Use of Additives in Foamed Plastics- Generic Scenario for Estimating Occupational Exposures and Environmental Releases

-Draft-

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3 June 2004

SUBJECT: ***Generic Scenario for the Use of Additives in Foamed Plastics Draft***

ERG collected readily available information that could be used to develop a generic scenario describing the use of prepolymers and other raw materials; additives; and processing aids in the production of foamed plastics. This memorandum presents a summary of the information and data sources that were found to be relevant in developing a generic scenario for the use of foamed plastic additives (to be entitled *Generic Scenario for the Use of Additives in Foamed Plastics*).

Specifically, the generic scenario will provide a methodology for calculating the environmental releases and worker exposures to chemicals incorporated into the foamed plastic during its manufacture. These chemicals include prepolymers and other reactive materials, plastic performance additives, and <u>certain</u> processing aids (e.g., catalysts, blowing agents).

The generic scenario will be applicable to the foaming processes used in the manufacture of flexible and rigid <u>polyurethane</u> foams. These processes include those used to produce flexible slabstock or rigid panels, as well as injection molding and are described later in this memorandum under "Industry Background and Process Summary - Polyurethane Foam Production". Based on the preliminary research, these processes may be used in the manufacture of certain other types of foams, although their most prevalent use is in polyurethane foams.

The generic scenario will include information on industry size; process description(s); the types of foamed plastics that may be manufactured by the processes; general polymerization reaction descriptions; typical additive and processing aid chemicals that are incorporated into foams; and the anticipated releases of and worker exposures to those chemicals. It is anticipated that much of the data used in the generic scenario will be based on polyurethane foams, but applicable to other foams manufactured by similar processes.

Note: nearly 73 percent of the PMNs pertaining to foamed plastic chemicals that have been reviewed by CEB since 1992 were for chemicals used in polyurethane foams.

The generic scenario will <u>not</u> cover the use of processing aids <u>not</u> directly incorporated into the foamed plastic (e.g., mold release agents). The generic scenario will also not cover the <u>formulation</u> of the pre-polymer, other reactive component, or additive products that are used in manufacturing the foamed plastic, nor will it cover the further processing or fabrication of the foamed plastics into the final article (e.g., via cutting, bonding, glueing, lamination to other substrates, etc.).

Polystyrene foams are also prevalent within the foamed plastics industry; however, ERG determined that the processes by which polystyrene foams are made are significantly different from those used for polyurethanes. In addition, none of the past PMNs reviewed by CEB indicate a new chemical use within polystyrene foams. Therefore, this generic scenario will not be applicable to the use of polystyrene foam additives (or to the processes by which polystyrene foams are manufactured).

Should CEB wish to develop a generic scenario that encompasses the use of polystyrene foam additives and polystyrene foam processes, ERG recommends that it be developed as a separate research effort and document. The available information for polystyrene foams that was obtained during this scoping effort has been included in this memorandum for future reference.

A list of the readily available resources that were found during this preliminary search and a brief description of the information provided is also included. In instances where information has been taken from a particular source, that source has been provided in parentheses at the end of the sentence. Some of this information was presented in a prior scoping document for the *Plastics Industry Generic Scenario*, delivered to you on June 11, 2003.

Please feel free to contact me at (404) 634-0038 or at leslie.churilla@erg.com to discuss any questions or comments that you have on the information presented in this memorandum.

Industry Background and Process Summary

In this section, descriptions are provided for the foamed plastic production industry including:

- Relevant NAICS codes for the foamed plastic manufacturing industry, including numbers of sites and production workers for each NAICS code;
- Foamed plastic production data;
- Typical additives that are used within foamed plastics;
- General information pertaining to foamed plastic processes, including a description of common processing aids that are used;

- Typical polystyrene foam process descriptions; and

- Typical polyurethane foam process descriptions.

