use

Industry Use	Flexible Polyurethane Foam Consumption (millions of pounds)		
	Total	Slabstock	Molded
Transportation	628	249	379
Carpet Cushion	524	514	10
Furniture	465	430	35
Bedding	181	177	4
Packaging	92	78	14
Textiles and Fibers	61	55	6
Other	95	92	3
Total	2,046	1,595	451

Toluene diisocyanate (TDI) and polymeric 4,4'-methylenediphenyl diisocyanate (MDI) are raw materials that must be used to produce polyurethane foam. A more detailed discussion on diisocyanate and the foam making reaction is presented in Section 3.3. TDI and MDI are used to manufacture both slabstock and molded flexible polyurethane foam. Table 3-2 presents data on TDI and MDI use in slabstock and molded foam (24). As shown in Table 3-2, the majority of TDI is used to manufacture slabstock foam (24).

Table 3-2

Diisocyanate Use in Flexible Polyurethane Foam

	Slabstock (millions of pounds)	Molded (millions of pounds)	Flexible Polyurethane Foam (millions of pounds)
TDI	478	100	578
MDI	60	42	102
Total	538	142	680

The process used to manufacture both slabstock and molded foam is described below.

3.1 Slabstock Foam

Slabstock foam represents approximately 75 percent of the flexible polyurethane foam industry (11,24). The slabstock manufacturing process is a continuous process that produces long, rectangular, continuous slabs of foam, called “buns”. Buns are cut into the desired configuration for an application, such as in furniture padding, bedding, automobile padding and seats, packaging materials, and carpet padding.

The typical commercial process for slabstock foam production consists of a single unit operation, operated in batches. Figure 3-1 presents a diagram of this process. The raw materials for this process include diisocyanates, polyol, water, auxiliary blowing agents (ABA), filler, chain modifying agents, and other additives (including flame retardants).

First, the raw materials and additives are metered into a single mix head (point 2 of Figure 3-1), which dispenses the mixed materials at the bridge to an enclosed conveyor system. Very quickly after leaving the mix head, the raw materials begin to create foam-producing reactions, producing the polyurethane foam on the conveyor. Most foam manufacturers have computerized controls at the mix head metering system that allow the raw materials mixture to be changed (11) to achieve the desired characteristics of the end product.

The conveyor moves the foam mixture down the conveyor at approximately 15 feet per minute. The conveyor is housed in a tunnel that is typically enclosed and ventilated to remove the gases that are produced in the foam reaction. The foam reaches its full height of 2 to 4 feet in approximately 1 to 2 minutes. After 5 to 10 minutes, polymerization reactions are complete enough for the foam to be handled and cut.

A "flying saw" moves in tandem with the conveyor to cut the foam. This is an overhead saw that moves at the same rate as the conveyor while cutting the foam, in order to produce a straight cut. Each cut of foam is removed from the conveyor and moved to a curing area. Typically, buns are cured for 24 hours before further fabrication or shipping. Fabrication includes cutting and slicing the foam to meet the specifications of the customer. A machine called a slitter cuts large buns into a desired thickness. Vertical bandsaws or hand cutting are used to convert slabs of foam into smaller components for the desired end use (e.g., furniture).

Typically, cushions in the furniture industry are composed of more than one component (e.g., foam and polyester fiber fill). These components are bonded together with adhesives. (Note, bonding with adhesives is not addressed in the releases and exposure section of this report.)

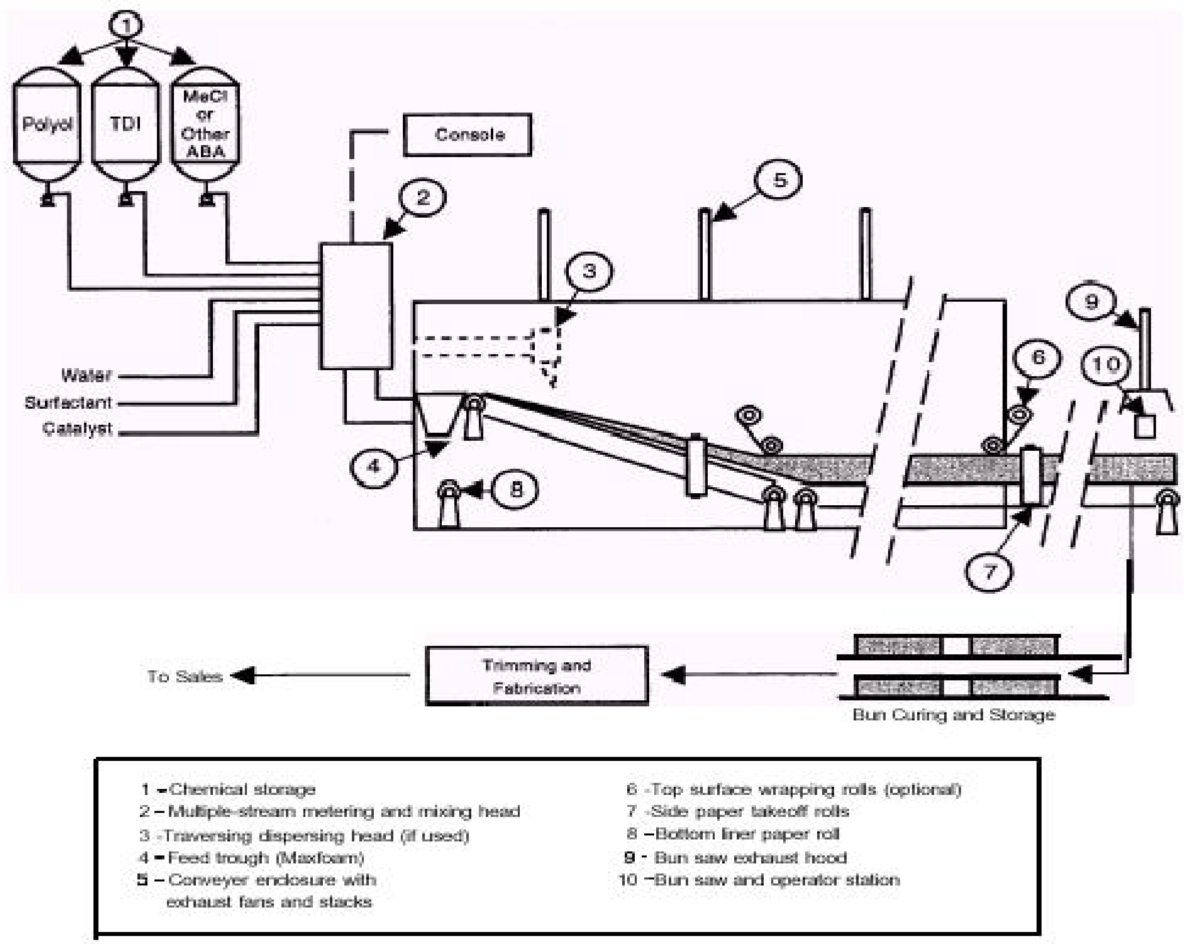


Figure 3-1. Typical Slabstock Production Line for Flexible Polyurethane Foam

Source: U.S. EPA, 1996

3.2 Molded Foam

Molded foam accounts for approximately 25 percent of the flexible polyurethane foam industry (11,24). Molded foam is produced when the foam polymerization reaction occurs in a closed mold resembling the final product. Molded foam is used in the transportation industry for seat cushions and interior trim, furniture, bedding, packaging materials, toys, and novelty items.

