



Flexible Polyurethane Foam Emission Reduction Technologies Cost Analysis

PRELIMINARY DRAFT

NESHA

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1.0 INTRODUCTION

1.1 PURPOSE OF DOCUMENT

This document describes the costs of hazardous air pollutant (HAP) emission reduction technologies for flexible polyurethane foam production facilities. The U.S. Environmental Protection Agency (EPA) reviewed information from the information collection request (ICR) responses that were received from flexible polyurethane foam producers, as well as the information contained in other pertinent project files, to identify potential HAP emission reduction and control technologies. The universe of all possible technologies was narrowed to include only technologies that are currently being used, or those under investigation that are generally considered to be promising. Information on cost and emission reduction potential, as well as process and operational information, was compiled for each technology. Information was collected from chemical manufacturers, product vendors, trade associations, foam producers, and other sources. The majority of the information was gathered by telephone communication.

Once the information was collected, it was analyzed and applied to "representative" facilities to evaluate the capital and operational costs, as well as the emission reduction and cost effectiveness, of each alternative. In several instances, the information provided was insufficient to permit an analysis of the total capital investment and total annual costs. Therefore, certain assumptions were necessary to allow the calculation of the representative facility costs. Where possible, assumptions were based on statements or partial information from industry and other contacts.

1.2 DOCUMENT CONTENTS

The comments of the vendors, manufacturers, and foam producers who had contributed to the original analysis were collected, and these have been incorporated into this document. Chapter 2 provides background on the industry. Chapter 3 describes the development of "representative" molded and

slabstock facilities, and the calculation of representative facility costs. Chapters 4 and 5 provide brief descriptions for each technology, along with costs for the representative facilities. Chapter 6 summarizes the analysis.

2.0 BACKGROUND

2.1 INDUSTRY DESCRIPTION

The term "polyurethane" is applied to a general class of polymers in which molecular chain segments are bound together with urethane linkages. Polyurethanes are used to produce an extremely wide range of products, including solid plastics, adhesives, coatings, rigid foams, and flexible foams. Flexible foams represent by far the largest application for polyurethanes, accounting for over half of the total U.S. production of polyurethanes.¹ Flexible polyurethane foam is used in furniture, bedding, automobile seats and cushions, packaging materials, and carpet underlay.² Another on-site operation at slabstock facilities is rebond. Rebond is a process that combines ground scrap foam and pieces and toluene diisocyanate (TDI) under steam and pressure to create a bonded material. This material is used to produce carpet underlay.

The flexible polyurethane foam industry can be divided into two major segments: slabstock foam production and molded foam production. Slabstock foam is produced in large "buns" that range in size from 300 cubic feet to over 5000 cubic feet. After they cure, the buns are cut, glued, or otherwise "fabricated" into the particular shapes and sizes for the desired end-use. Fabrication operations may be carried out by the slabstock plant itself, or by the foam purchaser. The largest uses of slabstock foams are in furniture, carpet underlay, and bedding.³

In molded foam production, the foam polymerization reaction is carried out in a mold in the shape of the desired product. This minimizes the need for fabricating the foam, although shaping and gluing operations may still be required. Molded foam is used primarily in the transportation market for car seats, cushions, and energy-absorbing panels; however, it is also used for novelty items, in office furniture, and in medical products.⁴

Total slabstock foam production in 1992 was approximately 550,000 tons. At the end of 1992, there were 25 companies

engaged in slabstock foam production, operating about 78 foam plants. Three large companies account for over half of the total U.S. production.

The production of molded foam is more difficult to quantify, because there are many small plants. The Society of the Plastics Industry, Inc. (SPI) reported production of molded foam at 215,000 tons in 1989. A recent survey of the foam industry by the EPA's Emission Standards Division (ESD) identified 49 plants producing molded foam. However, these plants accounted for only about half of the molded foam production reported by SPI in 1989. Estimates of the total number of plants producing molded foam range up to 200. Molded producers tend to be either quite large, or quite small. In the EPA/ESD survey, almost half of the 49 plants surveyed reported production rates less than 500 tons per year.

2.2 FOAM GRADES AND APPLICATIONS

Flexible polyurethane foam is produced in a wide range of grades which are usually identified by two parameters: density and firmness. Foam densities range from less than 1 pound per cubic foot to more than 3 pounds per cubic foot. Higher density foams are typically more durable than lower density foams, because they contain more mass of polymer per unit volume.⁵ However, the higher density foams require more raw materials, and hence have higher production costs.

The firmness of a foam determines its load bearing ability. This parameter is also related to the foam's softness. The most common measure of firmness is the "indentation force deflection" (IFD). This is the force required for a 50 square inch disk to cause a certain percentage of indentation in a foam block. Indentation force deflection is expressed in pounds (per square inch), and can range from 20 pounds to over 100 pounds.

Different grades of foam have different primary applications; however, there is no strict relationship between the grade and the application. For instance, the density of foam used for seat cushioning can range from 1 pound per cubic foot to 3 pounds per cubic foot, depending on quality and other

specifications.

In general, lower density and softer foams are used for seat backs and arm rests. Low density, stiff foams are well suited for packaging. Foams with moderate density and load bearing capacity are used for seat cushions and bedding. Higher density foams are generally used for carpet padding, and other heavy-duty applications.

2.3 CHEMISTRY OF POLYURETHANE FOAM PRODUCTION

Polyurethanes are made by reacting a polyol with a diisocyanate. For slabstock foam production, the polyol is typically a polyester or a polyether with two or more hydroxyl groups, and the diisocyanate is usually a mixture of 2,4- and 2,6- isomers of toluene diisocyanate (TDI), with the ratio being 80 percent 2,4- to 20 percent 2,6-. Molded foam producers frequently use methylene diphenyl diisocyanate (MDI) rather than TDI.

Polyurethane foams are made by adding water to the polyol and diisocyanate mixture. Once the ingredients are mixed, two main polymerization reactions occur. Isocyanate groups react with hydroxyl groups on the polyol to produce urethane linkages (hence the term polyurethane). The other main reaction is that of the isocyanate and water. The initial product of the reaction with water is a substituted carbamic acid, which breaks down into an amine and carbon dioxide (CO_2). The amine then reacts with another isocyanate to yield a substituted urea linkage. These reactions are illustrated in Figure 2-1.

Surfactants and catalysts are also added to the mixture. The surfactants aid in mixing incompatible components of the reaction mixture and also help control the size of the foam cells by stabilizing the forming gas bubbles. Catalysts balance the isocyanate/water and isocyanate/polyol reactions and assist in driving the polymerization reaction to completion.

The CO_2 formed in the initial reaction acts as the "blowing agent" and causes the bubbles to expand. The bubbles eventually come into close contact, forming a network of cells separated by thin membranes. At full foam rise, the cell membranes are

stretched to their limits and rupture, releasing the blowing agent and leaving open cells supported by polymer "struts."

The more water added and CO₂ formed, the more expanded the polymer network, and the lower the resultant density. However, the reaction of isocyanate with water is very exothermic. The addition of too much water can cause the foam to scorch or even auto-ignite.

The final polymer is composed of the urethane and urea linkages formed in the isocyanate/polyol and isocyanate/water reactions. The polyol-to-isocyanate urethane linkages provide strength, and the isocyanate-to-isocyanate urea linkages give the foam its firmness.

The amount of each ingredient used in a foam formulation varies, depending on the grade of foam desired. Foam formulations are generally denoted by the number of parts (by weight) of diisocyanate and water used, per 100 parts polyol.

2.4 BLOWING AGENTS

The gas which expands the polyurethane polymer to produce a foam is termed a "blowing agent." As noted in the previous section, one result of the isocyanate-water reaction is the

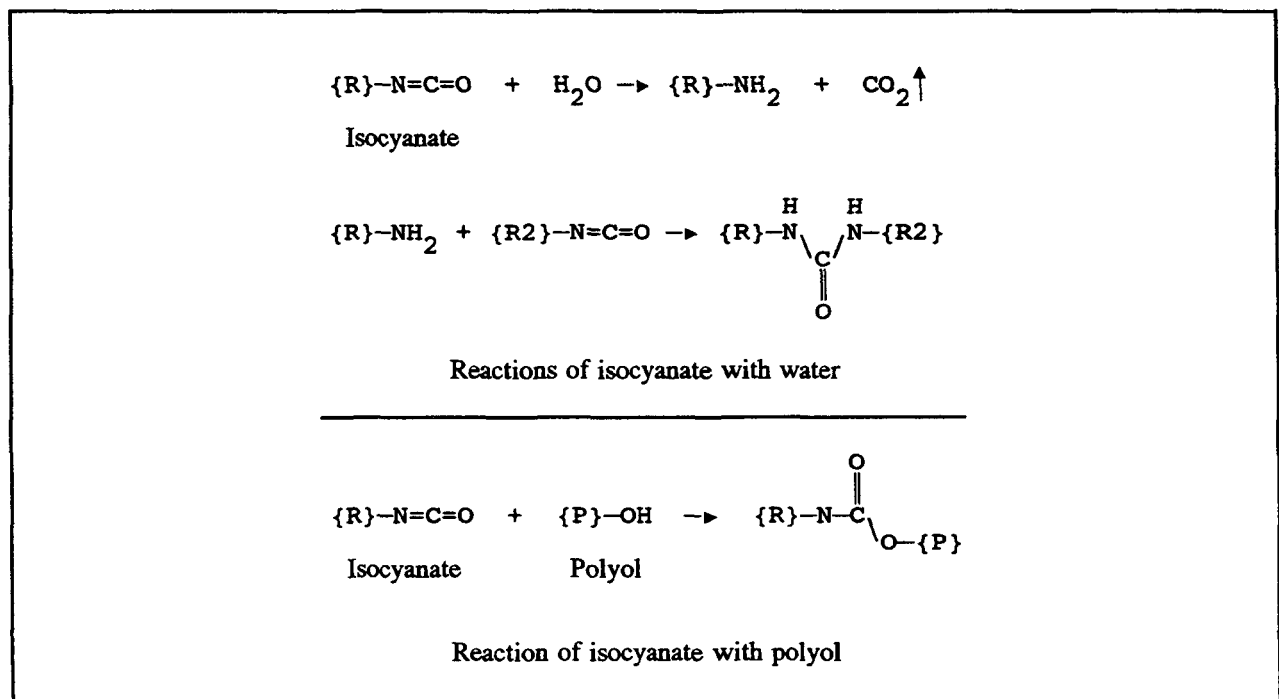


Figure 2-1. Polyurethane foam production reactions

liberation of CO₂ gas. The blowing action of this CO₂ is termed "water-blowing," because the CO₂ blowing agent is produced from the isocyanate-water reaction. Many grades of foam can be produced using only this CO₂ gas as a blowing agent.

Increasing the amount of water in a formulation generally produces a lower-density foam, because additional CO₂ blowing agent is produced. However, there is a practical limit to the amount of water that can be used. First, an increase in the water level results in an increase in the number of urea linkages in the final polymer. These linkages tend to make the polymer stiffer because they undergo hydrogen bonding. Second, the isocyanate-water reaction is extremely exothermic. An excessive level of water can cause high temperatures that can scorch the foam, or even cause the foam to ignite.

As a result, some grades of foam require the use of an auxiliary blowing agent (ABA). The ABA is mixed with the foam reactants as a liquid when the reactant mixture is first poured. As the exothermic polymerization reactions raise the temperature of the polymer mass, the ABA vaporizes, supplementing the blowing action of CO₂ from the water-isocyanate reaction. The vaporization of the ABA also serves to remove excess heat from the foam, reducing the potential for scorching or auto-ignition.

Auxiliary blowing agents are more widely used in the production of slabstock foams than in the production of molded foams. The amount of ABA required depends on the grade of foam being produced and the ABA used. Auxiliary blowing agents are most important for low density and soft foams. In these grades, water-blowing alone would cause problems with either overheating or with increased foam stiffness.

Previously, the principal ABA used was chlorofluorocarbon 11 (CFC-11). However, since this compound has been shown to deplete the earth's ozone layer, U.S. producers have almost completely phased out its use. Methylene chloride, a listed HAP, has replaced CFC-11 as the principal ABA. The consumption of methylene chloride for slabstock ABA applications in 1992 was approximately 14,500 tons. The second largest volume ABA in 1992

was 1,1,1-trichloroethane (TCA), at approximately 2,000 tons. Since the role of the ABA is simply to volatilize and expand the foam, it does not directly participate in the polyurethane reaction. Therefore, all of the ABA that is added eventually is emitted. Releases of HAP ABA's to the atmosphere are substantial (over 16,800 tons in 1992).

2.5 FOAM QUALITY MEASUREMENTS

In their evaluations of technologies to reduce or eliminate blowing agents, foam producers are sensitive to any potential degradation in foam quality. A number of physical properties are measured as indicators of foam quality. These include resilience, hysteresis, dynamic fatigue, air flow, tensile strength, elongation, and tear strength.