NAICS Codes

There are two relevant North American Industrial Classification System (NAICS) codes that pertain to plastic foam production industries:

- 326140 - Polystyrene Foam Product Manufacturing; and
- 326150 - Urethane and Other Foam Product (except polystyrene) Manufacturing.

Polystyrene foams are produced from a *thermoplastic* resin. Thermoplastic resins when heated during processing soften and flow as viscous liquids and when cooled solidify. Thermoplastic resins can be repeatedly heated and cooled many times with little property loss. In 2001, there were a total of 566 polystyrene foam production sites (USCB 2001a), employing a total of 27,479 production workers (approximately 81 percent of the total number employed) (USCB 2001b).

Polyurethane foams are produced from a *thermosetting* resin. Thermosetting resins liquefy when heated and solidify with continued heating. The polymer undergoes permanent cross-linking and retains it shape during subsequent cooling and heating cycles. In 2001, there were a total of 610 polyurethane and other plastic foam production sites (USCB 2001a), employing a total of 27,884 production workers (approximately 81 percent of the total number employed) (USCB 2001b).

In 1997, approximately one third (33 percent) of the facilities in this industry (NAICS 326150) were estimated to produce flexible polyurethane foam and approximately 10 percent are estimated to produce rigid polyurethane foam (USCB 1997a). Note: the percentages of facilities producing flexible and rigid polyurethane foams are based on data obtained for sites having product shipment values of $100,000 or more.

Foamed Plastic Production

The relative North American production of polyurethane foams and polystyrene resin is presented in Table 1 (next page).

The 1996 EPA reference provides production data for slabstock and molded flexible polyurethane foams. The 1997b Kirk-Othmer reference provides production data for flexible and rigid polyurethane foams. This reference also provides relative amounts of polyurethane foams used in various end-use applications.

Table 1

Resin	Production (millions of pounds, dry weight basis)	Common Uses [1]
Polyurethane foam	2,365 [2]	Furniture, cushioning, carpet underlay, bedding, packaging, textiles, automotive seating, safety padding, insulation
Polystyrene	6,442 [3]	Foam cups and containers, protective packaging, insulation

[1] *Definitions of Plastic Resins* web page, The Society of Plastic Engineering, http://www.plasticsindustry.org/industry/defs.htm.
[2] SRI. Amount represents U.S. Consumption in 2001. Note: this source contains proprietary information. Information provided from this reference is intended for internal EPA use only.
[3] *APC Year-End Statistics for 2003: Production, Sales & Captive Use 2003 vs. 2002*, American Plastics Council, March 10, 2004, http://www.americanplasticscouncil.org/s_apc/docs/1100/1014.pdf. Note: this number includes total polystyrene resin production (not just polystyrene resin used in foamed plastic).

Additives Used in Plastic Foams

In the case of polyurethane foams, the foam manufacturer performs the polymerization reaction to form the plastic simultaneously with the manufacture of a preliminary foam product (e.g., slabs, buns, boards, molded pieces). As such, the manufacturer receives formulations containing the raw materials for polymerization (e.g., pre-polymers and other reactants). These raw materials may contain other additives that enhance the properties of the final polymer and are typically supplied by a chemical manufacturer.

Many other types of foamed plastic products (including polystyrene foams) are created from compounded plastic resins. In these cases, the addition of the plastic additives and the polymerization reaction are performed at a compounding facility. The resin is then used within another facility or process to manufacture a finished foamed plastic article.

Below is a list of the type of additives that may be incorporated within plastic resins to enhance the properties of the final polymer: (EPA 1995) and (OECD 2004)

- Antioxidants: Inhibit the oxidation and degradation of plastic materials (e.g., polyethylenes, polypropylenes, and styrenic materials) that are exposed to oxygen or air at normal or high temperatures. *Ex: amines, phenols, phosphates.*

- Antistatic agents: Impart a minimal to moderate degree of electrical conductivity to the plastic compound, preventing electrostatic charge accumulation on the finished product.
  Ex: conductive powders, metal flakes, intrinsically conductive polymers