The typical commercial process for molded foam production consists of a circular production line containing multiple molds and process stations. Figure 3-2 presents a diagram of this process.

Raw materials for molded foam are similar to those used in slabstock foam production, including polyol, diisocyanates, water, catalyst, surfactant, and other additives (e.g., flame retardants). The raw materials are pumped to a common mix head above the production line. Many ingredients are premixed to minimize the streams being fed to the head and to ensure precise measurement (11). The mix head dispenses a measured amount of the mixture into each mold and the molds are then heated to accelerate foam curing. Heating takes place either by passing the mold through a curing oven or passing heated water through tubes in the mold. Then, the mold is opened and emptied. The mold continues through the process line to be conditioned for the next product.

After removal from the mold, the foam is further processed into the final desired shape. These activities include curing, trimming, and glueing.

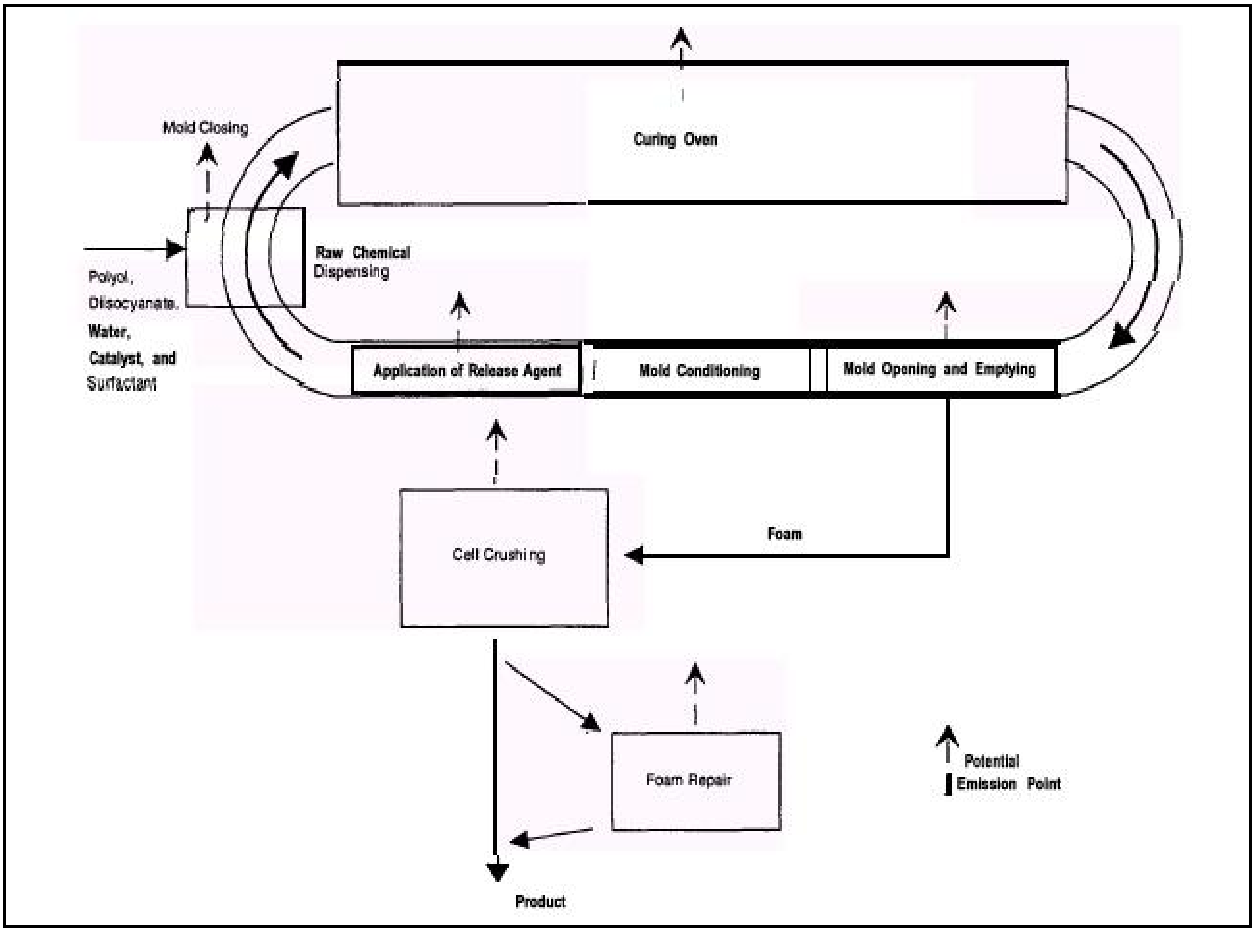


Figure 3-2. Typical Molded Foam Production Line for Flexible Polyurethane Foam

Source: U.S. EPA, 1996

3.3 Chemicals Used to Manufacture Flexible Polyurethane Foam

Two major reactions are responsible for producing polyurethane foam. The first reaction (gelling reaction) uses an isocyanate and a polyol to produce a polymer chain and heat. The second reaction (blowing reaction) uses an isocyanate and water to produce carbon dioxide. The amount of gas (CO_2) created is controlled by the water level in the formulation. The gas in the foam produces pockets which create voids in the foam after the gas is released. These voids give flexible polyurethane foam its softness. (15)

Many other chemicals are used to manufacture flexible polyurethane foam. These chemicals are used to enhance foam properties, as a catalyst, to provide flame retardancy, or as a filler. Table 3-3 presents types of chemicals used to manufacture foam and their purpose.

Table 3-3

Chemicals Used to Manufacture Polyurethane Foam

Type of Chemical	Purpose	Estimated Fraction in Foam
Tertiary Amines	Foster the blowing reaction (catalyst)	NA
Organometallics	promote gellation (catalyst)	NA
Additional blowing agents	Softer foams require auxiliary blowing agents (e.g., methylene chloride, acetone, CFC-11, or HCFC-141b)	NA
Silicone surfactants	Assist in controlling cell size and uniformity through reduced surface tension and sometimes to assist in the solubilization of various reactants.	NA
Flame retardants	Reduce flammablity of foam	0.05 to 0.4 (14,15)*
Fillers	Occasionally used in slabstock foam (e.g., calcium carbonate, barium sulfate)	0.1 to 0.5 (14,15)*
Colorants	Impart color to the foam (titanium dioxides, iron oxides, anthraquinones, carbon black)	0.005 to 0.03 (14)*
Diisocyanate	Raw material for polyurethane foam (toluene diisocyanates and methyl diphenyl diisocyanates)	NA
Polyols	Polyether polyols are used in 90% of polyurethane foams (e.g., typically trifunctional, but di or tetra also used).	NA

* These fractions are representative of all plastic materials. Fractions of additives used in foam may be within the range reported.
NA - Not available.

3.3.1 Diisocyanates

Diisocyanates are a group of low-molecular weight aromatic and aliphatic compounds. There are two main types of diisocyanates that are used to manufacture flexible polyurethane foams. Toluene diisocyanates (TDI) are used primarily in low-density flexible foam production. Methyl diphenyl diisocyanates (MDI) are used primarily in high-density flexible foam production. The difference between low and high-density foam is achieved through the reaction associated with the polymeric raw materials (TDI and MDI) used to manufacture foam. Specifically, MDI produces less gas than TDI during the foam-making reaction and thus, creates a more dense foam. Diisocyanates are an occupational health concern because they are known to have caused occupational asthma from inhalation of aerosol mists or vapors and are skin sensitizers.