2.6 CURRENT ENVIRONMENTAL RELEASES

Emissions to the atmosphere constitute the major environmental release from flexible polyurethane foam manufacturing. The bulk of emissions from the industry result from the use of ABAs, mainly in the manufacture of slabstock foam. However, substantial emissions also result from the use of organic solvents in adhesives and equipment cleaning operations. Table 2-1 gives a summary of emissions from different operations in slabstock and molded foam production. The emissions reported for hazardous air pollutants in Table 2-1 are based on a recent survey of these emissions by the EPA's Emission Standards Division.^{6,7} Emissions of freons are based on sales figures and company reports to EPA's Toxics Release Inventory.⁸

There are no process wastewater discharges from this industry. The water used in the foam reaction is entirely consumed in that reaction. Water is used in some cases for non-contact cooling of foam reactants, but no discharges are reported from these systems.

Solid waste generated by foam production processes is minimized, because most scrap is used in rebond operations. Foam production lines occasionally produce bad batches, which are unsuitable even for rebonding. This material must be treated as a hazardous waste under the Resource Conservation and Recovery

TABLE 2-1. SUMMARY OF HAP EMISSIONS FROM FLEXIBLE POLYURETHANE FOAM PRODUCTION - 1992^a

Emission Source	Total emissions (tons/yr)	Primary chemicals
Slabstock foam		
Blowing agent	16,968	Methylene chloride, methyl chloroform
Fabrication	1,401	Methyl chloroform
Chemical storage and handling	49	Methylene chloride, TDI
Rebond operations	11	Methylene chloride, TDI
Slabstock foam total	18,429	
Molded foam		
Equipment flushing and cleaning	205	Methylene chloride
Mold release	8	Methylene chloride
Chemical storage and handling	12	MDI, TDI
In-mold coating	6	MEK, Toluene
Foam repair	27	Methyl chloroform
Other	10	MDI, methylene chloride
Molded foam total	268	
INDUSTRY TOTAL	18,697	

^a Data Source: *Non-Confidential Summary of Flexible Polyurethane Foam Information Collection Request (ICR) Data*, prepared by EC/R Inc. February 10, 1995.

Act (RCRA), because it may contain some unreacted isocyanate. In addition, some solvent waste subject to RCRA is produced from equipment cleaning operations. These wastes are generally shipped off-site for treatment or disposal.

2.7 REFERENCES

1. SPI. 1990 *End-Use Market Survey on the Polyurethane Industry in the U.S. and Canada*. The Society of the Plastics Industry - Polyurethane Division.
2. Reference 1.
3. Reference 1.
4. Reference 1.
5. Kreter, P.E. 1985. Polyurethane Foam Physical Properties as a Function of Foam Density. In: *Proceedings of the SPI - 32nd Annual Technical/Marketing Conference*. The Society of the Plastics Industry, Inc., Polyurethanes Div. pp. 129-133.
6. Norwood, L.P., et al (EC/R Inc.). *Summary of Flexible Polyurethane Foam Information Collection Requests (ICRs)*. Presented at a meeting of EPA and the Polyurethane Foam Association. February 2, 1994.
7. Williams, A. (EC/R Inc.) *Updated Estimates of HAP Emissions from Slabstock Foam Production*. Letter to Lou Peters, Polyurethane Foam Association. February 8, 1994.
8. *Toxics Release Inventory*. U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. 1992.

3.0 REPRESENTATIVE FACILITIES

3.1 DEVELOPMENT OF REPRESENTATIVE FACILITY PARAMETERS

One purpose of this analysis was to estimate the impacts of the targeted emission reduction technologies on any individual facility. In order to conduct this study, "representative" slabstock and molded facilities were developed. The representative facilities only include those parameters needed to estimate representative facility costs.

In general, the parameters for the representative facilities were based on information provided in response to the ICR.¹ Where possible, the parameters are averages of the ICR responses. In some instances, assumptions were made based on knowledge gained during plant visits. In other cases, parameters are based on detailed information from an individual facility. For the representative slabstock facility, Polyurethane Foam Association (PFA) members provided input that affected the representative facility foam formulations. Table 3-1 shows the representative slabstock facility, Table 3-2 shows formulation information for the representative slabstock facility, and the representative molded facility is described in Table 3-3.

3.2 DEVELOPMENT OF REPRESENTATIVE FACILITY COSTS

There were no specific precedents to follow in the development of representative facility costs for process modifications. The *OAQPS Control Cost Manual* provided general guidance on the estimation of total capital investment and annual costs.²

Total capital investment includes three basic elements: (1) purchased equipment costs, (2) direct installation costs, and (3) indirect installation costs. Total capital investment may also include costs for land, working capital, and off-site facilities. The total annual cost consists of three elements: (1) direct costs, (2) indirect costs, and (3) recovery credits.

In the OAQPS manual, most components of the total capital investment are based on the purchased equipment costs. While the cost factors in the manual were developed for specific types of

TABLE 3-1. REPRESENTATIVE SLABSTOCK FACILITY PARAMETERS

	Value	Basis
OPERATING PARAMETERS		
Foam produced	7,500 tons/yr	ICR average
Operating schedule	4 hrs/day actual pouring 225 days/yr	ICR averages, plant visits
Number of lines	1 (Maxfoam)	plant visits, ICR
Speed of line	15 feet/min	plant visits
Line electricity use	120 kw	provided by foamer
MeCl ₂ used as ABA	325 tons/yr	calculated using formulations in Table 3-2
MeCl ₂ used as cleaner	5 tons/yr	EPA assumption
Waste MeCl ₂ from cleaning	2 55-gal drums/yr	foamer estimate that 10 percent by volume of total MeCl ₂ used as cleaner is not recoverable
Amount of foam fabricated	3,520 tons/yr	based on a facility that provided detailed adhesive usage information
Amount of adhesive used for fabrication	10,679 gallons	based on a facility that provided detailed usage information
HAP content of adhesive	70%	based on a facility that provided detailed adhesive usage information
Number of spray booths	6	plant visits, ICR
Fabrication operating schedule	16 hours/day 225 days/yr	plant visits, ICR
COST PARAMETERS		
Total chemical cost	\$10.8 million/yr	calculated from information provided by PFA chemical alternative informational work group
ABA-blown chemical cost	\$9.78 million/yr	calculated from information provided by PFA chemical alternative informational work group
Operating costs	\$2.7 million/yr	calculated using the total chemical cost and the PFA assumption that 80 percent of total costs are chemical costs
Cost of MeCl ₂	\$0.25/lb	PFA chemical alternative suppliers informational work group
Disposal cost of waste MeCl ₂	\$800 per 55-gal drum	vendor estimate
Cost of HAP adhesive	\$8.5/gal	vendor quote
EMISSIONS		
MeCl ₂ from ABA	325 tons/yr	all used is emitted
MeCl ₂ emissions from cleaning	4.5 tons/yr	90 percent of used (remainder is waste)
HAP emissions from fabrication	43 tons	based on a facility that provided detailed adhesive usage information

TABLE 3-2. FORMULATION INFORMATION FOR THE
REPRESENTATIVE SLABSTOCK FACILITY^a

Grade	Density (pcf)	IFD (25%)	amount produced (tons/yr)	MeCl ₂ (pph polyol)	MeCl ₂ emitted (tons/yr)
0930	0.9	30	440	10	29.3
1010	1.0	10	220	22	32.3
1015	1.0	15	360	19	44.4
1020	1.0	20	230	14	21.5
1030	1.0	30	680	8	34.0
1120	1.1	20	370	14	33.3
1130	1.1	30	170	7	7.4
1230	1.2	30	610	5	20.3
1330	1.3	30	300	6	11.0
1340	1.3	40	110	2	1.5
1440	1.4	40	180	2	2.4
1520	1.5	20	170	13	14.2
1530	1.5	30	510	6	20.4
1540	1.5	40	390	2	5.2
1640	1.6	40	220	1	1.5
1740	1.7	40	170	1	1.1
1820	1.8	20	160	10	10.7
1830	1.8	30	510	6	18.7
1840	1.8	40	570	1	3.8
1930	1.9	30	240	7	11.2
1940	1.9	40	150	1	1.0
	2.0	>20	740	0	0.0
TOTALS			7,500		325

^a Assuming 67 percent of foam weight is polyol.

TABLE 3-3. REPRESENTATIVE MOLDED FACILITY PARAMETERS

	Value	Basis
OPERATING PARAMETERS		
Type of foam products	non-automotive specialty parts	ICR and plant visits indicate these types of facilities were larger emitters
Foam produced	800 tons/yr	based on detailed facility data
Number of lines (carrousel)	3: 1 does not use HAP-based mold release agents	based on detailed facility data
Operating schedule	2 lines - 8 hrs/day 1 line - 15 hrs/day 240 days/yr	based on detailed facility data
Type of mixheads	low-pressure	ICRs
Mixhead delivery	9 to 26 lbs/min	based on discussion with foamer regarding appropriate throughput
MeCl ₂ used as mixhead flush	135 55-gal drums/yr	ICR average
Waste MeCl ₂	13 55-gal drums/yr	foamer estimate that 10 percent by volume of total MeCl ₂ used as cleaner is not recoverable
Amount of mold release agent used	1,688 gal/yr	based on a facility that provided detailed mold release agent information
HAP content of mold release agent	75%	based on a facility that provided detailed mold release agent information
Number of repair stations	2	site visits, ICRs
Amount of adhesive used for foam repair	345 gal/yr	based on a facility that provided detailed adhesive usage information
HAP content of adhesive	70%	based on a facility that provided detailed adhesive usage information
COST PARAMETERS		
Cost of MeCl ₂	\$0.36/lb	Chemical marketing reporter
Disposal cost of waste MeCl ₂	\$800/55-gal drum	foamer estimate
Cost of HAP-based mold release agent	\$4.82/gallon	vendor quote
Cost of Adhesive	\$8.50 per gallon	vendor quote
EMISSIONS		
MeCl ₂ emissions from mixhead flush	37.1 tons/yr	90 percent of used (remainder is waste)
HAP emissions from mold release agents	4.6 tons/yr	calculated
HAP emissions from foam repair	1.34 tons/yr	calculated

add-on control, the factors for incinerators and carbon adsorbers were used to estimate the total capital investment of the control technologies in this evaluation, unless detailed information was provided.

It was assumed that several items (instrumentation, foundations and support, insulation for ductwork, painting, engineering, construction and field expenses, contractor fees, a performance test, and a model study) would not be included in the total capital investment, unless specific costs for these items were provided by the vendor. Therefore, the total capital investment was calculated as shown in Table 3-4. For each type of polyurethane foam emission reduction technology, the information provided by the vendor(s) was evaluated to determine which of the items shown in Table 3-4 were included in the information provided, and to determine which additional items needed to be estimated.

The calculation of the total annual costs was also based on the OAQPS manual. Table 3-5 shows the items considered in the calculation of total annual costs. As with the total capital investment, other contributions to the total annual costs were determined based on the information provided by vendors and foamers.

3.3 REFERENCES FOR CHAPTER 3.0

1. B. Jordan, EPA:ESD, to flexible polyurethane foam producers. July 30, 1993. Section 114 information collection requests (ICRs).
2. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *OAQPS Control Cost Manual*, Fourth Edition. EPA 450/3-90-006. January 1990.

TABLE 3-4. CONTRIBUTIONS TO TOTAL CAPITAL INVESTMENT

DESCRIPTION	Cost Factor
Purchased Equipment Costs (PEC)	
Equipment	A ^a
Sales Tax	0.03*A
Freight	0.05*A
Total PEC	B
Direct Installation Costs (DC)	
Handling and erection	0.14*B
Electrical	0.04*B
Piping	0.02*B
Total DC	0.20*B
Indirect Installation Costs (IDC)	
Start-up	0.02*B
Contingencies	0.03*B
Total IDC	0.05*B
Total Capital Investment = PEC + DC + IDC	

^a equipment costs provided by vendor and/or foamer

TABLE 3-5. CONTRIBUTIONS TO TOTAL ANNUAL COST

Description	Method for Calculation
Direct Costs (DC)	
Materials	provided ^a
Utilities	electric use provided electric cost = \$0.04/kw-h
Maintenance materials	provided
Replacement parts	provided
Operating labor	amount provided labor rate = \$20/hr
Supervisory labor	15 percent of oper. labor
Maintenance labor	amount provided labor rate = \$20/hr
Waste treatment	provided or calculated
Indirect Costs (IDC)	
Capital recovery	7 percent interest rate equipment life varied, but default was 10 years
Overhead	60 percent of all labor costs
Administrative charges	4 percent of total capital investment
Recovery Credits (RC)	provided or calculated
Total Annual Cost = DC + IDC - RC	

^aprovided means information provided by vendor and/or foamer

4.0 EMISSION REDUCTION TECHNOLOGIES AND COSTS: MOLDED FOAM

In this chapter, the results of information gathering efforts are presented for molded foam. This discussion is organized by emission source. A brief description of each emission source is provided, followed by discussions and representative facility costs for all emission reduction technologies applicable to that source.