- Colorants: Impart color to the plastic resin.
  Ex: dyes, pigments

- Coupling agents: Improve the bond between polymer matrices and mineral fillers and fiber reinforcements.
  Ex: silane and titanate compounds

- Fillers: Inert materials added to a polymer to reduce cost, improve processibility, or improve mechanical properties of the finished article.
  Ex: powder or fiber; remain as a separate phase within the polymer

- Flame retardants: Reduce the tendency of the plastic product to ignite and burn.
  Ex: compounds based on halogens, boron, and phosphorous

- Impact modifiers: Prevent brittleness by absorbing crack-initiating energy.
  Ex: elastomers or elastomer/polymer blends

- Plasticizers: *Permanent* types enhance the plastic product's flexibility and/or inhibit the embrittlement of the material at low temperatures (designed to enhance the finished product throughout its life).
  Latent types improve the workability of the plastic during compounding and melt fabrication (typically removed during post-fabrication oven drying).
  Ex: liquids or waxy solids

- Preservatives: Occasionally added to enhance a plastic product's resistance to microbial growth.
  Ex: fungicides and bacteriocides

- UV and other weathering stabilizers: Absorb or screen out ultra-violet radiation or other environmental factor, thereby preventing the premature degradation of the plastic product.
  Ex: benzo derivatives, other polymers with good weathering properties (e.g., PVC)

Plastic Foams: General Process Information

In addition to the plastic additives listed above, converters or foamed plastic manufacturers may also use a combination of several processing aids in forming the final article. Below is a list of the types of processing aids that are commonly used by foamed plastic manufacturers in their processes: (EPA 1995) and (OECD 2004)

- Blowing agents: Produce a cellular structure within the plastic mass and can include compressed gases that expand upon pressure release, soluble solids that leach out and leave pores, polymerization reaction products (e.g., H_2O + diisocyanate → CO_2 gas in polyurethanes) or liquids that volatilize upon heating the polymer resin.
  Ex: CO_2, acetone, pentanes

- Curing agents/Catalysts: Initiate or control the rate of polymerization in thermosets and many thermoplastics.
  Ex: peroxides, amines, and organotin compounds

- Heat stabilizers: Assist in maintaining the chemical and physical properties of the plastic by protecting it from the effects of heat such as color changes, undesirable surface changes, and decreases in electrical and mechanical properties.
  Ex: organic or organometallic compounds

- Lubricants/Slip promoters: Assist in easing the flow of the plastic in the molding and extruding processes by lubricating the metal surfaces that come into contact with the plastic.

- Mold release agents: Sprayed or otherwise applied to the interior surfaces of a mold (prior to the addition of the plastic to be molded) to prevent the formed plastic from adhering to the mold surface and facilitate the "clean" removal of the formed article from the mold.

- Viscosity aids: Used to regulate the viscosity of polymer-plasticizer solvent mixtures during processing (e.g., often in PVC processing)
  Ex: other polymers

Below is a list of the shaping methods commonly used in creating foamed plastic products: (EPA 1995) and (Kirk-Othmer 1994):

- Injection molding: Plastic granules or pellets are heated and homogenized in a cylinder. By pressure the resin is injected into a cold mold where the plastic takes the shape of the mold as it solidifies (e.g., polystyrene beads).

- Reaction injection molding: Two liquid pre-polymers (e.g., polyols and isocyanates react to form a polyurethane) are mixed in a chamber with other additives and injected into a closed mold. The exothermic reaction occurs during the mixing. In the case of polyurethane foams, the polymerizing foam may be injected onto a moving conveyor (to make slabstock or rigid boards) or injected/poured/sprayed directly into a predefined space/chamber to be filled with the foam ("pour-in-place") (e.g., refrigerators, building insulation, boat hulls).

- Extrusion: Plastic pellets or granules are fluidized, homogenized, and formed continuously as the extrusion machine feeds them through a die (e.g., rigid polystyrene insulation sheets or boards; loose polystyrene packaging material).