3.3.2 Flame Retardants

The following are some of the chemicals currently used as flame retardants for flexible polyurethane foam.

- Ammonium polyphosphate
- Phosphate esters
- Melamine
- Reactive phosphorus polyols
- Tribromoneopentyl alcohol
- Tetrabromobenzoate
- Pentabromodiphenyl ether

The selection of a particular flame retardant to be used in a polyurethane foam product is related to the type of foam (high-density or low-density), product specification, and manufacturing concerns. One primary concern is “scorching”. Scorching occurs when high temperatures are generated due to the exothermic polymerization reaction (gelling reaction). The use of TDI to manufacture foam generates more heat than the use of MDI; thus, scorching is more prevalent in low-density foam manufacturing. Therefore, the use of a higher thermally resistant flame retardant is required for manufacturing low-density foams. Currently, pentabromodiphenyl ether (pentaBDE) is the most widely used flame retardant for low-density, flexible polyurethane foam. However, the European Union has banned the use of pentaBDE. The State of California has also banned the use of pentaBDE by the year 2008 (note: the manufacture of pentaBDE will be voluntarily phased out in the U.S. by December 31, 2004).

3.3.3 Chemicals of Concern

Chemicals reported to TRI for SIC 3086 and other selected chemicals (e.g., flame retardants) were compared to regulatory lists of chemical pollutants to identify pollutants of concern for this industry. Table 3-4 identifies chemicals expected to be used in the foam manufacturing industry with an indication of each regulatory list on which the chemical appears. Tetrabromobenzoate, ammonium polyphosphate, and tribromoneopentyl alcohol were not found on any of the regulatory lists in Table 3-4.

Table 3-4

Chemicals Used in Foam Manufacturing and Listed on Priority Lists

CAS Number	Chemical Name	Number of Lists	CCL	CERCLA NPL	HAP	HPV	NAP	OSW WMP	POP	TRI	PPL	TCLP	VCCEP
75683	1-Chloro-1,1-difluoroethane	2				X				X			
108781	1,3,5-Triazine-2,4,6-triamine	1				X							
584849	2,4-Toluene diisocyanate	3			X	X				X			
7440360	Antimony	3		X						X	X		
75003	Chloroethane (Ethyl chloride)	5		X	X	X				X	X		
74873	Chloromethane	5		X	X	X				X	X		
1163195	Decabromodiphenyl ether	3				X				X			X
111422	Diethanolamine	3			X	X				X			
N120	Diisocyanates	1								X			
1717006	Ethane, 1,1-dichloro-1-fluoro-	2				X				X			
50000	Formaldehyde	4		X	X	X				X			
107211	Glycol	3			X	X				X			
N230	Glycol ethers	2			X					X			
75456	Methane, chlorodifluoro-	2				X				X			
67561	Methanol	3			X	X				X			
78933	Methyl ethyl ketone	6		X	X	X				X		X	X
108101	Methyl isobutyl ketone	4		X	X	X				X			
75092	Methylene Chloride	5		X	X	X				X	X		
110543	n-Hexane	3			X	X				X			
872504	N-methyl-2-pyrrolidone	2				X				X			
32534819	Pentabromodiphenyl ether	2				X							X
85449	Phthalic anhydride	3			X	X				X			
75569	Propylene oxide	3			X	X				X			
100425	Styrene	4		X	X	X				X			
108883	Toluene	6		X	X	X				X	X		X
26471625	Toluenediisocyanate	2				X				X			
1330207	Total Xylenes	4		X	X	X				X			

Table 3-4 (continued)

Chemicals Used in Foam Manufacturing and Listed on Priority Lists

CAS Number	Chemical Name	Number of Lists	CCL	CERCLA NPL	HAP	HPV	NAP	OSW WMP	POP	TRI	PPL	TCLP	VCCEP
79016	Trichloroethylene	7		X	X	X				X	X	X	X
N982	Zinc compounds	1								X			

CCL: Contaminant Candidate List (Safe Drinking Water Act)
CERCLA NPL: Comprehensive Environmental Response, Compensation, and Liability Act National Priority List of Hazardous Substances
HPV: High Production Volume
HAP: Hazardous Air Pollutant (Clean Air Act)
PBT-NAP: Persistent, Bioaccumulative, Toxic National Action Plan
POP: Persistent Organic Pollutants; identified by the Organization of Economic Cooperation and Development
PPL: Priority Pollutants List (Clean Water Act)
OSW WMP: Waste Minimization National Plan
TCLP: Toxicity Characteristic Leaching Procedure; promulgated under the Land Disposal Restriction (LDR) regulations (51 FR 40572)
TRI: Toxic Release Inventory (Emergency Planning Community Right-to-Know Act)
VCCEP: Voluntary Children's Chemical Evaluation Program

4.0 ESTIMATES OF RELEASES AND EXPOSURES FROM FLEXIBLE POLYURETHANE FOAM MANUFACTURING

There are several occupational exposure and environmental release concerns associated with the production of flexible polyurethane foam. For example, isocyanate exposure is known to induce a negative respiratory response in humans; exposure to small particulate matter can cause unhealthy breathing conditions; pentabromodiphenyl ether is known to be persistent and bioaccumulative in the food chain and possibly toxic; and methylene chloride can cause respiratory and heart problems and is a potential carcinogen. This section presents general facility information for the flexible polyurethane foam industry, release estimates, 2001 TRI releases for the industry, and inhalation and dermal exposure estimates for workers.

4.1 General Facility Assessments

This subsection provides information regarding the daily amount of foam produced and daily use rate of diisocyanates and other chemicals.

4.1.1 Daily Throughput

Industry data from 1996 indicates that approximately 2 billion pounds of flexible polyurethane foam is produced in the U.S. (24). This data also shows that approximately 1,595 million pounds (723,480,700 kg) of slabstock foam and 451 million pounds (204,570,400 kg) of molded foam was produced in 1996 (24). According to industry contacts, in 2002 there were 65 locations producing slabstock polyurethane foam in the U.S. with a total production of 1.7 billion pounds (771,108,100 kg) per year (10). Another source estimated that in 1993 there were 78 slabstock plants which produced 600,000 tons (544,311,500 kg) and 49 molded foam plants which produced 215,000 tons (195,045,000 kg) in 1993 (11). Slabstock production information from 1996 and 2002 are similar (1.6 and 1.7 billion pounds, respectively); therefore, it is assumed that the 1996 production data can be used to determine the daily throughput of slabstock and molded foam. The 1993 data estimates a greater number of slabstock sites than the

2002 information. Therefore, 2002 information is used to estimate the total number of slabstock sites and 1993 molded foam sites are adjusted to reflect a similar decrease as the slabstock sites. This report estimates that there are 65 slabstock manufacturing sites and 41 molded foam manufacturing sites. It is also estimated that the typical number of operation days is 250 days per year. This estimate takes into account 5-day work weeks and 2 weeks of plant shutdown. The following equation estimates the average daily throughput of slabstock foam.