Information was obtained for emission reduction technologies for three HAP emission sources at molded facilities. The sources are (1) mixhead flushing, (2) mold release agents, and (3) adhesives for foam repair. Each of these sources are discussed in the following sections. Since the same HAP-based adhesives are used in slabstock foam fabrication, there is a section that includes costs of alternative adhesives for both molded foam repair and slabstock foam fabrication.

4.1 ALTERNATIVES TO HAP MIXHEAD FLUSHES

Methylene chloride (MeCl_2) from flushing of low-pressure mixheads was the largest emission source for flexible molded foam manufacture. According to the emissions estimates presented in the ICR's, over 75 percent (203 tons/yr) of the HAP emissions from molded foam facilities were from this application.¹ With low-pressure mixheads, the chemical streams enter the mixing chamber at approximately 40 to 100 pounds per square inch (psi), and are blended by rotating mixer blades before being released or "shot" into the mold.² Residual materials can remain in the chamber, as well as on the blades. This material needs to be cleaned out, either after every shot, or after several, depending on the conditions. Flushing is necessary because the residual froth can harden and clog the mixhead. This residual froth is also a problem due to the precision required in the volume of the foam shot.

Several technologies were found to have the capability of reducing or eliminating this source of HAP emissions for the molded foam producer. These technologies are described in detail below and include non-HAP flushes, high-pressure mixheads, self-

cleaning mixheads, and solvent recovery units. To make the costs as conservative as possible, it was assumed that no effort is made to prevent the evaporation of the waste MeCl_2 flush at the representative facility. The portion that does not evaporate (see Table 3-1) must be disposed of as a hazardous waste.

4.1.1 Non-HAP Mixhead Flushes

Three non-HAP solvent-based flushes were identified and investigated. The solvents they contain are primarily cyclic amide, ethyl ester, glutarate ester, and other esters.^{3,4} One product's major component is D-limonene, with small amounts of terpene hydrocarbons.⁵ The important characteristics of alternative flushes are that they are quick-drying, quick cleaning, and non-reactive with the foam raw ingredients.

All three flushes identified are direct replacements for MeCl_2 , meaning that changing to these flushes typically requires no equipment or operational changes. This is an advantage in that no additional capital, utility, maintenance, or operational costs are required. However, the manufacturers discourage the use of seals and o-rings made of materials such as PVC, neoprene, and butyl rubber with these non-HAP mixhead flushes.^{6,7,8}

All three solvent-based flushes eliminate HAP emissions, but the solvents in them are still classified as VOC. However, all three products have significantly lower evaporation rates, with maximum vapor pressures of 2 mm mercury (Hg), as compared to MeCl_2 (355 mm Hg vapor pressure). Another major advantage is that all three products are reclaimable and reusable. According to the vendors, if the solvent is filtered for solids, the non-HAP flushes can be reused 2 to 5 times, or more. Methylene chloride can only be reused if it is distilled.^{9,10,11}

There are also savings in disposal costs of the waste material, as the spent flush from these products is not classified as a hazardous waste, unlike MeCl_2 . A foamer using one of these products estimated that the disposal costs were approximately \$60 for a 55-gallon drum versus \$600 for disposal of a 55-gallon drum of MeCl_2 .¹² A manufacturer of one of these

products stated that the disposal cost for a drum of MeCl_2 was \$800.¹³ To be conservative, the disposal costs used in the representative facility calculation were \$800/drum for MeCl_2 , and \$60/drum for non-HAP flushes.

The costs of applying this system to the representative molded plant are presented in Table 4-1. Approximately the same volume of non-HAP flushes are required as would be necessary with the use of MeCl_2 . These non-HAP products are more expensive than MeCl_2 on a volume basis. A 55-gallon drum of MeCl_2 costs approximately \$219, while costs of the non-HAP flushes range from \$382 to \$1,375 a drum.^{14,15,16} For representative facility costs, an average cost of \$838 per drum was used. In calculating the representative facility costs, to be conservative, it was assumed that the non-HAP products are reused 3 times, meaning only 45 drums are needed, as compared to 135 drums of MeCl_2 .

4.1.2 High-Pressure (HP) Mixheads

Low-pressure mixheads can be replaced with high pressure (HP) mixheads to eliminate HAP emissions. Three manufacturers of HP mixheads were contacted. HP mixheads dispense the foam at a higher pressure, typically 1500 to 3000 psi, as compared to typical low pressure systems at 40 to 100 psi.^{17,18} These mixheads have already replaced low-pressure mixheads in many larger molded foam facilities.

With HP mixheads, the raw materials are fed into the mixing chamber through two or more opposing nozzles. The nozzles are sized to produce a sharp pressure drop that causes the liquid streams to be accelerated so that when they impinge, the streams are thoroughly mixed. HP mixheads eliminate the need for MeCl_2 as a flushing agent, as there is no residual froth left in the mixhead. HP heads may not be appropriate for manufacturers of small parts, as the low throughput rate required for these parts may be too low for the HP system to achieve the necessary mixing.

When a low pressure mixhead is flushed with solvent, polyurethane in the mixhead is lost. One vendor estimated the cost of the lost polyurethane to the foam manufacturer to be

TABLE 4-1. REPRESENTATIVE FACILITY COSTS FOR
NON-HAP MIXHEAD FLUSHES

Capital Investment ^a	
Total Capital Investment	\$0
Annual Costs	
Direct Costs ^a	
Materials ^b	\$8,120
Waste treatment ^c	\$-7,700
Indirect Costs	\$0
Total Annual Cost	\$ 420
Emission Reduction ^d (tons/yr)	37.10
Cost Effectiveness (\$/ton)	\$11

^a As discussed above, since these products are direct replacements for MeCl₂, there were no additional capital costs (equipment or installation, nor any additional annual costs for labor or maintenance) identified.

^b Material costs were calculated as follows:

cost of MeCl₂: (135 drums @ \$219/drum) = \$29,590/yr

cost of alternative = (45 drums @ \$838/drum) = \$37,710/yr

\$37,710 - \$29,590 = \$8,120

^c Waste treatment costs were calculated as follows:

MeCl₂ treated: 13 drums @ \$800/drum = \$10,400/yr

altern. : 45 drums @ \$60 = \$2,700/yr

2,700 - 10,400 = -7,700

^d A small amount of VOC may be emitted due to the use of these alternatives.

\$1.00/lb.¹⁹ The use of HP mixheads eliminates this cost, resulting in a cost savings. It was not possible to calculate this cost on a facility-wide basis without further information.

Replacing low-pressure mixheads with HP heads requires replacing more than just the mixing heads. It usually requires new metering pumps and metering controls, to deliver the chemicals at the higher pressures. The connecting hoses may also need to be replaced if they are not suitable for handling the chemicals under the increased pressure.^{20,21,22}

The cost of HP replacement systems ranges from \$75,000 to \$200,000, depending on the size of the system, the required throughput, and the sophistication of the system.^{23,24,25,26}

Based on detailed information from two manufacturers, an average price of \$97,500 per system was used for the representative facility.^{27,28} The machines are typically delivered as complete units, ready for connection. The cost of the systems includes:

- metering pumps, and auxiliary equipment (e.g., pressure indicators, pressure relief valve)
- high pressure filter on diisocyanate feed line between the metering unit and mixhead
- HP mixhead
- hydraulic manifold
- day-tank assembly
- a stored program controlled system with a control desk

It is assumed that there are no changes in energy requirements, as the vendor stated that the new pumps required for the increased pressure would not cause a significant increase in the amount of energy used.²⁹ There are increased maintenance costs involved in using a HP mixhead versus a low pressure mixhead. Because of the very high pressures involved, there is considerable wear on the injection components. One foamer indicated that the increased maintenance cost is about \$10,000 per year for each mixhead, as compared to a low-pressure mixhead.³⁰ A small cost savings would be seen, as only a small

amount of polyurethane material is lost when using this type of mixhead versus a low pressure mixhead. However, this cost savings was not included for the representative facility. The costs of applying this system to the representative molded plant are presented in Table 4-2.

4.1.3 "Self-Cleaning" Mixhead

Another alternative to HAP mixhead flushing is a self-cleaning tapered-screw mixhead. The mixhead uses a tapered mixing screw in a tapered chamber. The screw rotates rapidly to provide thorough mixing of the raw materials. For cleaning, the screw moves forward again, at a faster rate, and removes the residue from the mixing chamber.³¹

This technology is only applicable for molded systems manufacturing small parts.³² The throughput for this mixhead ranges from 2 to 16 lb/min, which is in the lowest range for manufacturers of non-automotive seating foam parts. However, for most material systems, HP mixheads would normally be the preferred technology for throughputs above approximately 9 lb/min.³³ Consequently, the self cleaning mechanical mixhead is most applicable at the lower half of the throughput range.³⁴ The vendor did state that there is at least one flexible foam molder using this technology in New York; however, the EPA was unable to confirm this information.³⁵ The ICRs did not identify any flexible molded foam producer using or investigating the self-cleaning mixhead technology.

The cost of this equipment, new, is approximately \$100,000. The cost of a conversion kit, which only includes the new mixhead and the drive system, is approximately \$35,000. Modifications would need to be made to the existing metering and control systems.^{36,37}

The costs of applying this system to the representative molded plant are presented in Table 4-3. A small cost savings would be seen, as only a small amount of polyurethane material is lost when using this type of mixhead, as opposed to a low pressure mixhead. However, this cost was not included for the representative facility. No increases in operating costs were

TABLE 4-2. REPRESENTATIVE FACILITY COSTS FOR HIGH PRESSURE MIXHEADS

Capital Investment	
Purchased equipment costs ^a	\$315,900
Direct installation costs ^b	\$63,180
Indirect installation costs ^c	\$15,795
Total Capital Investment	\$394,875
Annual Costs	
Direct Costs ^d	\$0
Maintenance ^e	\$30,000
Materials ^f	\$-29,590
Waste treatment ^g	\$-10,400
Indirect Costs	
Capital Recovery ^h	\$56,230
Administrative Charges ⁱ	\$15,795
Total Annual Cost	\$62,035
Emission Reduction (tons/yr)	37.1
Cost Effectiveness (\$/ton)	\$1,672

^a $\$97,500 * 3 = \$292,500$

$292,500 * [292,500 * (0.03 \text{ tax} + 0.05 \text{ freight})] = \$315,900$

^b $\$315,900 * (0.14 \text{ hardware and erection} + 0.04 \text{ electrical} + 0.02 \text{ piping}) = \$63,180$

^c $\$315,900 * (0.02 \text{ start-up} + 0.03 \text{ contingency}) = \$15,795$

^d There were no additional annual costs for labor identified.

^e $\$10,000 * 3 = \$30,000$

^f This technology eliminates any need for MeCl_2 , so there is a material cost savings of \$29,590

^g This technology eliminates any need for MeCl_2 , so there is a waste treatment savings of \$10,400/yr

^h $\$394,875 * 0.1424 \text{ (7\% for 10 yrs)} = \$56,230$

ⁱ $\$394,875 * 0.04 = \$15,795$

TABLE 4-3. REPRESENTATIVE FACILITY COSTS FOR SELF-CLEANING MIXHEADS

Capital Investment	
Purchased equipment costs ^a	\$108,450
Direct installation costs ^b	\$21,690
indirect installation costs ^c	\$5,423
Total Capital Investment	\$135,563
Annual Costs	
Direct Costs ^d	
Materials ^e	\$-29,590
Waste treatment ^f	\$-10,400
Indirect Costs	
Capital Recovery ^g	\$19,304
Administrative charges ^h	\$5,423
Total Annual Cost	\$-15,263
Emission Reduction (tons/yr)	37.1
Cost Effectiveness (\$/ton)	\$-411

^a \$35,000 * 3 = \$105,000

105,000 + [105,000 * (0.03 tax)] + \$300 freight = \$108,450
(Freight cost taken from Klockner-Desman letter, January 5, 1995.

^b \$108,450 * (0.05 hardware and erection + 0.13 electrical + 0.02 piping) = \$21,690

^c \$108,450 * (0.02 start-up + 0.03 contingency) = \$5,423

^d There were no additional annual costs for labor or maintenance identified.

^e This technology eliminates any need for MeCl_2 , so there is a savings of \$29,590

^f This technology eliminates any need for MeCl_2 , so there is a waste treatment savings of \$10,400

^g \$135,563 * 0.1424 (7% for 10 yrs) = \$19,304

^h \$135,563 * 0.04 = \$5,423

identified. There were no significant operational, maintenance, or utility usage differences identified by the vendor.