- Compression molding: Plastic powder or preformed plastic part is plugged into a mold cavity and compressed with pressure and heat until it takes the shape of the cavity (e.g., expanded polystyrene bead molding).

- Transfer Molding: The plastic is liquefied in one chamber and then injected into a closed mold cavity by means of a hydraulically operated plunger.

Appendix III of the OECD 1994 reference contains additive concentration data for several types of plastics, including expanded polystyrene and polyurethanes. The Kirk-Othmer 1997b reference includes a formulation for rigid polyurethane panels.

Polystyrene Foam Production

Expandable cellular polystyrene is used to manufacture molded articles or loose-fill packing materials. Expandable polystyrene particles (sizes ranging from 0.2 to 3.0 mm) may be of varying shapes from round beads to "chunks". In some cases, these polystyrene particles are manufactured with a blowing agent entrapped within the particle (i.e., the blowing agent was mixed with the styrene monomer during its polymerization). Other processes prepare these particles by heating them in the presence of a blowing agent, allowing the agent to penetrate the particle. Typical blowing agents include various isomeric pentanes and hexanes, and halocarbons. (Kirk-Othmer 1994)

Foamed polystyrene articles may be formed through extrusion. A solution of blowing agent in molten polystyrene is formed under pressure within the extruder. The heated, molten solution is then forced out of the extruder orifice and onto a moving belt at ambient temperature and pressure. As the pressure is decreased within the hot polymer, the blowing agent vaporizes, creating the foam cells and causing the molten polymer to expand. As the polymer cools, the structure stabilizes. (Kirk-Othmer 1994) Examples of articles manufactured by this process include rigid foams used for building insulation (Kirk-Othmer 1997a).

Forming molded polystyrene articles is typically performed in two steps. First, the polystyrene particles are *prefoamed* or *pre-expanded*, which entails heating the particles with steam, hot water, or hot air. These pre-expended particles are then placed into a mold and subjected to further heating with steam. This second expansion causes the particles to flow into the spaces between the pre-expanded beads and to fuse together. The article is stabilized by cooling it before being removed from the mold and sent on to subsequent finishing. (Kirk-Othmer 1994)

In the production of polystyrene loose fill packing material, the polystyrene particles are manufactured by deforming polystyrene resin under heat (creating various desired shapes) while impregnating the resin with a blowing agent in an aqueous suspension. These particles may also be produced via extrusion using various die orifice shapes. Finally, the packing material product is created by multiple expansions of these particles. Typically, the particles undergo two or three expansions via steam heating with at least one day of aging in air in between expansions. The polystyrene in the packing material is stabilized through the intermediate cooling processes, in which the polymer is cooled to below its glass-transition temperature. (Kirk-Othmer 1994)

Polyurethane Foam Production

It is estimated that the majority of the Urethane and Other Foam Product Manufacturing industry (NAICS 326150) comprises the manufacture of polyurethane foam products (USCB 1997a). Polyurethane foams are typically produced by the following methods: compression, injection, transfer molding, and reaction injection molding .

All polyurethane foams are made by way of a reaction between polyols, diisocyanates, and water. The reaction between the polyols and isocyanate creates the polyurethane polymer matrix. The reaction between the isocyanate and water generates carbon dioxide, which acts as an “in situ” blowing agent. In some applications, an auxiliary blowing agent (ABA) is added to the process (e.g., additional carbon dioxide, acetone, methylene chloride (in limited applications)).

Polyurethane foams are produced in one of two forms: *flexible* foam and *rigid* foam. Further, flexible polyurethane foam can be produced as *slabstock* foam and *molded* foam. The following subsections describe the manufacturing process for slabstock flexible polyurethane foam, molded flexible polyurethane foam, and rigid polyurethane foam.