Slabstock

$$Q_{slabstock\_foam\_day} = \frac{Q_{slabstock\_foam\_year}}{N_{slabstock\_sites} \times TIME_{year}}$$

$$= \frac{723{,}480{,}700 \text{ kg / yr}}{65 \text{ sites} \times 250 \text{ days / yr}} = 44{,}500 \text{ kg / site} - \text{day}$$

Where:

$Q_{slabstock\_foam\_day}$	=	Average daily throughput of slabstock foam (kg/site-day)
$Q_{slabstock\_foam\_year}$	=	Total production of slabstock foam in the U.S. (Default: 723,480,700 kg/year) (24)
$N_{slabstock\_sites}$	=	Number of slabstock flexible polyurethane foam manufacturers in the U.S. (Default: 65 sites) (10)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

Industry indicates that 8,000,000 pounds of TDI is used to manufacture 25,000,000 pounds of slabstock foam (10). This translates to a 3.125 to 1 ratio of foam to TDI. Industry data from 1996 shows that a total of 538 million pounds (244,033,000 kg) of diisocyanates were used to manufacture slabstock foam (478 million pounds of TDI and 60 million pounds of MDI) (24). The following equation estimates the daily use rate of diisocyanate at a slabstock foam manufacturing facility.

$$Q_{slabstock\_di\_day} = \frac{Q_{slabstock\_di\_year}}{N_{slabstock\_sites} \times TIME_{year}} = \frac{244{,}033{,}000 \text{ kg / yr}}{65 \text{ sites} \times 250 \text{ days / yr}} = 15{,}000 \text{ kg / site} - \text{day}$$

Where:

$Q_{slabstock\_di\_day}$	=	Average daily use rate of diisocyanate for slabstock foam
$Q_{slabstock\_di\_year}$	=	Yearly use of diisocyanate in slabstock foam in the U.S.

(Default: 244,033,000 kg/year) (24)

$N_{slabstock\_sites}$	=	Number of slabstock flexible polyurethane foam manufacturers in the U.S. (Default: 65 sites) (10)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

The following equation estimates the average daily throughput of molded foam.

Molded Foam

$$Q_{molded\_foam\_day} = \frac{Q_{molded\_foam\_year}}{N_{molded\_sites} \times TIME_{year}}$$

$$= \frac{204{,}570{,}400 \text{ kg / yr}}{41 \text{ sites} \times 250 \text{ days / yr}} = 20{,}000 \text{ kg / site} - \text{day}$$

Where:

$Q_{molded\_foam\_day}$	=	Average daily throughput of molded foam (kg/site-day)
$Q_{molded\_foam\_year}$	=	Total production of molded foam in the U.S. (Default: 204,570,400 kg/year) (24)
N_{molded_sites}	=	Number of molded flexible polyurethane foam manufacturers in the U.S. (Default: 41 sites) (10,24)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

Industry data from 1996 shows that a total of 142 million pounds (64,410,200 kg) of diisocyanates were used to manufacture molded foam (100 million pounds of TDI and 42 million pounds of MDI) (24). The following equation estimates the daily use rate of diisocyanate at a molded foam manufacturing facility.

$$Q_{molded\_di\_day} = \frac{Q_{molded\_di\_year}}{N_{molded\_sites} \times TIME_{year}} = \frac{64{,}410{,}200 \text{ kg / yr}}{41 \text{ sites} \times 250 \text{ days / yr}} = 6{,}280 \text{ kg / site} - \text{day}$$

Where:

$Q_{molded\_di\_day}$	=	Average daily use rate of diisocyanates for molded foam
$Q_{molded\_di\_year}$	=	Yearly use of diisocyanate in molded foam in the U.S. (Default: 64,410,200 kg/year) (24)
N_{molded_sites}	=	Number of molded flexible polyurethane foam manufacturers in the U.S. (Default: 41 sites) (10,24))
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

The daily throughput of a chemical additive used in foam manufacturing can be calculated from the daily output of foam manufactured and the percent of additive used in the foam.

$$Q_{chem\_day} = Q_{foam\_day} \times F_{chem\_foam}$$

Where:

Q_{chem_day}	=	Daily use rate of chemical additive used in foam (kg/site-day)
Q_{foam_day}	=	Average daily throughput of slabstock or molded foam (kg/site-day)
F_{chem_foam}	=	Fraction of chemical additive in foam (Defaults: see Table 3-3)

4.1.2 Number of Sites

Raw materials used to manufacture flexible polyurethane foam such as diisocyanate and polyols are expected to be used at all manufacturing sites. However, specialty additives may be used in only a fraction of the total amount of foam produced in the U.S. and therefore, may only be used at a fraction of the total foam manufacturing sites. The number of sites at which a particular chemical will be used is determined by the amount of chemical consumed in the flexible polyurethane foam industry and the daily use rate of the chemical per facility. The following equation can be used to estimate the number of sites.

$$N_{sites} = \frac{Q_{chem\_year}}{Q_{chem\_day} \times TIME_{year}}$$

Where:

N_{sites}	=	Number of sites estimated to use the chemical
Q_{chem_year}	=	Yearly consumption of chemical used in the flexible polyurethane foam industry (kg/yr)
Q_{chem_day}	=	Daily use rate of chemical additive used in foam (kg/site-day)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

4.2 Environmental Releases

Environmental releases of chemicals used to produce flexible polyurethane foam are expected to occur from 1) residual remaining in transport containers, 2) air releases during foam manufacturing, 3) equipment cleaning of manufacturing equipment, and 4) disposal of leaks, scraps, and off-spec foam. This subsection presents estimation techniques for each release described above and a summation of 2001 TRI-reported releases.

4.2.1 Transport Container Residue

Chemicals used to manufacture foam in the U.S. are expected to be in liquid form; however, additives may be received as a solid and mixed into a solution before charged to the foam making process. The majority of foam manufacturing facilities in the U.S. require liquid ingredients due to the process equipment used. It is expected that a small amount of liquid or solid will remain in the transport container after the container is emptied and the material is charged to the process equipment. The amount of liquid remaining in the container depends on the size of the container. For small containers (<5 gallons), it is estimated that 0.6 percent of the liquid remains in the container (7). For larger containers (<110 gallons), it is estimated that 3 percent of liquid remains in the container (8,9). Chemical used in large amounts may be delivered in tanker trucks. For tanker trucks, it is estimates that 0.2 percent of the liquid remains in the tanker truck (22). The amount of solids remaining in any size container is estimated as 1 percent (22). The media of release for container residue is not certain. Containers could be rinsed out with water or solvent, the rinsate could be sent to wastewater treatment or incineration, or the containers could be sent to a landfill or recycler. The following equations calculates the release of a chemical from container residue.

Number of containers per site

$$N_{container\_day} = \frac{Q_{chem\_year}}{Q_{container} \times TIME_{year}}$$

Daily release of chemical from container residue

$$Elocal_{container\_residue\_disp} = Q_{container} \times F_{container\_residue} \times N_{container\_day}$$

Where:

$N_{container\_day}$	=	Number of containers used at a site per day (container/day)
Q_{chem_year}	=	Yearly consumption of chemical used in the flexible polyurethane foam industry (kg/yr)
$Q_{container}$	=	Capacity of container used to transport chemical (Default: 200 kg/container for 55 gal drum)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)
$Elocal_{cotnainer\_residue\_disp}$	=	Daily release of chemical of interest to water, incineration, or landfill from container residue (kg/site-day)
$F_{container\_residue}$	=	Fraction of liquid that remains in the container (Defaults: Liquids: 0.002 for tank trucks, 0.006 for small container, and 0.03 for large containers; Solids: 0.01) (7,8,9,22)

4.2.2 Air Emissions

It is expected that after the first 24 hours of curing, approximately 100 percent of auxiliary blowing agents will be released to the environment or to air pollution controls. According to industry contacts, approximately 35 pounds of TDI is released (and not reacted) during the foam making process for every 1,000,000 pounds of TDI consumed. This means that 99.9965 percent of TDI is converted during foam manufacturing and that 0.0035 percent is released to the atmosphere or control technology. MDI conversions were not currently available; therefore, it is assumed that the MDI conversion rate is similar to TDI. The following equations estimate the amount of diisocyanates released to the air per day.