4.1.4 Solvent Recovery Systems

Two facilities were contacted that had solvent recovery systems in place.^{38,39} In both systems, the HAP flush is captured in a 55-gallon drum at each line. The drums are then taken to a reclamation room, and the flush is pumped into a 2000 to 2500-pound tote. This tote is placed in a solvent reclamation unit, which is heated to between 210° and 240° Fahrenheit (F). The solvent vapors are flashed off and go to a condenser where they cool and are collected for re-use. The solids from the still, containing scrap foam and other contaminants, are collected for disposal.⁴⁰ Both systems had a recovery rate of about 70 to 80 percent. The cost of the still system ranges between \$20,000 and \$40,000.^{41,42}

One of the systems had an additional step to reduce emissions at the capture area.⁴³ The three molded lines that use solvent flush are equipped with a "closed-loop system" for capturing the MeCl₂ vapors from the area around the 55-gallon drum that is used to capture the flush. This system consists of a fan that draws the vapors generated in the flush area through a carbon filter, which captures the solvent vapors before the air is released to the atmosphere. The cost for this system is between \$500 and \$2000 per line. The carbon filter needs to be replaced approximately once a month at an estimated cost of \$100 to \$200.⁴⁴

Table 4-4 presents the estimated representative facility costs. The capital costs used were \$30,000 for the still system and \$1,000 per line for the recovery system. One foam manufacturer stated that it would take an additional 2 hours per day to load and unload the system.⁴⁵ A carbon disposal cost of \$150 per month was used.⁴⁶ While there would be increased utility and maintenance costs, sufficient information was not available to allow for a reasonable estimate of these costs. One foamer indicated that the cost of the disposable bags used to hold the solvent flush waste and to transport these bags to the

TABLE 4-4. REPRESENTATIVE FACILITY COSTS FOR SOLVENT RECOVERY SYSTEMS

Capital Investment	
Purchased equipment costs ^a	\$35,640
Direct installation costs ^b	\$7,128
indirect installation costs ^c	\$1,782
Total Capital Investment	\$44,550
Annual Costs	
Direct Costs	
Materials ^d	\$-22,193
Utilities ^e	
Maintenance materials ^e	
Replacement parts ^e	insufficient information to estimate
Maintenance labor ^e	
Operating labor ^f	\$9,600
Supervisory labor ^g	\$1,440
Waste treatment ^h	\$-6,000
Indirect Costs	
Capital Recovery ⁱ	\$6,344
Overhead ^j	6,624
Administrative charges ^k	\$1,782
Total Annual Cost	\$-2,403
Emission Reduction (tons/yr) ^l	27.8
Cost Effectiveness (\$/ton)	\$-86

^a $[\$30,000 + (\$1,000 * 3)] = 33,000$

$33,000 + [33,000 * (0.03 \text{ tax} + 0.05 \text{ freight})] = \$35,640$

^b $\$35,640 * (0.14 \text{ hardware and erection} + 0.04 \text{ electrical} + 0.02 \text{ piping}) = \$7,128$

^c $\$35,640 * (0.02 \text{ start-up} + 0.03 \text{ contingency}) = \$1,782$

^d Savings of 75 percent of MeCl_2 costs due to recovery: $\$29,590 * 0.75 = \$22,193$

^e It is assumed that there would be additional utility and maintenance costs, but sufficient information was not provided to allow an estimation of these costs.

^f $2 \text{ hours/day} * 240 \text{ days/yr} * \$20/\text{hr} = \$9,600$

^g $\$9,600 * 0.15 = \$1,440$

^h Savings of 75 percent of MeCl_2 disposal costs due to recovery: $\$10,400 * 0.75 = \$7,800$. Added cost of carbon disposal = $\$150/\text{month} * 12 \text{ months} = \$1,800$.

Total disposal costs = $\$1,800 - \$7,800 = \$-6,000$

ⁱ $\$44,550 * 0.1424 \text{ (7\% for 10 years)} = \$6,344$

^j $(\$9,600 + \$1,440) * 0.60 = \$6,624$

^k $\$44,550 * 0.04 = \$1,782$

^l $37.1 \text{ tons} * 0.75 = 27.8 \text{ tons/yr}$

dumpster was approximately \$30/dozen.⁴⁷ Because it was not possible to determine the consumption rate of these bags, this cost was not included in the representative facility calculations. An MeCl_2 recovery efficiency of 75 percent was used.

4.2 ALTERNATIVE MOLD RELEASE AGENTS

According to the emissions estimates presented in the ICRs, approximately 3 percent (7.9 tons) of the HAP emissions from molded foam facilities were due to the evaporation of the carrier solvent from mold release agents.⁴⁸ Mold release agents are sprayed on the mold surface(s) before the foam mixture is poured into the mold to prevent adhesion and create a smooth surface. Traditional mold release agents consist of a resin or wax in a solvent carrier. This solvent carrier is often composed of MeCl_2 or 1,1,1-trichloroethane (methyl chloroform). The carrier evaporates, leaving the resin, which prevents the foam from sticking to the mold. Alternatives being used or investigated by the industry include water-based agents, naphtha-based agents, and reduced-VOC solvent agents. The following sections discuss these three options.

4.2.1 Reduced-VOC Mold Release Agents

The reduced-VOC mold release agents are produced through high-solids, solvent-based formulations. The advantage of these agents over traditional HAP-based agents is a reduction in VOC emissions of up to 80 percent. The one vendor that was contacted stated that the reduced VOC carrier solvent used was a non-HAP; however, it was unclear if the solvents used in most reduced-VOC mold release agent formulations are HAP.⁴⁹ The vendor stated that most users have seen a reduction in mold release agent consumption of 20 to 50 percent after switching to the reduced-VOC release agents.⁵⁰ No equipment changes are necessary in switching to this type of release agent, and no significant operator training or mold temperature changes are necessary.

The representative facility costs are presented in Table 4-5. The price per gallon of this reduced-VOC agent is over twice

TABLE 4-5. REPRESENTATIVE FACILITY COSTS FOR REDUCED-VOC MOLD
RELEASE AGENTS

Capital Investment ^a	
Total Capital Investment	\$0
Annual Costs	
Direct Costs ^a	
Materials ^b	\$2,077
Indirect Costs	\$0
Total Annual Cost	\$2,077
Emission Reduction ^c (tons/yr)	4.6
Cost Effectiveness (\$/ton)	\$452

^a As discussed above, since these products are direct replacements for HAP-based release agents, there were no additional capital costs (equipment or installation) identified. No additional annual costs for labor or maintenance were identified.

^b Material costs were calculated as follows:

HAP-based: \$4.82/gal * 1688 gal = \$8,136

Reduced-VOC: \$9.31/gal * 1097 gal = \$10,213

\$10,213 - \$8,136 = \$2077/yr

^c HAP emissions will be replaced by VOC emissions, but at a rate of 40% of the HAP emissions (1.8 tons/yr VOC emissions)

as much as that for traditional solvent-based agents, at \$9.31 per gallon.^{51,52} However, much of this material cost is offset by the reduction in usage.⁵³ For the representative facility, an average usage reduction of 35 percent was assumed, and a HAP emission reduction of 100 percent was used.

4.2.2 Naphtha-based Release Agents

Naphtha-based release agents are composed of resins in a hydrocarbon naphtha carrier solvent. Naphtha typically comprises at least 90 percent of the mold release agent.⁵⁴ While naphtha is not a HAP, it is listed as a VOC.

The cost of naphtha-based release agents is approximately \$0.65 per pound, or \$4.16 per gallon.⁵⁵ Foam manufacturers have found that a smaller amount of mold release agent is needed when naphtha-based agents are substituted for HAP-based agents.⁵⁶ Because it was not possible to quantify this reduction, a conservative estimate of a 5 percent reduction in usage was chosen for the calculation of the representative facility costs shown in Table 4-6. There were no necessary process or equipment changes identified, nor any increase in maintenance or labor costs.

4.2.3 Water-based release agents

Using water-based mold release agents is a more complicated substitution than using naphtha or reduced-VOC solvent based agents.^{57,58} However, unlike the other two alternatives, water-based mold release agents totally eliminate organic emissions.

All water-based mold release agent manufacturers spoken to emphasized that selection of a water-based release agent is customer-specific, and that the correct selection can require time and several trials before the appropriate product is found.^{59,60} The developmental procedures can be costly in time, as well as in scrap foam, during the transitional period.⁶¹ However, the up-front developmental procedures may eventually result in additional benefits and cost reductions.

There are a few production changes that need to be made when converting from a solvent-based to a water-based agent. Water-based release agents are more application-sensitive than the

TABLE 4-6. REPRESENTATIVE FACILITY COSTS FOR NAPHTHA-BASED
MOLD RELEASE AGENTS

Capital Investment ^a		
	Total Capital Investment	\$0
Annual Costs		
	Direct Costs ^a	
	Materials ^b	\$-1,463
	Indirect Costs	\$0
	Total Annual Cost	\$-1,463
	Emission Reduction ^c (tons/yr)	4.6
	Cost Effectiveness (\$/ton)	\$-318

^a As discussed above, since these products are direct replacements for HAP-based release agents, there were no additional capital costs (equipment or installation) identified. No additional annual costs for labor or maintenance were identified.

^b Material costs were calculated as follows:

HAP-based: $\$4.82/\text{gal} \times 1688 \text{ gal} = \$8,136$

Naphtha-based: $\$4.16/\text{gal} \times 1604 \text{ gal} = \$6,673$

$\$6,673 - \$8,136 = \text{savings of } \$1,463/\text{yr}$

^c HAP emissions will be replaced by an approximately equal level of VOC emissions.

solvent-based agents, so some spray retraining may be necessary. However, the spray retraining can benefit the foam producer by giving the producer an opportunity to teach the production line operators to reduce use levels, resulting in further cost reductions.⁶² Mold temperature changes may also be necessary when switching to some water-based agents, due to the higher evaporation temperature of water. There are no equipment changes necessary, except that some manufacturers recommend High Volume Low Pressure (HVLP) sprayers for use with the water-based agents, due to the need for increased application sensitivity.^{63,64}

The major disadvantages of water-based agents are the increased drying time and a development period which may be extensive. Also, foams produced using water-based mold release agents have a less porous surface than those poured with conventional release agents, which can be a disadvantage when adhering fabrics to the foam.⁶⁵

The cost of the water-based agents is higher per gallon than HAP-based agents, at \$6.00 per gallon.⁶⁶ The usage of water-based release agents, as compared to HAP-based agents, seemed to vary from case to case, so it was assumed that the usage was equivalent for the representative facility costs shown in Table 4-7.

4.3 ALTERNATIVE ADHESIVES

HAP-based adhesives are used in both slabstock and molded foam facilities. In slabstock facilities, spray adhesives are used to glue fabric-to-foam, or foam-to-foam. In the slabstock industry, only about 40 percent of the fabrication is done "in-house," and not all fabrication involves gluing.⁶⁷ Fabrication covers the broad range of die cut parts, cut parts, as well as glued parts. Adhesives used for fabrication accounted for 1,382 tons, or 7.5 percent of the total HAP emissions from slabstock facilities. Normally, these adhesives are approximately 20 to 40 percent solids, while the remainder consists of a solvent carrier, such as methyl chloroform or MeCl_2 .

The main use of adhesives in molded foam facilities is for

TABLE 4-7. REPRESENTATIVE FACILITY COSTS FOR WATER-BASED MOLD
RELEASE AGENTS

Capital Investment ^a	
Total Capital Investment	\$0
Annual Costs	
Direct Costs ^a	
Materials ^b	\$1,992
Indirect Costs	\$0
Total Annual Cost	\$1,992
Emission Reduction (tons/yr)	4.6
Cost Effectiveness (\$/ton)	\$433

^a As discussed above, since these products are direct replacements for HAP-based release agents, there were no capital (equipment or installation) costs identified. There were no additional annual costs for labor or maintenance identified. No costs could be estimated for development and training, but there will be costs for these items.

^b Material costs were calculated as follows:

HAP-based: $\$4.82/\text{gal} * 1688 \text{ gal} = \$8,136$

Water-based: $\$6.0/\text{gal} * 1688 \text{ gal} = \$10,128$

$\$10,128 - \$8,136 = \text{cost } \$1,992/\text{yr}$

the repair of voids and tears in the molded pieces. There were 26 tons of HAP emissions (less than 10 percent) reported at molded facilities from this source in the ICR's.⁶⁸

Three alternatives were identified that eliminate HAP emissions from the use of adhesives. These are (1) hot-melt adhesives, (2) water-based adhesives, and (3) Hydrofuse. Each is discussed in the following sections.

4.3.1 Hot-Melt Adhesives

Hot-melt adhesives are sold as solids that are melted in a tank system before being used. They are then sprayed on like solvent-based adhesives. They have a quick drying, or "tack," time. This feature has both advantages and disadvantages. The main advantage is that the quick tack time allows for a faster production time than many other adhesives. The main disadvantage is that the adhesive may cease to be sticky before the assembly is complete. However, the tack time varies between manufacturers, and some manufacturers produce hot-melts with expanded tack times. Another problem is the possibility of operator injury, as the temperature of the adhesive is maintained above 200° F, which could cause burns.⁶⁹ An additional problem is that hot melt adhesives tend to produce hard seams, which are not acceptable in a soft, flexible foam product.