Slabstock Flexible Polyurethane Foam

Slabstock foam represents 75 percent of the flexible polyurethane foam industry (EPA 1996). 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. The raw materials for this process include diisocyanates, polyols, water, ABAs, fillers, curing agents, and other additives (e.g., flame retardants). First, the raw materials and additives are metered into a single mix head, which dispenses the mixed and reacting materials onto an enclosed conveyor system. Within a few minutes of leaving the mix head, the raw materials begin to create foam-producing reactions, producing the polyurethane foam on the conveyor. 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 into “buns”. Each bun is removed from the conveyor and moved to a curing area where it is allowed to cure for about 24 hours. Once cured, the buns are further processed through trimming and other fabrication steps (e.g., shaping and gluing/bonding to pieces of foam or other materials). (EPA 1996)

Molded Flexible Polyurethane Foam

Molded foam accounts for about 25 percent of the flexible polyurethane foam industry. Molded foam is produced when the foam polymerization reaction occurs within a closed mold in the shape of the final product. Molded foam is most often 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. Raw materials include polyols, diisocyanates, water, catalysts, surfactants, 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 number of streams fed into the head and to ensure precise measurement (EPA 1996). The mix head dispenses a measured amount of the mixture into each mold (often coated with a release agent) 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 within the mold. Once curing is complete, the mold is opened and the foamed article is removed. The mold is cleaned and returned to the process line to be conditioned for the next product.

The molded article is then sent to a “crushing” process where it is passed through a set of rollers. This procedure is designed to open the newly formed cells within the cell and to release any residual CO_2 or ABA that was trapped within the cells. Another method includes subjecting the article to reduced pressure within a vacuum chamber. The molded article is then further processed through trimming and other fabrication steps (e.g., shaping and gluing/bonding to pieces of foam or other materials) or repair. (EPA 1996)

Rigid Polyurethane Foam

Rigid polyurethane foam is a closed-cell foam and produced from high functionality polyols (with molecular weights of approximately 500) and poly(methylene)-poly(phenyl isocyanate). Other additives include blowing agents, catalysts, and foam stabilizers. Rigid foams are often produced in slabs that are cut into panels using a process similar to that described above for slabstock flexible polyurethane foams They can also be sprayed (e.g., onto structural components as building insulation) or poured/pumped into molds (similar to that described for molded flexible polyurethane foams). Rigid polyurethane foams may also be poured/sprayed into a permanent space to be filled (e.g., insulation for refrigerators, boat hulls) (Kirk-Othmer 1994 and 2003).

Primary Release Sources

In general, the primary release sources of the additive chemicals used in the manufacture of polyurethane foamed plastics are listed below:

- Residual amounts remaining in shipping containers; may be liquid or solid residues (consistent with EPA 2004a, which cites the existing CEB container residual models). Additional research will be required to determine the most prevalent (or appropriate default) container type used.

- Residual amounts remaining in process equipment (e.g., mixing/dispensing head, polymerization chamber/mold). It will be important to distinguish between residues containing unreacted chemical vs. those containing polymerized material, in which the chemical is either reacted (e.g., prepolymers) or is bound within the polymer matrix (e.g., fillers, other additives). The OECD 2004 reference provides several emission estimates for various plastic additives and processing aids (not specific to polyurethane foams or polyurethane foaming processes). The EPA 2004a reference states that the standard CEB model of 2 percent is reasonable for estimating polyurethane foaming process equipment residues.

- Release of ABAs from the process and subsequent foamed plastic curing and "crushing". Conservative estimates would likely assume the ABA is a gas and is not consumed in the polymerization reaction; and that 100 percent is released from the process (OECD 2004).

- Approximately 0.0035 percent of the isocyanate used in flexible foams is not converted and is released from the process as a volatile gas (EPA 2004a; supporting data obtained through industry contacts).

- Scrap or off-spec foamed product; the EPA 1996 reference estimates up to 12 percent of slabstock flexible polyurethane foams are waste/scrap material. The PFA 1994 reference estimates that up to 30 percent of all polyurethane foams are scrapped. The majority of flexible polyurethane foams are sent to rebond facilities/processes where the scrap is ground into small pieces that are then bound together with a polyurethane binder. The rebound foam is typically used in carpeting and furniture applications. The EPA 2004a reference states that at least 99 percent of the scrap polyurethane foam is recycled in this way (supporting data was obtained through industry contacts).