Slabstock

$$Elocal_{slabstock\_air\_di} = Q_{slabstock\_di\_day}(15{,}000 \text{ kg / site} - \text{day}) \times 0.000035 = 0.525 \text{ kg / site} - \text{day}$$

Molded

$$Elocal_{molded\_air\_di} = Q_{molded\_di\_day}(6{,}280 \text{ kg / site} - \text{day}) \times 0.000035 = 0.220 \text{ kg / site} - \text{day}$$

Where:

$Elocal_{slabstock\_air\_di}$	=	Daily release of diisocyanates to air from slabstock processes (kg/site-day)
$Q_{slabstock\_di\_day}$	=	Average daily use rate of diisocyanate for slabstock foam (Default: 15,000 kg/site-day)

$Elocal_{molded\_air\_di}$	=	Daily release of diisocyanate to air from molding foam processes (kg/site-day)
$Q_{molded\_dia\_day}$	=	Average daily use rate of diisocyanate for molded foam (Default: 6,280 kg/site-day)

An industry contact in 2002, estimated that a typical slabstock foam site released 280 kg per site-year of diisocyanate to the air (10). The calculation above estimates that 131 kg per site-year (slabstock) and 55 kg per site-year (molded) on average is released to air. A review of TRI releases also show that for three categories (diisocyanate, toluene diisocyanates mixed isomers, and toluene-2,4-diisocyanates) the average air release (fugitive and stack) per site in SIC 3086 is 46 kg per site-year (diisocyanate), 275 kg per site-year (toluene diisocyanates mixed isomers), and 431 kg per site-year (toluene-2,4-diisocyanates). All air emission estimates discussed above are at the same order of magnitude, thus seem reasonable.

4.2.3 Equipment Cleaning

Chemicals used to manufacture foam are in contact with multiple pieces of process equipment including storage tanks, mixing heads, and dispensing equipment. As a default, it is assumed that a small amount of the chemical (2% by volume) remains in the equipment and is released to water or incineration after cleaning activities (12). Information regarding the frequency of equipment cleaning, type of cleaning media (i.e., water or solvent), and media of release are not currently available. Therefore, it is assumed that equipment cleaning takes place daily and the waste is released to water or incineration. The following equation can be used to estimate the daily release of a chemical to water or incineration from equipment cleaning.

$$Elocal_{equip\_disp} = Q_{equipment} \times F_{equip}$$

Where:

$Elocal_{equip\_disp}$	=	Daily release of chemical to water or incineration from equipment cleaning (kg/site-day).
$Q_{equipment}$	=	Capacity of foam making equipment (kg/equipment) (Default: daily use rate of chemical per site Q_{chem_day} (kg/site-day))
F_{equip}	=	Fraction of liquid that remains in the equipment (Defaults: 0.02 for multiple vessels and 0.01 for single vessel) (12)

4.2.4 Scraps and Off-spec Foam Disposal

One major flexible polyurethane foam manufacturer estimates that 10 to 15 percent of foam produced becomes scrap (13). Scrap foam is produced during cutting operations and from the production of off-spec foam, which can be the result of the foam becoming "scorched", discolored during manufacturing, or foam that does not meet the specification of the order. Industry estimates that at least 99 percent of scrap foam is recycled and used as carpet padding (13). This results in approximately 0.15 percent of scrap (15% scrap ×1% not recycled) is disposed of as solid waste. The following equation estimates the daily release of foam to a landfill.

$$Elocal_{scrap\_disp} = Q_{foam\_day} \times F_{scrap}$$

Where:

$Elocal_{scrap\_disp}$	=	Daily release of foam from waste scrap to landfill (kg/site-day)
Q_{foam_day}	=	Average daily throughput of slabstock or molded foam (kg/site-day)
F_{scrap}	=	Fraction of foam produced disposed of as scrap (Default: 0.0015)

Some additives such as flame retardants and fillers do not react during the foam making process and remain in the final foam product . Other raw materials are expected to be completely released after curing (such as blowing agents) or completely reacted (such as diisocyanates). Chemicals that remain in the foam will be present in scrap foam and are expected
to be released to landfill when the scrap foam is disposed. The following equation estimates the amount of chemical released to landfill from scrap disposal.

$$Elocal_{scrap\_additive\_disp} = Q_{foam\_day} \times F_{scrap} \times F_{chem\_foam}$$

Where:

$Elocal_{scrap\_additive\_disp}$	=	Daily release of foam from waste scrap to landfill (kg/site-day)

Q_{foam_day}	=	Average daily throughput of slabstock or molded foam (kg/site-day)
F_{scrap}	=	Fraction of foam produced disposed of as scrap (Default: 0.0015)
F_{chem_foam}	=	Fraction of chemical additive in foam (Defaults: see Table 3-3)

4.2.5 TRI Releases

A total of 224 facilities reported releases under the primary SIC code of 3086. These 224 facilities reported nearly 19 million total pounds of releases, consisting of a total of 59 chemicals/chemical groups. Pounds released include all direct releases to air, surface water, and land; transfers offsite for disposal; and transfers of metals to POTWs. No releases to underground injection wells, RCRA Subtitle C landfills, land treatment/application, or surface impoundment were reported for this industry. Table 4-1 presents the top 25 chemicals (by pounds) released from TRI reporting facilities in SIC 3086.

Table 4-1

2001 TRI Releases for SIC 3086 Top 25 Chemicals

CAS No.	CHEMICAL NAME	No. of Facilities Reporting	2001 TRI Releases and Other Waste Management (pounds)									
			Total Quantity Released	Sub-Categories of Releases					Quantities to Waste Management			
									Off-Site Transfers			On Site Treatment
				Fugitive Air Emissions	Stack Air Emissions	Discharged to Surface Water	Released to Onsite Land	Transferred Offsite for Disposal	Treatment	Energy Recovery	Recycled	
000075683	1-CHLORO-1,1-DIFLUOROETHANE	9	3,461,162	430,540	3,021,849	0	0	9,087	0	0	0	0
001717006	1,1-DICHLORO-1-FLUOROETHANE	39	1,889,271	936,840	836,745	0	20,498	94,426	2,713	0	0	0
007440360	ANTIMONY	1	7,052	0	0	0	0	7,052	0	0	0	0
N230	CERTAIN GLYCOL ETHERS	3	24,100	1,000	22,800	0	5	250	3,050	0	0	0
000075456	CHLORODIFLUOROMETHANE	24	399,534	357,827	36,203	0	0	5,935	0	0	0	0
000075003	CHLOROETHANE	5	674,620	340,617	330,368	0	0	3,635	0	0	0	0
000074873	CHLOROMETHANE	1	53,560	53,560	0	0	0	0	0	0	0	0
001163195	DECABROMODIPHENYL OXIDE	1	26,503	0	0	0	0	26,503	0	0	0	0
000075092	DICHLOROMETHANE	36	9,917,129	3,276,696	6,655,565	5	5	250	147,797	0	10,500,286	0
N120	DIISOCYANATES	123	109,150	2,815	2,848	0	92,295	25,219	40,808	0	550	2,450
000050000	FORMALDEHYDE	3	7,219	6,954	239	0	0	26	0	0	0	89,079
000067561	METHANOL	3	27,704	25,695	35,492	0	0	0	438,207	0	0	0
000108101	METHYL ISOBUTYL KETONE	5	37,120	19,740	17,379	0	0	0	4,403	0	0	66,000