Hot-melt adhesives do not contain any HAP; however, very small amounts of low molecular weight hydrocarbons may be emitted at the application temperatures. There is also a decrease in the amount of adhesive needed for the same amount of foam.⁷⁰ Because it was not possible to quantify this reduction, a conservative estimate of 15 percent reduction was used, based on information received from vendors.

The costs for using hot-melt adhesives at both the slabstock and molded foam representative facilities are presented in Table 4-8. The tanks to melt the adhesives cost approximately \$3,000 per tank, and the hot-melt adhesive costs approximately \$20.30 per gallon.⁷¹ There is a small electricity cost for the glue tanks.⁷² There were no direct installation costs, as the equipment does not need any additional erection, wiring, or

TABLE 4-8. REPRESENTATIVE FACILITY COSTS FOR HOT-MELT ADHESIVES

Capital Investment	Slabstock	Molded
Purchased equipment costs ^a	\$19,440	\$6,480
Direct installation costs	0	0
indirect installation costs ^b	\$970	\$340
Total Capital Investment	\$20,410	\$6,820
Annual Costs		
Direct Costs ^c		
Materials ^d	\$93,491	\$3,015
Utilities ^e	\$149	\$50
Indirect Costs		
Capital Recovery ^f	\$2,906	\$971
Administrative charges ^g	\$816	\$273
Recovery Credits	\$0	\$0
Total Annual Cost	\$97,362	\$4,309
Emission Reduction ^h (tons/yr)	43	1.34
Cost Effectiveness (\$/ton)	\$2,264	\$3,216

^a \$3,000 * 6 = \$18,000

18,000 + [18,000 * (0.03 tax + 0.05 freight)] = \$19,400 (slabstock)

\$3,000 * 2 = \$6,000

6,000 + [6,000 * (0.03 tax + 0.05 freight)] = \$6,480 (molded)

^b \$19,400 * (0.02 start-up + 0.03 contingency) = \$970 (slabstock)

\$6,804 * (0.02 start-up + 0.03 contingency) = \$340 (molded)

^c There were no additional annual costs for labor or maintenance identified.

^d HAP-based: 10,679 gal @ \$8.50/g = \$90,772 (slabstock)

Hot-melt: 9,077 gal @ \$20.30/g = \$184,263 (slabstock)

HAP-based: 345 gal @ \$8.50/g = \$2,933 (molded)

Hot-melt: 293 gal @ \$20.30/g = \$5,948 (molded)

^e 1725 watts/1000 = 0.1725 kw * 16 hr = 2.76 kw-h/d

2.76 kw-h/d * 225 d/yr = 621 kw-h/yr * \$0.04/kw-h =

\$24.84/yr/spray station

^f \$20,410 * 0.1424 (7% for 10 yrs) = \$2,906 (slabstock)

\$6,820 * 0.1424 (7% for 10 yrs) = \$971 (molded)

^g \$20,410 * 0.04 = \$816 (slabstock)

\$6,820 * 0.04 = \$273 (molded)

^h A small amount of VOC may be emitted due to the use of this alternative

pipng. There were no additional maintenance or labor costs identified.

4.3.2 Water-Based Adhesives

The largest advantage of water-based adhesives is that all HAP have been replaced by water, and there is a complete elimination of organic emissions. A major drawback is the slower drying times of these adhesives, which may create a need for larger drying areas. To solve this problem, some fabrication operations use an additional heat source to speed up the evaporation of the water, which would increase the utility costs, due to operation of the heat lamps. However, there are no other equipment or operational changes necessary to replace HAP-based adhesives with water-based. Only one vendor provided a cost per gallon for water-based adhesives. He stated that the average cost is approximately \$7.00 per gallon.⁷³

The costs of this alternative for the representative slabstock and molded facilities are presented in Table 4-9. The increased utilities cost was not determined, but it is expected to be minimal. The usage was found to be the same for water-based adhesives as for HAP-based. It was assumed that no additional heat source was used at the representative facility, due to the unavailability of information on the use of heat sources for this application.

4.3.3 Hydrofuse

Another water-based alternative to spray-applied solvent-based adhesives is a product called Hydrofuse. Hydrofuse is a two component, water-based adhesive that allows immediate contact bonding without the need for drying. The two-components, a water-based latex adhesive, and a mild citric acid solution, are externally co-sprayed causing the adhesive to immediately coagulate.⁷⁴

This process does require process and equipment changes. Equipment alterations will include changing to new spray guns, and assuring that all equipment parts that come in contact with the adhesive are stainless steel or plastic. Process considerations include operator training in the use of a two-

TABLE 4-9. REPRESENTATIVE FACILITY COSTS FOR WATER-BASED ADHESIVES

Capital Investment	Slabstock	Molded
Total Capital Investment ^a	\$0	\$0
Annual Costs ^a		
Direct Costs		
Materials ^b	\$-15,699	\$-508
Utilities ^c		
Indirect Costs ^d		
Total Annual Cost	\$-15,699	\$-508
Emission Reduction (tons/yr)	43	1.34
Cost Effectiveness (\$/ton)	\$-365	\$-379

^a As discussed above, since these products are direct replacements for HAP-based adhesives, there were no capital costs (equipment or installation), identified. There were no additional annual costs for labor, maintenance, or waste treatment identified.

^b HAP-based: $\$8.50/\text{g} * 10,679\text{g} = \$90,772$ (slabstock)
Water-based: $\$7.03/\text{g} * 10,679\text{g} = \$75,073$ (slabstock)
 $75,073 - 90,772 = -15,699$ (slabstock)
HAP-based: $\$8.50/\text{g} * 345\text{g} = \$2,933$ (molded)
Water-based: $\$7.03/\text{g} * 345\text{g} = \$2,425$ (molded)
 $2,425 - 2,933 = -508$ (molded)

^c Unable to quantify

^d No indirect costs identified

component adhesive, and in application rates. Another special requirement for this adhesive is that one of the two surfaces to be adhered must be porous. A significant advantage of this product is that there is little or no penetration of the surface to which it is applied, and it dries almost instantly.⁷⁵

The costs for using Hydrofuse at both the slabstock and molded foam representative facilities are presented in Table 4-10. There were no direct installation costs, as the equipment does not need any additional erection, wiring, or piping. There were no additional maintenance or labor costs identified. The cost of the spray equipment ranges for \$2,000 to \$3,000 (\$2,500 used for analysis) and the adhesive's material cost is approximately 6 percent less than HAP-based adhesives.⁷⁶ The usage for hydrofuse is less than for HAP-based adhesives, but the percentage difference was not quantified.

TABLE 4-10. REPRESENTATIVE FACILITY COSTS FOR HYDROFUSE ADHESIVE

Capital Investment	Slabstock	Molded
Purchased equipment costs ^a	\$16,200	\$5,400
Direct installation costs	\$0	\$0
indirect installation costs ^b	\$810	\$270
Total Capital Investment	\$17,010	\$5,670
Annual Costs		
Direct Costs ^c		
Materials ^d	\$5,446	\$176
Utilities ^e		
Indirect Costs		
Capital Recovery ^f	\$2,422	\$807
Administrative charges ^g	\$680	\$227
Total Annual Cost	\$8,548	\$1,210
Emission Reduction (tons/yr)	43	1.34
Cost Effectiveness (\$/ton)	\$199	\$903

^a \$2,500 * 6 = \$15,000

15,000 * [15,000 * (0.03 tax + 0.05 freight)] = \$16,200 (slabstock)

\$2,500 * 2 = \$5,000

5,000 * [5,000 * (0.03 tax + 0.05 freight)] = \$ 5,400 (molded)

^b \$16,200 * (0.02 start-up + 0.03 contingency) = \$810 (slabstock)
\$5,400 * (0.02 start-up + 0.03 contingency) = \$270 (molded)

^c There were no additional annual costs for labor or maintenance identified.

^d HAP-based: 10,679 gal @ \$8.50/g = \$90,772 (slabstock)

Hydrofuse: \$90,772 * 0.94 = \$85,326 (slabstock)

90,772 - 85,326 = 5,446

HAP-based: 345 gal @ \$8.50/g = \$2,933 (molded)

Hydrofuse: \$2,933 * 0.94 = \$2,757

2,933 - 2,757 = 176

^e Unable to determine

^f \$17,010 * 0.1424 (7% for 10 yrs) = \$2,422 (slabstock)

\$5,670 * 0.1424 (7% for 10 yrs) = \$807 (molded)

^g \$17,010 * 0.04 = \$680 (slabstock)

\$5,670 * 0.04 = \$227 (molded)

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5.0 EMISSION REDUCTION TECHNOLOGIES AND COSTS: SLABSTOCK FOAM

Information was obtained for emission reduction technologies for three HAP emission sources at slabstock facilities. These are (1) auxiliary blowing agent (ABA) usage, (2) equipment cleaning, and (3) adhesives for fabrication. Emission reduction technologies for ABA reduction/replacement and equipment cleaning are discussed in the following sections. Alternative adhesives for slabstock foam fabrication were discussed in the molded foam section.

5.1 ALTERNATIVES TO METHYLENE CHLORIDE AS AN ABA

Methylene chloride is the principal ABA used in the production of slabstock flexible polyurethane foam. The role of the MeCl_2 is simply to volatilize and expand the foam, it does not directly participate in the polyurethane reaction. Therefore, all of the MeCl_2 that is added eventually is emitted. The use of MeCl_2 as an ABA was the largest emission source of HAP reported in the ICR's, at over 14,600 tons, accounting for over 79 percent of the total HAP emissions from slabstock facilities.¹

Several alternatives were identified that either reduce or eliminate the use of MeCl_2 as an ABA in the manufacture of slabstock foam. The technologies identified were the use of acetone or liquid CO_2 as an ABA, foaming in a controlled environment, forced cooling, and chemical modifications. These alternatives are discussed in the following sections.

It should be pointed out that slabstock foam grades of identical density and firmness made by different chemical or mechanical techniques do not necessarily have the same strength, durability, or other quality properties. However, the best way to determine comparability of foam quality properties is through in-use testing. The EPA's analysis assumes that foam properties are comparable, unless detailed information was provided that stated otherwise.

5.1.1 Acetone as an ABA

In response to environmental concerns over the use of MeCl_2 ,

Hickory Springs developed and patented a technology in 1992 to allow the use of acetone as an ABA. One of acetone's biggest advantages is that it only requires 55 percent (by weight) as much acetone as MeCl_2 to blow the same amount of foam.² Another advantage is that acetone typically costs less per pound than MeCl_2 . Current estimates of chemical costs for slabstock manufacturers are \$0.20/lb for acetone versus \$0.25/lb for MeCl_2 .³ This factor, combined with the reduced usage, can result in large chemical cost savings. The chemical cost savings is somewhat counteracted by the licensing fee. This licensing fee operates on a graded scale depending on the amount of acetone used by the facility. For the first 50,000 pounds of acetone used, the fee is \$0.16 per pound, \$0.14/lb for the next 75,000 pounds, and \$0.12/lb for any additional acetone. This fee is subject to change with trends in acetone and MeCl_2 costs.⁴

Because of the high flammability of acetone, it is necessary to make certain equipment modifications in order to use acetone as an ABA. The largest costs of switching to acetone from MeCl_2 are due to this increased flammability. These modifications include:

- The foam tunnel needs to be completely enclosed.
- The lighting needs to be explosion-proof.
- The motors that run the conveyor need to be moved outside the foam tunnel (the cost is in moving the motors and putting on longer shafts).
- Electric bun saws need to be replaced by explosion-proof saws.
- There must be an auxiliary power generator for the ventilation fans.
- Air flow in the tunnel area must be increased, due to an insurance requirement.
- Storage tanks for acetone must be fire-rated, completely diked, and placed away from the other buildings. This modification is a large part of the conversion cost.
- A low-level metering system may be necessary as

some foam formulations only require 1-3 parts per hundred of acetone, and traditional metering systems do not go that low.