Primary Exposure Activities

Number of Workers Exposed

The available U.S. Census data shows the following (USCB 2001a):

- There are a total of 566 polystyrene foam production sites, employing a total of 27,479 production workers (<50 workers/site); and

- There were a total of 610 polyurethane and other plastic foam production sites (USCB 2001a), employing a total of 27,884 production workers (<50 workers/site).

The UCSB 2001a, 1997a, and 1997b references also contain data showing the distribution of the relative number of production workers among the sites.

Duration of Exposure

The UCSB 1997a and 1997b references provide total annual hours worked within each industry sector. These data suggest that production workers average 8 hours per day in both sectors (assuming a 250-day work year).

Exposure Activities

In general, the activities that result in the most significant exposures to the reactants and additives used in the manufacture of polyurethane foamed plastics are listed below:

- Transfer from shipping containers - The activity resulting in one of the most significant exposures to workers is the transfer/connection of the prepolymer, reactants, and additives from their shipping containers into bulk storage or intermediate "day" tanks (dermal (liquid or solid) and inhalation of volatile liquids). Nearly all polyurethane foaming products are liquids, though some additives may be powders which are premixed with one of the components of the polymerization/foaming reaction (EPA 2004a).

- Operation/supervision of the foam mix head/dispenser - Significant exposures also exist for the operator stationed at or near the foam equipment mix head/dispenser. At this point, the components are actively reacting to generate the polyurethane and foamed structure. Inhalation exposures to volatile components of the reaction (e.g., ABAs, isocyanate monomers) are expected. Dermal exposures are not expected (EPA 2004a, which references a 2002 PFA Technical Proceeding, and EPA 2004b).

- Exposures during foam production - Most of the processes are considered to be closed (OECD 2004); however, there are some observances of foam lines being semi-enclosed to permit workers could enter the tunnel for maintenance or supervision of the process. There may be some potential for inhalation exposures to fugitive volatile process chemicals by workers positioned near the foaming process (EPA 2004a) or by workers using foam-in-place, pour-in-place or other application of an in situ rigid foam product.

- Transfer/handling of newly foamed articles - Some inhalation exposures of residual volatile materials and ABAs are expected during the transfer and curing of the newly foamed articles; some dermal exposures may also be expected when handling the articles, as they may not be fully cured.

Isocyanate Exposure Data

Nearly all polyurethanes are created via a reaction involving isocyanate compounds. Many isocyanates used in these processes are monomers with relatively high vapor pressures, such that they may be volatilized from the process or during transferring operations. There are several sources that discuss worker inhalation exposures and provide workplace air concentration data pertaining to the use of isocyanates in polyurethane foam production (e.g., NIOSH HHEs). The EPA 2004a reference also discusses available data obtained from other sources. Due to the hazard concern that exists for these compounds, much of the exposure data pertaining to foam production is focused on these isocyanate compounds.

Relevant PMN Case Information

ERG searched the PMN database in April 2004 to identify past submissions pertaining to new chemicals used in foam production. A summary of pertinent statistics is provided below:

- A total of 81 PMNs pertaining to foam production were submitted between 1992 and April 2004;
- 21 of the 81 cases were identified as being for polymer/pre-polymer chemicals;
- 23 of the 81 cases were identified as being for catalyst chemicals;
- 9 of the 81 cases were identified as being for flame retardant chemicals;
- 28 of the 81 cases were submitted for other additive chemicals (the functions of 9 of these other additives were not specified);
- 59 of the 81 cases pertain to polyurethane foams (11 of these indicated rigid foam application; 9 of these indicated flexible foam application);
- Other foam types identified were for isocyanate (4 cases), polyimide (6 cases), polyvinyl chloride (1 case), silicone foam (1 case), and other unspecified foams (10 cases);
- 16 of the 81 cases were identified as being applicable to rigid foam uses (11 of these are rigid polyurethane foams); and
- 10 of the 81 cases submitted were identified as being applicable to flexible foam uses (9 of these are flexible polyurethane foams).