Table 4-1 (continued)

2001 TRI Releases for SIC 3086 Top 25 Chemicals

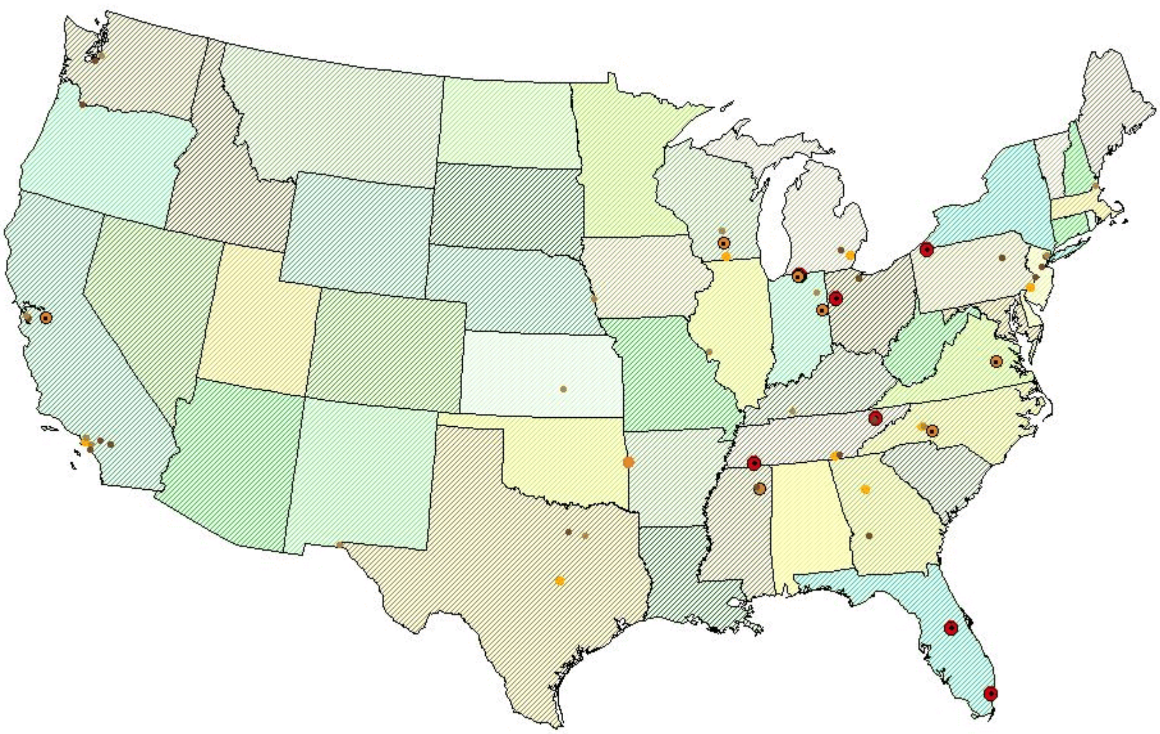
CAS No.	CHEMICAL NAME	No. of Facilities Reporting	2001 TRI Releases and Other Waste Management (pounds)									
									Quantities to Waste Management			
				Sub-Categories of Releases					Off-Site Transfers			
			Total Quantity Released	Fugitive Air Emissions	Stack Air Emissions	Discharged to Surface Water	Released to Onsite Land	Transferred Offsite for Disposal	Treatment	Energy Recovery	Recycled	On Site Treatment
000078933	METHYL ETHYL KETONE	8	903,827	774,788	129,955	0	5	250	179,540	0	12,312	310,000
000110543	N-HEXANE	5	26,655	8,462	18,191	0	0	0	0	0	0	39,932
000872504	N-METHYL-2-PYRROLIDONE	5	123,336	1,000	122,036	0	5	750	207,780	0	0	0
000085449	PHTHALIC ANHYDRIDE	2	6,067	0	5	0	0	6,067	0	0	0	0
000075569	PROPYLENE OXIDE	3	12,210	6,147	6,063	0	0	0	250	0	0	0
000100425	STYRENE	7	80,405	25,136	55,227	0	0	0	122,495	160,899	0	0
026471625	TOLUENE DIISOCYANATE (MIXED ISOMERS)	74	27,080	4,131	16,225	0	250	6,768	77,382	0	0	745
000108883	TOLUENE	12	726,623	395,257	330,969	0	0	345	104,717	0	0	76,747
000584849	TOLUENE-2,4-DIISOCYANATE	8	8,855	1,137	2,315	0	0	5,663	920	0	0	2
000079016	TRICHLOROETHYLENE	2	23,199	232	22,967	0	0	0	7,177	0	0	0
001330207	XYLENE (MIXED ISOMERS)	4	319,849	304,940	14,661	0	0	248	62,830	0	0	9,524
N982	ZINC COMPOUNDS	8	60,607	255	2,250	0	5	3,366	250	0	0	0

Table 4-1 (continued)

2001 TRI Releases for SIC 3086 Top 25 Chemicals

Figures 4-1 and 4-2 present the geographic distribution and total TRI releases for each facility of SIC 3086 and the top 8 foam manufacturers identified in Section 2.0, respectively. Figure 4-1 presents total TRI releases for the top 10 highest discharges. Of these companies listed in Figure 4-1, five are flexible polyurethane foam manufactures (Foamex (Milan, TN), Foamex (Corry, PA), Foamex (Elkhart, IN), Carpenter, and GFC Foam (which is now owned by Foamex)). Texas Recreation produces boat accessories and floatation devices and Pactiv produces packing material. These two companies may produce flexible polyurethane foam.

TRI Releases From the Top 8 U.S. Flexible Foam Producers



LEGEND

TRI Releases (in pounds)

- 0-99
- 100-999
- 1,000-9,999
- 10,000-99,999
- 100,000-999,999
- >1,000,000

Top 10 TRI Dischargers Among Top 8 Producers

1. Foamex (Milan, TN)	4,401,064 lbs
2. Foamex (Corry, PA)	3,738,651 lbs
3. Carpenter (Elkhart, IN)	3,214,265 lbs
4. Foamex (Elkhart, IN)	1,815,824 lbs
5. Flexible Foam Products (Spencerville, OH)	1,648,698 lbs
6. Foamex (Morristown, TN)	1,343,736 lbs
7. Flexible Foam Products (Miami, FL)	1,326,096 lbs
8. Foamex (Orlando, FL)	1,060,749 lbs
9. Carpenter (Lathrop, CA)	753,440 lbs
10. Flexible Foam Products (Elkhart, IN)	586,358 lbs

Figure 4-1. Geographic Distribution and TRI Releases for SIC 3086

Figure 4-2. Geographic Distribution and TRI Releases of Top 8 Foam Producers

4.3 Occupational Exposures

This section presents information on worker activities in flexible polyurethane foam manufacturing facilities, estimated worker inhalation, and estimated dermal exposures.