Hickory Springs estimated the cost of the equipment plus installation of the above items to be \$194,000.⁵

Acetone is not a HAP, but it is still listed as a VOC. The EPA has proposed to remove it from the VOC list (59 FR 49877). The costs of applying this system to the representative slabstock plant are presented in Table 5-1. All capital, labor, and licensing costs were provided by Hickory Springs.⁶

5.1.2 Liquid CO₂ as an ABA

A procedure for using liquid CO₂ as the ABA in slabstock foam manufacture called CarDio™ has been developed by Cannon USA. There is a full scale unit in operation in Italy, but there are no plants in the United States using this technology. However, in four to six months a few facilities are expected to have CarDio™ installed. The largest benefit of CarDio™ is that it completely eliminates HAP emissions.⁷ Another benefit is the chemical cost savings, as CO₂ is less expensive than MeCl₂, and it only requires 33 percent as much CO₂ as MeCl₂ to produce the same amount of ABA-blown foam.⁸

The CarDio™ system operates by adding liquid CO₂ to the polyol stream before the polyol stream is injected into the mixing head. This generates a rapidly expanding froth immediately after the pouring nozzle. Cannon developed a special laydown device to counteract this rapid expansion. This device controls the expansion phase immediately after the mixing head, and allows for the depositing of a homogenous pre-expanding and reacting mixture over the entire section of the fall-plate. The laydown device's special design allows for a progressive release of blowing agent in the reacting mass, avoiding local concentrations of free gas that can cause pinholes or "chimneys" in the foam.⁹

The retrofit kit consists of:¹⁰

- CO₂ metering pump assembly with mass flowmeter
- Polyol/activator booster pump assembly

TABLE 5-1. REPRESENTATIVE FACILITY COSTS FOR ACETONE AS AN ABA

Capital Investment	
Purchased equipment costs ^a	\$161,700
Direct installation costs ^a	\$32,300
indirect installation costs ^a	
Total Capital Investment	\$194,000
Annual Costs	
Direct Costs	
Materials ^b	\$-90,500
Utilities ^c	\$5,881
Maintenance materials ^d	\$2,500
Licensing ^e	\$46,700
Maintenance labor ^f	\$2,500
Waste treatment	\$0
Indirect Costs	
Capital Recovery ^g	\$27,626
Overhead ^h	\$1,500
Administrative charges ⁱ	\$7,760
Total Annual Cost	\$3,967
Emission Reduction (tons/yr) ^j	325
Cost Effectiveness (\$/ton)	\$12

^a Hickory Springs estimated a total capital investment of \$194,000. The EPA estimated the cost of purchased equipment at \$161,700, and total installation at \$32,300.

^b 325 tons MeCl_2 * 0.55 = 179 tons/yr acetone (360,000 lbs).
 360,000 lbs * \$0.2/lb = \$72,000 for acetone/yr
 325 tons/yr MeCl_2 = 650,000 lbs
 650,000 lbs * \$0.25/lb = \$162,500 for MeCl_2 /yr.
 \$72,000 - \$162,500 = \$-90,500 (savings)

^c 3 fans * 7.5 hp/fan * 8760 hr/yr = 197,100 hp-h/yr
 197,100 hp-h/yr * 0.746 kw-hr/hp-h = 147,037 kw-hr/yr
 1992 electricity cost/hr = \$0.040/kw-h
 147,037 kw-h/yr * \$.04/kw-h = \$5,881/year electricity cost

^d quoted by Doug Sullivan, Hickory Springs Manufacturing Co.

^e Licensing fee for 360,000 lb/yr:
 50,000 lb * \$0.16 = \$8,000
 75,000 lb * \$0.14 = \$10,500
 235,000 lb * \$0.12 = \$28,200
 total licensing fee = \$46,700

^f quoted by Doug Sullivan

^g \$194,000 * 0.1424 (7% for 10 yrs) = \$27,626

^h \$2,500 * 0.6 = \$1,500

ⁱ \$194,000 * 0.04 = \$7,760

^j HAP emissions replaced by approximately 180 tons of VOC emissions.

- CO₂/polyol premixing unit
- CarDio™ mixing head
- Necessary pipework and valves
- Flushing system
- Laydown device
- Controls

The costs of applying this system to the representative slabstock plant are presented in Table 5-2 below. The cost of the retrofit kit for the representative facility is approximately \$350,000, excluding installation.¹¹ The liquid CO₂ costs approximately \$0.05 per pound, and the necessary tank can be rented for \$500 per month. It was assumed that all the foam formulations requiring ABA would be made using this system. The pouring time was assumed to be the same for CarDio™ as for Maxfoam™. The increased energy costs, estimated at 100 to 120 KW, are for the electricity to run the booster pump assembly, and to keep the CO₂ cool. There were no increased labor or maintenance costs identified.¹²

5.1.3 Foaming in a Controlled Environment

The idea that foam expands more under conditions of decreased atmospheric pressure is not new. Many types of foam can be manufactured at higher altitudes with little or no ABA. In other words, when a given foam formulation is processed at less than atmospheric pressure (i.e., under vacuum), a lower density and a softer foam will result when compared to the same foam formulation being processed at atmospheric pressure. This principle can be applied under standard atmospheric conditions through enclosure of the foam line, and subsequent reduction of pressure during foam production. Two systems that control the atmospheric conditions during foam production were identified: variable pressure foaming and controlled environment foaming. Descriptions of these systems follow.

5.1.3.1 Variable Pressure Foaming (VPF)

The VPF system is patented worldwide by Foamex, L.P. The system involves processing foam in an enclosed chamber under a controlled pressure. The pressure in the chamber is fixed before

TABLE 5-2. REPRESENTATIVE FACILITY COSTS FOR CARDIO™

Capital Investment	
Purchased equipment costs ^a	\$378,000
Direct installation costs ^b	\$75,600
indirect installation costs ^c	\$18,900
Total Capital Investment	\$472,500
Annual Costs	
Direct Costs	
Materials ^d	\$-151,532
Utilities ^e	\$35,040
Carbon dioxide tank rental ^f	\$6,000
Indirect Costs	
Capital Recovery ^g	\$67,284
Administrative charges ^h	\$18,900
Total Annual Cost	\$-24,308
Emission Reduction (tons/yr) ⁱ	325
Cost Effectiveness (\$/ton)	\$-75

^a $\$350,000 + [350,000 * (0.03 \text{ tax} + 0.05 \text{ freight})] = \$378,000$

^b $\$378,000 * (0.14 \text{ hardware and erection} + 0.04 \text{ electrical} + 0.02 \text{ piping}) = \$75,600$

^c $\$378,000 * (0.02 \text{ start-up} + 0.03 \text{ contingencies}) = \$18,900$

^d $325 \text{ tons MeCl}_2 * .33 = 107 \text{ tons CO}_2$
 $107 \text{ tons MeCl}_2 * \$102.5/\text{ton} = \$10,968$
 $325 \text{ tons MeCl}_2/\text{yr} = 650,000 \text{ lbs}$
 $650,000 \text{ lbs} * \$0.25/\text{lb} = \$162,500 \text{ for MeCl}_2/\text{yr}$
 $\$10,968 - \$162,500 = -\$151,532$

^e Additional electricity costs: $100 \text{ kw} * 8760 \text{ hr} = 876,000 \text{ kw-h}$
 $876,000 \text{ kw-h} * \$0.04/\text{kw-h} = \$35,040/\text{yr}$

^f tank rental \$500/month

^g $\$472,500 * 0.1424 \text{ (7\% for 10 yrs)} = \$67,284$

^h $\$472,500 * 0.04 = \$18,900$

ⁱ HAP emission reduction replaced by around 108 tons/yr of CO₂

foaming and remains constant during the foaming operation. The mixhead is outside the chamber, and the chemicals are pumped into the chamber, into a trough, and onto the foam machine fall-plates. The enclosed chamber is fitted with a fan which evacuates the vapors generated during the reaction and pumps them through carbon bed absorbers. When the desired length of foam is produced, an automatic cut-off saw cuts the bun. This bun is then passed into a second airlock chamber, which is at the same pressure as the foaming chamber. This airlock chamber is fitted with a second fan and carbon bed absorber. Once the cut bun has completely entered the airlock system, the airlock is closed from the foaming chamber. This chamber is then opened to the atmosphere, and the bun is removed and transported to a storage rack. During this time, foam production is continuing in the first chamber. In the United States, Foamex has one VPF facility in full-scale operation, and a few others are being installed.

The main procedural advantages over a conventional Maxfoam line are that the system is fully automated, and the pressure can be adjusted and kept consistent from run to run. This automation results in products with density and hardness properties that are easily reproducible. Variable pressure foaming allows for the total elimination of ABAs, with no reduction in quality reported. In addition, the carbon absorbers in the foaming and airlock chambers can be expected to practically eliminate the toluene diisocyanate (TDI) emissions (5 tons/yr reported by industry in ICRs) from the foaming process.¹³

The conversion of an existing facility to VPF will involve the installation of a new foaming chamber, revisions to the existing line, and an extended shutdown period. Cost information for VPF was obtained directly from Foamex.¹⁴ The total capital investment for conversion of a Maxfoam line to VPF was estimated at between \$4.0 and \$5.0 million dollars (\$4.5 million was used for the representative facility). This estimate included installation and start-up costs. Foamex indicated that the annual operating costs are estimated to be 35 percent higher than a conventional Maxfoam line. However, this is offset somewhat by

a savings in chemical costs due to the elimination of the need for MeCl_2 . For the representative facility cost calculations, the annual operating costs of the facility (\$2,700,000) were increased by 35 percent for an incremental increase of \$945,000.¹⁵ This was assumed to include all direct and indirect annual costs except capital recovery (minus the savings from MeCl_2).

The costs of applying this system to the representative slabstock plant are presented in Table 5-3.

5.1.3.2 Controlled Environment Foaming (CEF)

FOAM ONE company has developed and patented a polyurethane foam manufacturing process, which is called Controlled Environment Foaming (CEF). The CEF process is a discrete block production method which uses a containment vessel to control the pressure and temperature during foaming.

The system consists of two molds (as large as 10 feet long by 9 feet wide by around 4 feet tall). One mold is inside a pressure-controlled containment vessel, and the other is outside this vessel. During production, foam is poured into the mold inside the containment vessel, which is lined with a flexible polyethylene film liner. The foam reaction is allowed to take place under the controlled conditions of the containment vessel. While the foaming is occurring in the mold in the containment vessel, the finished block in the other mold is removed, and the mold is prepared for production of the next block. This operation allows the production of up to 10 blocks per hour, which is equivalent to around 2 linear feet per minute.¹⁶

In addition to the complete elimination of ABA, there are other advantages to the CEF system. Since the blocks are prepared in heated molds, the finished block has a perfectly flat top and a very thin skin, thus maximizing foam yield. The process is under complete computer control, ensuring exact duplication of products. In addition, TDI emissions from the foaming reaction are vented through a carbon bed, thus practically eliminating TDI emissions.¹⁷

While there are low energy requirements and low maintenance

TABLE 5-3. REPRESENTATIVE FACILITY COSTS FOR VARIABLE PRESSURE FOAMING

Total Capital Investment ^a	\$4,500,000
Annual Costs	
Increase in annual operating costs ^b	\$945,000
Materials ^c	\$-162,500
Capital Recovery ^d	\$640,800
Total Annual Cost	\$1,423,300
Emission Reduction (tons/yr)	325
Cost Effectiveness (\$/ton)	\$4,379

^a Provided by Foamex. Assumed to include all direct and indirect installation costs.

^b \$2,700,000 (operating costs for representative facility) * 0.35 = \$945,000. This 35 percent factor is assumed to include utilities, maintenance items, labor, operating labor, overhead, and administrative charges.

^c 325 tons MeCl₂ * 2000 lbs/ton * \$0.25/lb = \$162,500

^d \$4,500,000 * 0.1424 (7% for 10 yrs) = \$640,800

expenses, the production rate is considerably slower than a traditional Maxfoam line.¹⁸ Therefore, it would take longer to make the same amount of foam on a CEF machine. A possible approach is to produce only the foams requiring ABA on a CEF machine, while continuing to produce other foams on a Maxfoam machine. For the representative facility cost calculations, it was assumed that the 6,760 tons of foam produced with an ABA would be produced on the CEF machine, and that the 740 tons that did not require ABA would continue to be produced on a Maxfoam machine. It was calculated that the representative slabstock plant would need to operate 16 hours/day using the CEF system to produce the same amount of formerly ABA-blown foam.

The costs of applying this system to the representative slabstock facility are presented in Table 5-4. The estimated cost of the CEF equipment provided by the vendor was \$250,000. In the annual cost calculations, it was assumed that 2 additional operators were needed, and that the energy requirements were approximately equal to a Maxfoam line.¹⁹ It is assumed that any additional maintenance costs for the CEF system would be offset by the reduced maintenance on the Maxfoam line due to the reduction in its use.

5.1.4 Forced-Cooling

The two primary functions of an ABA are to reduce the density of the foam and to provide cooling effects. Increasing the amount of water in the formulation will reduce the foam density, but increases the exothermicity of the reaction, which can lead to bun scorching or even auto-ignition (even well after the bun exits the foam tunnel.) The cooling of the bun by mechanical means can eliminate this potentially dangerous situation, while allowing the production of low density foams.