Several cases were examined to determine the extent of submitter-supplied data that was provided for each:

- A total of 21 PMN submissions contained submitter-provided data on the use of the chemical in foam production;
- 18 of the 21 chemicals were used in a liquid/solution form;
- Nearly all of the 21 chemicals had a negligible vapor pressure at 25° C;

- 10 of the 21 submissions estimated total operating days to range from 100 to 350 days per year; and

- 11 of the 21 submissions estimated between 3 and 35 workers per site.

Readily Available Sources

ERG searched readily available sources for information on the foamed plastic manufacturing industry. Most of the information presented above was collected from EPA documents and the Internet. ERG did not perform a literature search for articles in journals related to the foamed plastics industry. Below is a list of these sources with a short description of the type of information presented in each source.

EPA Sources

EPA 1995 *Profile of the Rubber and Plastics Industry*, U.S. EPA Office of Compliance Sector Notebook, EPA 310-R-95-016, September 1995.
This sector notebook describes the plastic processing industry and includes information on industrial processes and chemical releases.

EPA 1996 *Manual: Best Management Practices for Pollution Prevention in the Slabstock and Molded Flexible Polyurethane Foam Industry*, U.S. EPA Office of Research and Development, EPA/625/R-96-005, September 1996.
This document describes the polyurethane foam industry structure and provides process descriptions and pollution prevention information.

EPA 1998a *Fact Sheet: Air Toxics Regulation for the Flexible Polyurethane Foam Industry*, U.S. EPA Office of Air Quality Planning and Standards, September 15, 1998.
This fact sheet summarizes final NESHAP (Subpart III) requirements, as well as the anticipated benefits as a result of the rule. This rule reduces the polyurethane foam production and rebonding industry emissions of HAPs (especially methylene chloride).

EPA 1998b *Preferred and Alternative Methods for Estimating Air Emissions from Plastic Products Manufacturing*, U.S. EPA, Emission Inventory Improvement Program, Volume II, Chapter 11, December 1998.
This document describes the plastics industry and describes methods for estimating releases of monomers, solvents, and other process materials from the plastics manufacturing industry (contains some information on foamed plastics and blowing agents).

EPA 2004a *Industry Profile for the Flexible Polyurethane Foam Industry* (draft), U.S. EPA Design for the Environment Program, prepared by ERG, Inc., February 16, 2004. This unpublished draft document describes the flexible polyurethane foam industry, relevant processes, releases and worker exposures; the document is focused on isocyanates used and released from these processes.

EPA 2004b Site visit summaries for two foam manufacturing sites, U.S. EPA Design for the Environment Program, prepared by ERG, Inc., February 2004. Internal project documentation. One site produces high quality flexible foam products; a molded foam process was observed. The other site produces low end flexible polyurethane foam for the automotive and furniture industries; a slabstock foam process was observed.

NIOSH Health Hazard Evaluations (HHE) Reports

The NIOSH HHE reports were searched. 15 reports related to foamed plastics were found (most pertained to isocyanate exposures).

Occupational Safety and Health Administration (OSHA)

OSHA permissible exposure limits for various chemicals used in foamed plastic production (e.g., isocyanates, methylene chloride) may be used to estimate worst case exposures.

Organisation for Economic Cooperation and Development (OECD)

OECD 2004 *Emission Scenario Document on Plastic Additives*, draft for declassification, Environment Directorate Organisation for Economic Co-Operation and Development, Series on Emission Scenario Documents No. 3, May 2004. This document describes the plastics industry in Europe (primarily in the UK). It includes information on the general structure of the industry, plastics processing and use descriptions, and emission rates for various components used in plastics (including foamed plastics).