4.3.1 Number of Workers

Based on the analysis presented in Section 2.2, it is estimated that there are approximately 58 employees per facility. According to the 2001 Annual Survey of Manufacturers, 80 percent of employees in NAICS 326150 are production workers (6). Assuming that all production workers could be exposed to chemicals used in the foam manufacturing process, approximately 47 workers per facility could be exposed to chemicals or involved in the production of foam.

4.3.2 Worker Activities

Foam line worker activities can be divided into four basic job functions: foam head operator, foam line operator, cut-off saw operator, and bun handler. Workers also handle foam after manufacturing and perform post production (further trimming and cutting and glueing) and packing activities.

The foam head operator works primarily on the bridge at the front of the foam line, and rarely leaves the bridge (where raw materials are dispensed onto the conveyor), except during upset conditions. Depending on the particular plant layout, the foam head operator may be situated close to the foam head or some distance away. The foam head operator is the least likely to go into or under the tunnel during operation.(1)

The working area of the foam line operator ranges along the entire foam line including the bridge, and often leaves the bridge to attend to problems with the paper or plastic on the conveyor line. The foam line operator is the most likely to go into or under the tunnel during operation, and sometimes enters the tunnel for start-up. (1)

The cut-off saw operator, generally, does not leave the saw area; however, it is routine for the saw operator to enter the tunnel to label foam buns and to remove scrap. Saw operators might also be required to enter the tunnel at start-up. (1)

The fourth job category, the bun handler, is responsible for moving foam blocks, or buns, from the cut-off saw area to the curing area. The nature of the bun handler's job varies from plant to plant. At some facilities, this position might require moving short buns with a dolly or forklift, or long buns with a crane, while some newer plants have conveyor systems that require no operator. The bun handler may sometimes enter the tunnel at start-up. (1)

4.3.3 Inhalation Exposures

Occupational exposures to diisocyanates and methylene chloride are regulated by Occupational Safety and Health Administration (OSHA). In addition, the American Conference of Governmental Industrial Hygienists (ACGIH) issues recommended guidelines. Table 4-2 presents the exposures limits.

Table 4-2

OSHA PELs and ACGIH TLVs for Chemicals Used During the Manufacture of Flexible Polyurethane Foam

Chemical	OSHA PEL			ACGIH TLV	
	TWA	STEL	Ceiling	TWA	STEL
Toluene-2,4-Diisocyanate (TDI)	NE	NE	20 ppb 0.14 mg/m^3	5 ppb 0.036 mg/m^3	20 ppb 0.14 mg/m^3
Methylene Diphenyl Diisocyanate (MDI)	NE	NE	20 ppb 0.2 mg/m^3	5 ppb 0.05 mg/m^3	NE
Methylene Chloride	25 ppm	125 ppm	NE	50 ppm 174 mg/m^3	NE

NE - Not established.

Sources: OSHA 29 CFR Subpart Z
American Conference of Governmental Industrial Hygienists'. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. 1996.

An industrial hygiene study of six slabstock foam manufacturers, conducted by Bayer Corporation, examined occupational exposures to airborne TDI (1). Short-term (~15 min.) samples were collected to detect peak exposures that might exceed OSHA ceiling limits. Such exposures can occur due to an upset condition, for example, a break in the conveyor belt's bottom paper or plastic, which allows liquid to spill out onto the floor. Such conditions typically require the immediate response of all those working on the foam line. While OSHA regulates only the 2,4-TDI isomer, total TDI values, including the 2,6-TDI isomer, are often used in industry, including in this study, for comparison to exposure limits. Because the 2,4-TDI isomer is more reactive than 2,6-TDI, the latter tends to contribute more to airborne levels of TDI. Table 4-3 presents a summary of short term sample results from personal monitor data for each job category (1).

Table 4-3

Short Term Personal Monitoring Data

Job Function	Number of samples	Mean 2,4-TDI concentration (ppb)	Mean 2,6-TDI concentration (ppb)	Mean Total TDI concentration (ppb)
Foam Head Operator	110	2.04	2.13	4.2
Foam Line Operator	91	3.57	8.01	11.6
Saw Operator	79	1.24	4.97	6.2
Bun Handler	123	1.18	3.32	4.5

4.3.4 Dermal Exposures

Dermal exposures during the manufacturing of flexible polyurethane foam are expected during all the worker activities described above. However, the largest exposure to chemicals used is expected during the transferring of chemicals from the transport container to the process equipment. This is assumed because foam manufacturing is highly automated but workers are expected to be physically involved in transferring operations and chemicals will be at their highest concentrations before mixing with other raw materials. Most chemicals used in the flexible polyurethane foam manufacturing process are liquids. No dermal monitoring data was found relating to this industry. In the absence of data, a simplified model is used to estimate potential dermal exposures.

This model is based on experimental data with liquids of varying viscosity. Measurements were made of the amount of exposure to hands for various types of contact. Judgements were then made as to the types of common industrial activities that could be associated with experimental data. Additionally, available data on pesticide exposures collected by EPA's Office of Pesticide Programs and values for dermal contact for solids handling from TNO Nutrition and Food Research Institute were also used in the development of a Table of Dermal Assessments Factors which are presented in Table 4-4.

Table 4-4

Factors for Screening-Level Assessments of Dermal Exposure to the Hands

Type of Contact1	Typical Examples	AREA[2] (cm^2)	Q[3] (mg/cm^2)	Resulting Dermal Contact (mg)
Routine, direct handling of solids - 2 hands	• Filling/dumping containers of powders, flakes, granules • Weighing powder/ scooping/mixing (i.e., dye weighing) • Handling wet or dried material in a filtration and drying process	NG	NG	up to 3,100 [4]
Routine contact with surfaces - 2 hands - solids	• Handling bags of solid materials (closed or empty)	NG	NG	up to 1,100 [4]
Routine immersion, 2 hands - liquids	• Handling wet surfaces • Spray painting	840	1.3 - 10.3	up to 8,700
Routine contact, 2 hands - liquids	• Maintenance • Manual cleaning of equipment • Filling drum with liquid	840	0.7 - 2.1	up to 1,800
Incidental contact, 2 hands - liquids	•Connecting transfer line	840	0.7 - 2.1	up to 1,800
Incidental contact, 1 hand - liquids	• Sampling • Ladling liquid/bench scale liquid transfer	420	0.7 - 2.1	up to 900

NG - Not given, values for AREA and Q are not provided because contact values for solids were determined by experimental data.

Notes:

[1] The terms "routine" and "incidental" reflect typical CEB judgments on likelihood of contact for the example activities.

[2] Values of the skin surface area of the hands taken from: EPA Exposure Factors Handbook, 1997 and are the mean values for men.

[3] Selected ranges of 'Q' Values for liquid handling activities taken from: EPA, 1992. A Laboratory Method to Determine the Retention of Liquids on the Surface of Hands, Exposure Evaluation Division, Office of Pollution Prevention and Toxic, U.S. EPA, EPA 747-R-92-003, September, 1992.