Information was obtained and reviewed on two different patented types of forced-cooling techniques that are in full-scale operation: Enviro-Cure® by Crain Industries and Rapid-Cure® by General Foam. The EPA is also aware of other companies experimenting with similar forced cooling processes. Since the Enviro-Cure® technology is fully operational at several

TABLE 5-4. REPRESENTATIVE FACILITY COSTS FOR CONTROLLED ENVIRONMENT FOAMING

Capital Investment	
Purchased equipment costs ^a	\$270,000
Direct installation costs ^b	\$54,000
indirect installation costs ^c	\$13,500
Total Capital Investment	\$337,500
Annual Costs	
Direct Costs ^d	
Materials ^e	\$-162,500
Operating labor ^f	\$144,000
Supervisory labor ^g	\$21,600
Utilities ^h	\$12,960
Indirect Costs	
Capital Recovery ⁱ	\$48,060
Administrative charges ^j	\$13,500
Total Annual Cost	\$77,620
Emission Reduction (tons/yr)	325
Cost Effectiveness (\$/ton)	\$239

^a $\$250,000 + [250,000 * (0.03 \text{ tax} + 0.05 \text{ freight})] = \$270,000$

^b $\$270,000 * (0.14 \text{ hardware and erection} + 0.04 \text{ electrical} + 0.02 \text{ piping}) = \$54,000$

^c $\$270,000 * (0.02 \text{ start-up} + 0.03 \text{ contingencies}) = \$13,500$

^d Any additional maintenance costs for the CEF system were assumed to be offset by the reduced maintenance on the Maxfoam line due to the reduction in its use

^e Savings from the elimination of methylene chloride as ABA

^f $2 \text{ operators} * 16 \text{ hrs/day} * 225 \text{ days/yr} * \$20/\text{hr} = \$144,000/\text{yr}$

^g $\$144,000 * 0.15 = \$21,600/\text{yr}$

^h Additional electricity costs: $120 \text{ kw} * 12 \text{ hr/day} * 225 \text{ days/yr} = 324,000 \text{ kw-h/yr}$

$324,000 \text{ kw-h} * \$0.04/\text{kw-h} = \$12,960/\text{yr}$

ⁱ $\$337,500 * 0.1424 \text{ (7 percent for 10 years)} = \$48,060$

^j $\$337,500 * 0.04 = \$13,500$

facilities across the United States, the following discussion focuses on this system.

Most of the Enviro-Cure® systems in operation in the United States are installed on Vertifoam® lines. Vertifoam® is a vertical, rather than horizontal foam line.²⁰ Crain is the only company currently using this technology in the United States. Crain has also retrofit a traditional Maxfoam system with Enviro-Cure®. This type of retrofit is described in the following section, but the general Enviro-Cure® principle is applicable to the Vertifoam® system as well.

The Maxfoam Enviro-Cure® system is an enclosure with an associated conveyor system, which is put in place after the traditional slabstock pouring line. The cut blocks from the Maxfoam machine are transferred to the unit, where a special multi-slat conveyor system transports the block through the cooling enclosure.²¹ There is a slight delay before the foam enters the enclosure to allow the block to stabilize prior to cooling. Controlled air is passed through the block by means of a vacuum process after the blocks are inside the enclosure. The vacuum process cools the blocks by convection and conduction.²² The heat transfer to the cooling process air is handled by exhausting some air to the atmosphere, and by recirculating some back through the Enviro-Cure® process. Airflow is controlled over the whole length of the block to ensure a consistent flow through the block for even cooling. This air flow consistency results in a foam bun that is more uniform, meaning that the properties are more consistent between the outer portion of the bun and the core.²³

There are some differences in the forced cooling systems. Enviro-Cure® is limited to producing short blocks. Rapid-Cure® can be used on line to produce continuous blocks, or off-line to produce blocks limited to the length of the off-line conveyor. The basis for choosing one system over the other depends at least partly on the type of business in a specific plant. General Foam states that the projected capital costs for Rapid Cure® are less than for Enviro-Cure®, varying mainly with the size of carbon bed

used, which in turn depends on production rates and amounts.²⁴ Enviro-Cure® provides no exhaust purification.

There are also drawbacks to the use of forced cooling technology. A complete range of foam grades can be produced using forced cooling, but it is generally agreed by industry representatives that the quality of the some of the lower-density, soft foam grades is not acceptable in the United States foam market. Chemical alternatives can be used in connection with forced cooling to improve foam quality. However, even with this combination of technologies, the complete elimination of ABAs is probably not possible without a degradation in foam quality for certain grades.

The cost information used for the representative facility was obtained from a paper written by Cannon-Viking, the manufacturers of the Enviro-Cure® machine.²⁵ The cost of the Enviro-Cure® system will depend upon the layout of the facility, but is in the region of 1 to 2.2 million dollars for a complete Maxfoam conversion.²⁶ A cost of \$2 million was used for the representative facility. This 2 million dollars included all direct and indirect installation costs. EPA assumed that all the foam requiring ABA would be made using the Enviro-Cure® system, so there would also be material cost savings from the elimination of MeCl_2 . However, the MeCl_2 savings will be offset by increased formulation costs in many cases. To maintain equal density in the absence of MeCl_2 , additional water is used, which requires the use of more TDI. The need for additional TDI is reduced somewhat by either using a lower TDI index, or by adding other additives to maintain the lower IFD associated with the use of MeCl_2 .²⁷ These additives are discussed in the next section of this report. An industry representative indicated that analysis has indicated that the increased formulation costs were approximately equal to the savings in MeCl_2 cost.²⁸

As mentioned previously, the process is patented by Crain, and its use will entail a licensing fee of 1.5 percent of the raw material costs for all Enviro-Cured foams. The costs for the representative facility are presented in Table 5-5.

TABLE 5-5. REPRESENTATIVE FACILITY COSTS FOR ENVIRO-CURE®

Capital Investment	
Purchased equipment costs ^a	\$2,000,000
Total Capital Investment	\$2,000,000
Annual Costs	
Direct Costs ^b	\$0
Utilities ^c	\$18,400
Licensing Fee ^d	\$146,756
Indirect Costs	
Capital Recovery ^e	\$284,800
Administrative charges ^f	\$80,000
Total Annual Cost	\$529,956
Emission Reduction (tons/yr)	325
Cost Effectiveness (\$/ton)	\$1,631

^a Includes direct and indirect installation costs

^b There were no additional labor or maintenance costs identified

^c Based on Enviro-Cure® paper entitled "Cannon Enviro-Cure® Equipment Applied to the Vertifoam and Maxfoam Processes."

^d $0.015 * \$9,783,743 = \$146,756$

^e $\$2,000,000 * 0.1424 \text{ (7\% at 10 yrs)} = \$284,800$

^f $\$2,000,000 * 0.04 = \$80,000$

5.1.5 Chemical Modifications

Chemical modifications are demonstrated methods of reducing ABA usage. The types of chemical modifications included in this analysis can be separated into two groups: chemical additives, and alternative or "soft" polyols. Additives are usually added to the foam formulation at the mixhead. The alternative polyols are substituted for a portion of the traditional polyols in the foam formulations.

Chemical additives and alternative polyols have proven to be successful in the reduction of the amount of ABA used for foam softening.²⁹ There are two basic methods by which these technologies soften the foam. The most common method is by reducing the TDI index, which reduces the number of diisocyanate groups available to form urea linkages. One of the additives studied softens foam by changing the reactivity of the diisocyanate groups of the TDI isomers so that the resulting polyurea segments of the foam are altered.³⁰

These chemical modification technologies can allow the elimination of ABA for foams with densities greater than 1.0 lb/ft³, and IFDs greater than 20 lbs, although there will likely be a deterioration in foam properties at densities less than 1.5 lbs and IFDs lower than around 25 lbs. However, the use of these chemical alternatives for the lower density/lower IFD foams does allow a reduction in the amount of ABA needed, without sacrificing foam property quality. The actual amount of reduction will vary with the combination of density, IFD, and other desired foam properties, but can be as high as 70 percent.

These technologies have not been as successful in the area of density reduction. Unlike MeCl₂, they do not directly decrease the density by auxiliary "blowing" of the foam. They also do not provide the necessary cooling effects to allow increased water levels. However, as noted above in the section on forced cooling, the combination of forced cooling and chemical modification can allow further reduction in the ABA usage for density reduction.

An advantage of chemical modifications is that their use

does not change the production method for slabstock foam. Capital improvements may be necessary, including a new storage tank and associated plumbing, and new pump(s) and a metering system. The specific needs will depend on the existing situation at each facility. Estimates of purchased equipment costs for these improvements ranged from \$5,000 to \$50,000. For the representative facility costs, it was assumed that the following improvements are necessary:

Storage tank	\$ 5,000
Plumbing	\$ 2,000
Pump	\$ 4,000
Metering system	<u>\$12,500</u>
TOTAL	\$23,500

The costs are based on information provided by the PFA-member chemical suppliers.³¹

The annual costs will include the material cost of the chemical alternative (minus the cost of the MeCl_2 no longer needed), and the capital recovery of the necessary improvements. The chemical costs and ABA reduction potential of these chemical technologies are different for each foam grade. Grade-specific information provided by PFA-member chemical suppliers was used.

Table 5-6 compares the standard formulations and the chemical alternative formulations. Arithmetic averages of the information provided by the chemical suppliers were used to calculate the totals in Table 5-6.

The chemical alternatives represented include Dow's XUS15216.00 polyol, Arco's DP-1022 additive and F-1500 polyol, OSI's GEOLITE®91 and 201 modifiers, and Goldschmidt's Ortegol® modifier.

The total representative facility costs for using chemical alternatives are shown in Table 5-7. Since much of the information related to chemical alternatives was claimed as confidential business information (CBI), there is not an attachment related to this technology.

5.2 EQUIPMENT CLEANERS

Methylene chloride is used as a cleaner to rinse and/or soak

TABLE 5-6. REPRESENTATIVE FACILITY COSTS FOR CHEMICAL MODIFICATIONS

Grade	Density (pcf)	IFD (25%)	amount produced (tons/yr)	MeCl ₂ needed (pph polyol)		MeCl ₂ Emissions (tons/yr)		Chemical Costs (\$/yr)	
				standard form	chem. alts.	standard form.	chem.alts	standard form.	chem.alts.
0930	0.9	30	440	10	7.5	29.3	22.0	\$686,949	\$705,369
1010	1.0	10	220	22	16.3	32.3	23.9	\$324,504	\$331,438
1015	1.0	15	360	19	13.7	44.4	32.8	\$533,946	\$551,468
1020	1.0	20	230	14	8.5	21.5	13.0	\$343,834	\$354,504
1030	1.0	30	680	8	5.4	34.0	24.4	\$1,039,637	\$1,098,679
1120	1.1	20	370	14	8.1	33.3	20.0	\$541,175	\$569,982
1130	1.1	30	170	7	2.1	7.4	2.3	\$254,700	\$260,990
1230	1.2	30	610	5	1.4	20.3	5.7	\$896,599	\$921,407
1330	1.3	30	300	6	1.7	11.0	3.4	\$435,701	\$462,888
1340	1.3	40	110	2	0.1	1.5	0.0	\$162,446	\$168,858
1440	1.4	40	180	2	0.2	2.4	0.2	\$261,513	\$262,594
1520	1.5	20	170	13	7.4	14.2	8.3	\$236,137	\$244,648
1530	1.5	30	510	6	1.7	20.4	5.7	\$719,320	\$749,583
1540	1.5	40	390	2	0.2	5.2	0.6	\$558,269	\$581,412
1640	1.6	40	220	1	0.3	1.5	0.4	\$312,853	\$312,180
1740	1.7	40	170	1	0.3	1.1	0.3	\$238,264	\$239,040
1820	1.8	20	160	10	4.6	10.7	4.9	\$215,817	\$233,277
1830	1.8	30	510	6	1.7	18.7	5.7	\$698,680	\$719,806
1840	1.8	40	570	1	0.3	3.8	1.0	\$790,269	\$793,630
1930	1.9	30	240	7	2.1	11.2	3.3	\$326,903	\$329,402
1940	1.9	40	150	1	0.3	1.0	0.3	\$206,227	\$207,095
	2.0	>20	740	0	0.0	0.0	0.0	\$1,016,760	\$1,016,760
TOTALS			7,500			325	178	\$10,800,503	\$11,115,009

TABLE 5-7. REPRESENTATIVE FACILITY COSTS FOR CHEMICAL MODIFICATIONS

Capital Investment	
Purchased equipment costs ^a	\$25,380
Direct Installation Costs ^b	\$5,076
Indirect Installation Costs ^c	\$1,269
Total Capital Investment	\$31,725
Annual Costs^d	
Direct Costs	
Materials ^e	\$314,506
Indirect Costs	
Capital Recovery ^f	\$4,505
Administrative charges ^g	\$1,265
Total Annual Cost	\$320,276
Emission Reduction ^h (tons/yr)	147
Cost Effectiveness (\$/ton)	\$2,179

^a $\$23,500 + [23,500 * (0.03 \text{ tax} + 0.05 \text{ freight})] = \$25,380$

^b $\$25,380 * (0.14 \text{ handling and erection} + 0.04 \text{ electrical} + 0.02 \text{ piping}) = \$5,076$

^c $\$25,380 * (0.02 \text{ start-up} + 0.03 \text{ contingency}) = \$1,269$

^d There are no additional annual costs for operating labor, maintenance, utilities, or waste treatment.

^e $\$11,115,009 - \$10,800,503 = \$314,506$ (See Table 5-6)

^f $\$31,725 * 0.1424$ (7% for 10 years) = \$4,518

^g $\$31,725 * 0.04 = \$1,269$

^h 325 tons - 178 tons = 147 tons (see Table 5-6)

foam machine parts such as mixheads and foam troughs. This use resulted in six tons of emissions (less than 1 percent of total slabstock HAP emissions).³² The two alternatives identified to eliminate these HAP emissions were steam cleaning and non-HAP cleaners. To make the costs as conservative as possible, it was assumed that no effort is made to prevent the evaporation of the MeCl_2 used for cleaning. The portion that does not evaporate (see Table 3-3) must be disposed of as hazardous waste.