Other Sources

API 2004 *MDI/Polymeric MDI Emissions Reporting Guidelines for the Polyurethane Industry*, Alliance for the Polyurethanes Industry, 2004. Document designed to assist polyurethane companies in completing TRI reporting requirements for isocyanates (specifically 4,4'-methylene diphenyl diisocyanate (MDI)).

Kirk-Othmer 1994	"Foamed Plastics", *Kirk-Othmer Encyclopedia of Chemical Technology* via online subscription, 1994. This encyclopedia article provides a description of the different types of foamed plastics and details on different plastic processing techniques.
Kirk-Othmer 1997a	"Styrene Plastics", *Kirk-Othmer Encyclopedia of Chemical Technology* via online subscription, 1997. This encyclopedia article provides a description of styrene plastics and processes by which polystyrenes are manufactured (including expanded polystyrenes for use in foamed plastics).
Kirk-Othmer 1997b	"Urethane Polymers", *Kirk-Othmer Encyclopedia of Chemical Technology* via online subscription, 1997. This encyclopedia article provides a description of polyurethanes and the relevant processes by which they are manufactured (including polyurethane foams).
Kirk-Othmer 2003	"Plastics Processing", *Kirk-Othmer Encyclopedia of Chemical Technology* via online subscription, 2003. This encyclopedia article provides a description of the different types of plastics and details on different plastic processing techniques (including those for polyurethane and polystyrene foams).
SRI	*Chemical Economics Handbook*, "Plastics" and "Plastics Additives". This source identifies the type of plastic additives groups, describes expected trends for the plastic manufacturing industry, and lists current economic data for the industry such as consumption rates. Note, this source contains proprietary information. Information provided from this reference is intended for internal EPA use only.
PFA 1994	"Efficient Solid Waste Management", *IN TOUCH Information on Flexible Polyurethane Foam*, Volume 4, No. 1, Polyurethane Foam Association, February 1994.
USCB 1997a	*Urethane and Other Foam Product (except polystyrene) Manufacturing*, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, EC97M-3261H, issued November 1999.
USCB 1997b	*Polystyrene Foam Product Manufacturing*, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, EC97M-3261G, issued November 1999.

USCB 2001a *Number of Firms, Number of Establishments, Employment and Annual Payroll by Employment Size of the Enterprise for the United States, All Industries 2001*, U.S. Census Bureau, 2001, http://www.census.gov/csd/susb/susb01.htm.

USCB 2001b *Statistics for Industry Groups and Industries: 2001*, U.S. Census Bureau, Annual Survey of Manufacturers, issued January 2003.

State Operating Permits for Foam Manufacturers. Some States post copies of the active operating permits for the various regulated facilities in their jurisdiction. These permits contain information regarding foaming unit operations, identification of permitted release points within the process, identification of the chemicals expected to be released, control technologies used, and the chemical concentration/amount limits for the facility. For example, Arkansas is one such state that allows the public to search for and view facility operating permits via:

http://www.adeq.state.ar.us/air/isteps/isteps.asp.

To view a permit for a polyurethane foam manufacturer:
http://www.adeq.state.ar.us/ftproot/Pub/WebDatabases/PermitsOnline/Air/1456-AR-3.pdf

Alliance for the Polyurethanes Industry (API), www.polyurethane.org
The API is a business unit of the APC, below.

American Plastics Council, www.americanplasticscouncil.org
American Plastics Council website contains useful information about plastic processing and industry statistics.

Polyurethane Foam Association (PFA), www.pfa.org

Plastic Facts, www.epa.gov/grtlakes/seahome/houswaste/src/plastic.htm
This website lists the major type of plastics and recycling information.

Plastics Resource, www.plasticsresource.com
This website provides information on plastics and the environment.

The Society of the Plastic Industry, www.plasticsindusrty.org
The SPI website contains useful information about the types of plastic resins, the processing methods, and economic trends. Detail reports are available for purchase.