[4] Values for dermal contact for solids handling activities were taken from: Lansink, 1996. Lansink, C.J.M., M.S.C. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modeling of Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

Source: CEB 2000. Options for Revising CEB's Method for Screening-Level Estimates of Dermal Exposure. Final Report. June 01, 2000.

Table 4-4 is used to determine screening level dermal estimates to solids and liquids. Dermal exposures in the foam manufacturing industry are expected to occur during the unloading of chemicals from transport containers and charging chemicals to the process equipment. Dermal exposure is also expected during maintenance activities and spill containment/clean up. According Table 4-4, these activities correspond to 2-hand routine contact to liquids or 2-hand incidental contact to liquids. The following equation calculates dermal exposure to liquid chemicals.

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem}$$

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical of interest/day)
Q_{liquid_skin}	=	Quantity of liquid remaining on the skin (default: 2.1 mg/cm^2-incident)
$AREA_{surface}$	=	Surface area of contact (Default: 840 cm^2 for two hands and 420 cm^2 for one hand) (10)
$N_{exp\_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem}	=	Fraction of chemical of interest in formulation (Default: 1)

Dermal exposure to solids are expected to occur during the transferring and mixing of solid materials and during handling of sold foam during trimming and cutting activities. The following equation calculates dermal exposure to solid chemicals.

$$EXP_{dermal} = Q_{solid\_skin} \times N_{exp\_incident} \times F_{chem}$$

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical of interest/day)
Q_{solid_skin}	=	Quantity of solid remaining on the skin (default: 3,100 mg-incident)
$N_{exp\_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem}	=	Fraction of chemical of interest in formulation (Default: 1)

5.0 ENGINEERING CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT

This section presents information on engineering controls that may be used in the industry to control TDI and other chemical emissions, personal protective equipment used, and regulatory requirements pertaining to TDI and methylene chloride.

5.1 Engineering Controls[2]

In order to meet OSHA workplace exposure limits for diisocyanates and methylene chloride, many polyurethane manufacturers have incorporated engineering controls, in addition to process changes, such as the replacement of methylene chloride with liquid CO_2 systems. Since worker exposure to these chemicals is highest near the foam tunnel, a combination of containment (i.e., enclosure) and local exhaust ventilation (LEV) is a common method of control. The balance between containment and LEV is governed by both exposure limitation and economic factors, e.g., capital and operating costs.

In the past, the exhaust from LEV units has typically been released directly to the atmosphere through a stack, but due to a NESHAP promulgated by EPA in October 1998, more manufacturers are considering the addition of air pollution control (APC) equipment to control air releases to the environment. Three methods to control TDI as well as other chemicals were found and discussed below.

Wet scrubbers remove vapor-phase chemicals by absorption into water. Such systems typically can remove 65 to 85 percent of TDI in the exhaust stream. The reaction of diisocyanates with water to produce CO_2 limits the efficiency of such systems. In addition, large water recirculation requirements can make such units energy intensive, and the spent water (blowdown) must be treated downstream.

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[2]The mention of any company in this section does not constitute a U.S. Environmental Protection Agency endorsement of the company or its products.

Activated carbon filtration systems clean exhaust gas through adsorption of vapor-phase organics onto carbon granules. One or more prefilter stages precede the carbon bed to prevent fouling or clogging. Camfil Farr offers annular and vertical deep bed systems that can remove greater than 99.97 percent of TDI, as well as methylene chloride, other auxiliary blowing agents, catalysts, and additives from the exhaust stream. The cost of the filter unit and one charge of carbon ranges from $65,000 (15,000 cfm exhaust) to $150,000 (60,000 cfm exhaust). The typical bed-life is five to seven years and the cost for replacement of the carbon and prefilters ranges from $17,000 to $70,000 (~50 % for carbon). Camfil Farr advocates using virgin carbon, rather than regenerated, as the adsorption medium. The used carbon can be disposed to landfill, or sold for incineration or regeneration. (2)

In Australia, Dunlop Foams developed a TDI abatement method to meet strict emissions requirements. TDI reacts with existing urethanes to form an allophanate. Dunlop uses blocks of polyurethane foam as a reactive scrubbing medium resulting in TDI removal efficiencies of 97 to 99 percent. The foam blocks are replaced on a monthly basis and are relatively inexpensive compared to activated carbon or recirculated water (specific pricing is not available). Dunlop claims that the blocks can be easily disposed to a landfill although the foam would need to be evaluated to determine disposal options. (3)

5.2 Personal Protective Equipment (PPE)

To supplement containment and LEV, foam line workers should use personal protective equipment, particularly when responding to an upset condition or other spill. The Alliance for the Polyurethanes Industry offers guidelines for selecting appropriate protective equipment when handling TDI and MDI (4,26). These guidelines include eye protection, respiratory protection, and selecting gloves and suits. For facilities using methylene chloride, it should be noted that methylene chloride can penetrate many materials impervious to TDI, and may carry TDI with it through barrier clothing.

According to the industrial hygiene study by Bayer Corporation (1), the use of respirators is dependant on job function. In general, the use of respirators limits overexposure to airborne TDI and other chemicals when entering the tunnel or responding to upset conditions.

Foam head operators are the least likely to be overexposed to TDI, provided that there are good work practices and proper ventilation, and tend not to use respirators. However, the foam head operator should don a respirator when responding to an upset condition.

The foam line operator is the most likely to be exposed to airborne TDI levels higher than the OSHA PEL Ceiling. The study found that 4 of the 5 foam line operators exposed to short-term levels greater than 20 ppb (total TDI) used respiratory protection (1). Due to the need for high mobility, this typically entails the use of half-face or full-face air-purifying respirators (APRs) with organic vapor (OV) cartridges.

Saw operators have the potential to be overexposed to TDI, due to their frequent entry into the tunnel. In some cases, the ventilation system is sufficient for removing TDI. However, 5 of the 6 saw operators in the study were exposed to short-term levels greater than 20 ppb (total TDI) and wore loose, hooded supplied-air respirators (SARs) (1).

Bun handlers' exposure to TDI is greater if handling hot, or freshly cut, buns. In such cases, respiratory protection, most likely APRs, should be used. In the Bayer Corporation study, all bun handlers exposed to short-term exposure levels of greater than 20 ppb (total TDI) used respiratory protection (1). In general, if bun handlers do not come into direct contact with hot buns (e.g., a crane operator) overexposure to TDI is less likely.

5.3 Regulatory Requirements and Controls

In October 1998, the EPA promulgated a NESHAP for the flexible polyurethane foam industry. This NESHAP required a 68 percent reduction of methylene chloride emissions from slabstock foam production, and the elimination of the use of methylene chloride as a cleaning solvent or release agent in molded foam production. This NESHAP also requires the control of diisocyanate emissions from storage vessels, transfer pumps, and other components in service (e.g., connectors, valves, pressure-relief devices, etc.). (25)

OSHA and ACGIH have developed exposure limits for chemicals used in the foam manufacturing industry. See Table 4-2 for a summary of OSHA PELs and ACGIH TLVs of key chemicals used in the flexible polyurethane foam manufacturing industry.

There are other regulations pertaining to chemicals used the flexible polyurethane foam manufacturing industry including the Toxic Release Inventory where TDI, MDI, methylene chloride, and other chemicals are required to be reported. The above paragraphs, however, focus on the regulations that pertain to diisocyanates.

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