ALTERNATIVE ADHESIVE TECHNOLOGIES IN THE FOAM FURNITURE AND BEDDING INDUSTRIES: A CLEANER TECHNOLOGIES SUBSTITUTES ASSESSMENT

VOLUME 3: EXECUTIVE SUMMARY

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The Design for the Environment (DfE) Program in EPA's Office of Pollution Prevention and Toxics (OPPT) is a voluntary, cooperative program that works in partnership with industry to develop and distribute pollution prevention and environmental and human health risk information on alternative chemicals, processes, and products. The DfE approach uses cleaner technologies substitutes assessments (CTSAs) to evaluate the performance, cost, and environmental and human health impacts of competing technologies. A CTSA is a compilation of considerations and reference materials related to available and emerging technologies in a given industrial sector. The aim of the CTSA is to assist businesses in making more informed decisions that fit their situation.

The foam fabrication, upholstered furniture manufacturing, and mattress manufacturing industries rely heavily on adhesives throughout their operations. Many of these companies are small businesses. Historically, the adhesives used by these industries were based on 1,1,1-trichloroethane (TCA), an ozone-depleting substance. When production of TCA was banned, these industries generally converted to adhesives based on methylene chloride (METH), a suspect carcinogen. The Occupational Safety and Health Administration (OSHA) developed a very stringent regulation on METH which became effective for most METH users in April, 2000. Most companies could not meet the new worker exposure limits without a substantial investment in ventilation equipment. As a result, nearly all companies plan to convert away from METH-based adhesives. Various types of alternative adhesives are available and the businesses need guidance on their cost, performance and relative risks so they can select the alternative that is best for their operation. This project provides the comparative information on the adhesive alternatives.

This document contains an overall summary of the Furniture Adhesives CTSA project and results. More detailed information can be found in *Volume 1: Cost and Performance Evaluation*, which describes cost and performance of the adhesive technologies, and in *Volume 2: Risk Screening and Comparison*, which presents comparative risk information.

I. INDUSTRY DESCRIPTION

Flexible slabstock polyurethane foam currently is produced by 23 companies in about 75 pouring plants in the United States. In 1998, approximately 1.6 billion pounds of slabstock foam were produced. Flexible slabstock foam is fabricated (cut and shaped) into pieces to be used in carpet underlay, furniture, bedding, packaging, transportation seating, and other products where a durable resilient cushioning material is required. Flexible foam manufacturers fabricate about half of the foam produced in their own facilities. The other half is purchased by independent fabricators who cut and shape it into various products. There are approximately 350 foam fabrication plants in the United States. All foam fabricators perform fabrication services for other companies that manufacture bedding, upholstered furniture, and other products.

Some of the foam is fabricated using adhesives and some is not. It is estimated that about one-third of the foam used in furniture manufacture and five percent of the foam used in bedding manufacture requires adhesive in the fabrication operation.

Upholstered furniture manufacturers purchase foam from foam manufacturers or foam fabricators and they use the foam to manufacture home furniture, office furniture including office chairs, stadium seating, or transportation seating for use in conveyances like buses. In the United States, there are more than 2,600 upholstered home furniture manufacturers, about 950 companies that manufacture wood and non-wood office furniture, 14 stadium seating manufacturers, and 26 manufacturers that make seating for buses and other public conveyances. In these operations, the furniture manufacturers bond foam, fabric, wood, metal, and plastic using adhesives.

Mattress manufacturers purchase foam from foam manufacturers or from foam fabricators and they use the foam to manufacture their bedding. There are an estimated 1,270 mattress manufacturers in the United States. Perhaps 200 of these manufacturers make pillow top mattresses, which are generally considered a high-end bedding item. These mattresses are manufactured by using adhesive to bond the pillow top to the mattress.

II. ADHESIVE ALTERNATIVES

Table 1 summarizes the different types of adhesives, the markets in which they are primarily used, and some of their characteristics.