5.2.1 Steam Cleaning

Three flexible polyurethane foam slabstock plants were identified in the ICR database that use steam to flush hoses, mixheads, and other pouring equipment. All three identified were owned by Ohio Decorative Products, and it was indicated that this is becoming a company-wide practice. The costs of switching varied between the plants contacted, as one utilized steam already produced on-site for another function (rebond), while the other had to purchase a generator specifically for steam production.^{33,34} The reacted foam scrap from both operations was collected and shredded for use in either the on-site rebond operation, or sent off-site to a rebond operation. For the facility that already had a source of steam, the conversion cost was only about \$200, which was mostly for hoses.³⁵ The facility using a gas-fired mobile steam generator estimated their costs to be between \$3,000 and \$5,000.³⁶

The use of steam for equipment cleaning may be a cost effective method of HAP emission reduction. However, no one was able to provide any estimate of the additional energy costs needed to generate the steam, the costs of maintenance materials, labor, and replacement parts, or the amount of additional operating labor needed. Since the items listed above could make up a large portion of the total annual costs, and the fact that no information, or statements that could lead to informed assumptions, was available, representative facility costs were not developed for steam cleaning.

5.2.2 Non-HAP Cleaners

There were several alternative cleaners identified that were

not HAP-based. The solvents they contain are furanone, cyclic amide, ethyl ester, other esters, N-Methylepyrrolidone (NMP), and D-limonene.^{37,38}

All three cleaners identified, Strip-TZ®, Foamflush, and Dynasolve, are direct replacements for MeCl_2 , meaning that they typically require no equipment or operational changes. This is an advantage as there are no additional utility, maintenance, or operational costs. However, the manufacturers discourage the use of seals and o-rings made of certain materials such as PVC, neoprene, and butyl rubber with non-HAP cleaners.³⁹

All three non-HAP solvent-based cleaners eliminate HAP emissions, but the solvents they contain may still be classified as VOC. Like the non-HAP mixhead flushes discussed in the molded foam section, all three products have low evaporation rates, and can be reclaimed and reused. There are also savings in disposal costs of the waste material, as none of the spent cleaner from these products is classified as a hazardous waste, unlike MeCl_2 .

The costs of applying these products to the representative slabstock plant are presented in Table 5-8. Approximately the same volume of non-HAP cleaners is needed as would otherwise be needed of MeCl_2 . These non-HAP products are more expensive than MeCl_2 on a volume basis. The three vendors of non-HAP cleaners contacted provided costs ranging from \$310 to \$1,375 per 55-gallon drum, while 55 gallons of MeCl_2 costs approximately \$175 (at \$0.25 per pound).⁴⁰ For the representative facility costs, an average cost of \$919 per drum of the non-HAP cleaner was used. In calculating the representative facility costs, it is assumed that the non-HAP products are reused 3 times, meaning only around 370 gallons (6.7 drums) are needed, as compared to the equivalent of 20 drums of MeCl_2 .

TABLE 5-8. REPRESENTATIVE FACILITY COSTS FOR NON-HAP CLEANERS

Capital Investment ^a	
Total Capital Investment	\$0
Annual Costs	
Direct Costs ^a	
Materials ^b	\$2,657
Waste treatment ^c	\$-1,560
Indirect Costs	
	\$0
Total Annual Cost	\$1,097
Emission Reduction ^d (tons)	4.5
Cost Effectiveness (\$/ton)	\$244

^a As discussed above, since these products are direct replacements for MeCl_2 , there were no capital (equipment or installation) costs identified. There were no additional annual costs for labor or maintenance identified.

^b Material costs were calculated as follows:
cost of MeCl_2 : (20 drums @ \$175/drum) = \$3,500/yr
cost of alternative: (6.7 drums @ \$919/drum) = \$6,157
\$6,157 - \$3,500 = \$2,657

^c Waste treatment costs were calculated as follows:
 MeCl_2 : (20 drums * .10) @ \$800/drum = \$1,600/yr
altern. : (6.7 drums * .10) @ \$60/drum = \$40/yr
This assumes that 10% of these substances will be non-recoverable, due to contamination, and will need to be properly disposed of.

^d HAP emissions will be replaced by a small amount of VOC emissions from the use of these products

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6.0 SUMMARY

Tables 6-1 and 6-2 summarize the representative facility costs for the emission reduction technologies included in this analysis for molded and slabstock foam, respectively. Conclusions of this analysis are discussed in this section.

The technologies investigated can be grouped into three basic categories: (1) chemical substitutions, (2) alternative process equipment, and (3) combinations of (1) and (2). The implementation of these types of technologies will result in partial or total changes in the existing polyurethane foam production methods.

There are special challenges in attempting to estimate the costs of these changes. In general, the capital costs of conversion were readily obtainable. However, several elements of the annual cost were particularly difficult to obtain or estimate. These include the operating labor, utility costs, and maintenance and repair costs. Therefore, the level of uncertainty in some of the annual cost estimates is relatively high.

Two other considerations of these process-modifying technologies that are extremely difficult to incorporate into costs are (1) site-specific applicability problems, and (2) changes in product quality. A process modification may not be technically feasible for the products and processes at one facility, while it may work quite well at a facility producing a relatively similar foam product.

6.1 MOLDED FOAM

The three emission source types at molded foam facilities studied in this analysis (mixhead flushing, mold release agents, and foam repair) account for approximately 88 percent of the total HAP emissions reported in the ICRs.¹ This analysis shows that there are cost-effective options for completely eliminating HAP emissions from these three sources at molded foam facilities. However, as noted above, there may be limitations, due to product differences, that cannot be adequately included in a simplified

TABLE 6-1. SUMMARY OF REPRESENTATIVE FACILITY COSTS FOR
MOLDED FOAM EMISSION REDUCTION TECHNOLOGIES

Emission Reduction Technology (representative plant emissions)	Total Capital Investment (\$)	Total Annual Cost (\$/yr)	Emission Reduction (tons/yr, %)	VOC Emissions ^a	Cost Effective- ness (\$/ton)
Mixhead Flush (37.1 tons/yr)					
Non-HAP flushes	0	420	37.1 (100%)	Y	11
High-pressure mixheads	394,875	62,035	37.1 (100%)	N	1,672
Self-cleaning mixheads	135,563	savings	37.1 (100%)	N	savings
Solvent recovery	44,550	savings	27.8 (75%)	N	savings
Mold Release Agent (1.3 tons/yr)					
Reduced-VOC agents	0	2,077	4.6 (100%)	Y	452
Naphtha-based agents	0	savings	4.6 (100%)	Y	savings
Water-based agents	0	1,992	4.6 (100%)	N	433
Foam Repair (4.6 tons/yr)					
Hot-melt	6,820	4,309	1.3 (100%)	Y	3,216
Water-based	0	savings	1.3 (100%)	N	savings
Hydrofuse	5,670	1,210	1.3 (100%)	N	903

^a Does the emission reduction technology result in emissions of non-HAP VOC?

TABLE 6-2. SUMMARY OF REPRESENTATIVE FACILITY COSTS FOR
SLABSTOCK FOAM EMISSION REDUCTION TECHNOLOGIES

Emission Reduction Technology (representative plant emissions)	Total Capital Investment (\$)	Total Annual Cost (\$/yr)	Emission Reduction (tons/yr, %)	VOC Emissions ^a	Cost Effectiveness (\$/ton)
Auxiliary Blowing Agent (325 tons/yr)					
Acetone	194,000	3,967	325 (100%)	Y	12
Liquid CO ₂	472,500	savings	325 (100%)	N	savings
Variable Pressure Foaming	4,500,000	1,423,300	325 (100%)	N	4,379
Controlled Environment Foaming	337,500	77,620	325 (100%)	N	239
Quick-Cooling	2,000,000	529,956	325 (100%)	N	1,631
Chemical Modifications	31,725	320,276	149 (55%)	N	2,179
Fabrication (43 tons/yr)					
Hot-melt adhesives	20,410	97,362	43 (100%)	Y	2,264
Water-based adhesives	0	savings	43 (100%)	N	savings
Hydrofuse	17,010	8,548	43 (100%)	N	199
HAP Cleaning (4.5 tons/yr)					
Non-HAP cleaners	0	1,097	4.5 (100%)	Y	244

^a Does the emission reduction technology result in emissions of non-HAP VOC?

cost analysis.

The telephone conversations with vendors and foamers revealed that small molded foam facilities that continue to use large amounts of HAP's tend to be extremely specialized. Each has unique technical and economic considerations that must be considered in the application of many of the technologies studied. Therefore, a technology may be generally considered to be cost-effective, but it may not be truly cost effective for a specific molded facility.

For mixhead flushing, this analysis shows three options with cost-effectiveness values less than \$1,150 per ton that totally eliminate the use of HAPs for mixhead flushing. However, two of the three, non-HAP flushes and self-cleaning mixheads, are not in widespread use in this industry. This could be an indicator that there are technical problems in their application, or that there are prohibitive costs that are not reflected in this analysis. Another explanation offered by vendors was that these options are relatively new and just have not had time to penetrate the market. Also, while this analysis shows the high-pressure mixheads to be cost-effective, there are technical limitations for some product lines, and many small molded foam companies are not able to bear the initial capital investment.

There are also many technical challenges associated with the elimination of HAPs in foam repair adhesives and mold release agents. However, the extensive utilization of non-HAP products for these functions leads to the conclusion that the technical hurdles can be overcome.

6.2 SLABSTOCK FOAM

The emission source types included in this analysis for slabstock foam (ABA usage, equipment cleaning, and fabrication) make up over 99 percent of the total HAP emissions reported in the ICRs.² This analysis shows that cost-effective solutions exist to completely eliminate HAP emissions from these sources, which would virtually eliminate all HAP emissions at slabstock foam facilities.

The use of equipment cleaning technologies that use no HAP's

is common. The use of non-HAP and water-based adhesives is also widespread, although challenges remain in the production methods for these products. For these two emission sources, the EPA believes that it can be concluded that HAP's could be totally eliminated with demonstrated, cost-effective technologies.

However, the total elimination of HAP ABA presents numerous problems that are not reflected in the representative facility costs. Many of these problems are associated with foam product quality. For instance, a complete range of foam grades can be produced using forced-cooling techniques without any ABA. However, it is generally agreed that the low-density foams produced in this manner would not be of an acceptable quality for the United States market.

Proponents of variable pressure foaming, controlled environment foaming, and liquid CO₂ as an ABA maintain that the foam quality of all grades will be acceptable. However, since none of these technologies has been in full-scale operation in the United States for an extended period of time, it is too early to draw conclusions regarding the technical feasibility of operation, or the acceptability of products in the United States market.

Acetone as an ABA is the only alternative studied in this analysis that (1) completely eliminates HAP ABAs, and (2) has been demonstrated in full-scale production in the United States. However, there are limitations in the application of this technology. One is the increased safety hazard due to the flammability of acetone. Another is that this is not a "pollution prevention" option, since MeCl₂ emissions are being replaced by acetone emissions. This may be of less concern if acetone is no longer considered to be photochemically reactive. Pentane as an ABA has also been demonstrated in the United States, but it was not included in this analysis.

Chemical alternatives have been widely demonstrated in the reduction of HAP emissions from the use of ABAs. The costs for chemical alternatives probably represent the most realistic estimate of costs in this analysis. These costs take into

account technical limitations and product quality, since the formulations used are representative of actual formulations currently used in the industry.

The fundamental conclusion that can be drawn from this preliminary analysis is that cost-effective solutions that essentially eliminate HAP emissions from flexible polyurethane foam facilities are available. Technical feasibility and product quality issues will need to be addressed, but they do not appear to be insurmountable at this time.

6.3 REFERENCES

1. A. Williams, EC/R Inc., to D. Svendsgaard, EPA:ESD:OCG. February 10, 1995. Non-confidential summary of Flexible Polyurethane Foam Information Collection Request (ICR) Data.
2. Reference 1.

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16. ABSTRACT Under the authority of Section 112 of the Clean Air Act, the EPA is currently developing a Maximum achievable control technology (MACT) standard for the manufacture of flexible polyurethane foam. As part of this effort, the EPA initiated a study to allow the estimation of the costs of hazardous air pollutant (HAP) emission reduction technologies for the flexible polyurethane foam industry. This document describes this study and its results. Only technologies that are currently being used, or those under investigation that are generally considered to be promising were included in the study. Information on cost and emission reduction potential, as well as process and operational information, was compiled for each technology. Information was collected from chemical manufacturers, product vendors, trade associations, foam producers, and other sources. Once the information was collected, it was analyzed and applied to "representative" facilities to evaluate the capital and operational costs, as well as the emission reduction and cost effectiveness, of each alternative.					
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