Table 1. Markets and Characteristics of Alternative Adhesives

Adhesive	Markets[a]	Classified as VOC[b]	Ozone Depleter	Flash Point	Issues
TCA	FF, MM, UF	No	Yes	No	Production banned
METH	FF, MM, UF	No	No	No	Heavily regulated
n-Propyl Bromide	FF	Yes	Low	No	Unknown but Likely High Toxicity
Acetone	FF, UF	No	No	Yes	Fire regulations
Acetone Blends	FF, MM, UF	Yes	No	Yes	Fire regulations
Water-Based	FF, UF	No	No	No	Forms aerosols
Hot Melt	MM, UF	No	No	No	High temperature application

[a] FF is foam fabrication, MM is mattress manufacturing, and UF is upholstered furniture manufacture.

[b] Chemicals are considered to be VOCs unless they are specifically exempted by EPA.

1,1,1-Trichloroethane-Based Adhesives

In the 1980s and early 1990s, most of the adhesive used by foam fabricators, upholstered furniture manufacturers, and mattress manufacturers was based on TCA. TCA evaporates readily, is relatively low in toxicity, does not have a flash point and is not classified as a Volatile Organic Compound (VOC) the contributes to ground-level ozone. In the 1990s, TCA was designated as a Class I ozone depleting compound which destroys ozone in the upper atmosphere; production of the chemical was banned in 1996 for that reason. Although inventory was still available, the chemical had become very expensive because of a Federal tax on ozone-depleting substances. Virtually all adhesive formulators stopped making TCA adhesives and began offering adhesives based on METH. Like TCA, METH evaporates readily, does not have a flash point and is not classified as a VOC. It is a suspect carcinogen, however.

Methylene Chloride-Based Adhesives

In 1997, OSHA issued a regulation on METH that lowered the worker exposure level from 500 ppm to 25 ppm measured as an 8-hour time weighted average. The regulation also established an action level at 12.5 ppm -- companies with worker exposure above that level are required to institute monitoring and medical surveillance.

Water-Based Adhesives

In the early 1990s, the formulators developed one-part and two-part water-based adhesives. The early one-part water-based adhesives were based exclusively on natural latex and they did not bond instantly like the solvent-borne adhesives. The two-part adhesives are based on synthetic materials and they were difficult to use in equipment but did bond instantly. New one-part water-based adhesives composed of natural latex and a small amount of synthetic material are now available. These adhesives bond more rapidly than the adhesives based only on latex.

Acetone-Based Adhesives

Acetone is low in toxicity; evaporates readily, and is not classified as a VOC. It does have a very low flash point, however, and companies using acetone-based adhesives must take measures to minimize the chance of fire or explosion. Some formulations based on acetone also contain other chemicals like hexane, heptane, and mineral spirits. These other chemicals may be classified as VOCs and some may be relatively toxic.

n-Propyl Bromide-Based Adhesives

Another alternative that has become available more recently is an adhesive based on n-propyl bromide (nPB). This chemical evaporates readily, has no flash point, and is classified as a VOC. A Japanese study and another reproductive/developmental toxicity test sponsored by the nPB producers indicate that nPB is a reproductive toxin. nPB-based adhesives contain some 2-bromopropane (2-BP) as a contaminant. 2-BP has caused reproductive toxicity problems in Korean workers.

Hot Melt Adhesives

An additional alternative is the hot melt adhesive, which is 100 percent solids. This is applied with a special spray gun that heats the resins in the adhesive to 300 degrees F or higher so they can flow. The applied adhesive quickly cools and sets up.

III. PERFORMANCE OF ALTERNATIVE ADHESIVES

This project involved visits to 32 facilities in the United States to investigate how adhesives were used in the processes and what alternatives companies had adopted or were planning to adopt. The performance of alternative adhesives was evaluated for 23 verification facilities including 14 foam fabrication facilities, five upholstered furniture manufacturing facilities, and four mattress manufacturing facilities. Performance was judged and compared based on qualitative input from facility personnel. In general, the findings indicated that the alternatives performed as well as or better than the TCA or METH adhesives used originally by the facility.

In foam fabrication, the location and size of the facility influenced the choice of alternatives. Foam fabricators located in Southern California could not use METH-based adhesives because of local air district toxics regulations and the stringent VOC regulations prevented them from using nPB-based adhesives. Generally, these companies used TCA-based adhesives until suitable alternatives were found.

Most Southern California fabricators now are using water-based adhesives. Very few companies in the rest of the country adopted water-based adhesives because their use requires process changes. Companies in Southern California where the regulations are more stringent were willing to take on the challenge of adopting a new technology that requires process changes. Once they resolved the issues and optimized their processes, they quickly adapted to the new application methods without loss of productivity.

Nationally, the four largest foam fabricators that participated in the study adopted water-based or acetone-based adhesives in their five plants. The larger facilities expressed a concern for the potential toxicity of nPB. Of the remaining nine smaller fabricators, three adopted acetone adhesives, five adopted nPB adhesives, and one is still using a METH adhesive.

In the upholstered furniture manufacturing sector, one manufacturer converted from TCA to a water-based adhesive. Two of the other companies relied on hot melts. Water-based adhesives appear to be a good choice in the home upholstered furniture sector while hot melts appear to be the best option for office chairs and public seating.

In the mattress manufacturing sector, two companies are using hot melt adhesives, one is using an acetone-based aerosol adhesive, and one uses sewing as an alternative to adhesives.

IV. COST OF ALTERNATIVE ADHESIVES

Cost analysis was performed for 22 facilities. In seven cases, the costs of the adhesive system used currently by the company were determined. In 14 cases, the costs of the new and original adhesive system used by the company were determined and compared. In one case, the costs were not quantified and qualitative costs of the new and original system were compared. Cost information was collected in eight categories for some or all of the facilities. The cost categories included:

- Capital
- Adhesive
- Labor
- Maintenance
- Electricity
- Training
- Regulatory
- Production Adjustment

Some of the facilities had not yet decided which alternative to adopt. Of 14 facilities that had adopted an alternative, seven reduced their cost through the conversion. Seven of the facilities increased their cost through the conversion. Three of these converted from METH to acetone adhesives; three converted from TCA or METH to nPB adhesives; and one converted from TCA to a hot melt adhesive.

In general, the costs of all the alternative adhesive systems are comparable. In some cases, the companies that had made the conversion worked hard to optimize the use of the alternative they selected and they reduced their costs through this process. nPB adhesives are generally more costly than any of the alternative adhesives. In three cases where companies converted to nPB adhesives, the costs increased; in two other cases, the companies evaluated their adhesive use during the conversion and were able to implement measures that reduced their overall cost.

V. CASE STUDIES

Eleven stand-alone case studies were developed based on the cost and performance analysis. These case studies are presented in three documents entitled *Cleaner Technologies Substitutes Assessment Case Studies: Foam Fabrication, Cleaner Technologies Substitutes Assessment Case Studies: Upholster Furniture, and Cleaner Technologies Substitutes Assessment Case Studies: Mattress Manufacturing*. The decisions made by the 11 companies featured in these documents should help similar companies make informed decisions on which alternative technology would be most suitable for their operation.

VI. RISK SCREENING AND COMPARISON

Seven adhesive technologies were evaluated for their risk to human health in order to identify areas of concern among the adhesive types and compare the exposure and health risks of the evaluated adhesives. The types of risk that were evaluated include public and worker health risks, and process safety concerns for workers. In addition, potential environmental impacts (specifically, ozone depletion) are discussed.

To collect the human health hazards information necessary for the risk evaluation, adhesive formulations were required that specified all ingredients and their concentrations. The adhesive types that were evaluated included:

- METH-based adhesives
- nPB-based adhesives
- Acetone-based adhesives
- Adhesives based on an acetone/heptane blend
- Water-based latex adhesives
- Water-based latex/synthetic adhesives
- Hot melt adhesives

A "typical" adhesive formulation was developed for each of these categories (as well as TCA adhesive). The information used to develop the typical formulations included Material Safety Data Sheets for various adhesive formulations, several literature sources, and guidance from adhesive formulators. TCA-based adhesive was not carried through the risk calculations because of the TCA phaseout as an ozone-depleting substance. There are no TCA-based adhesives used today. For the risk comparison, methylene chloride is considered the baseline, against which the alternative adhesives are compared.

Potential hazards posed by adhesives to workers and nearby residents were evaluated by collecting available toxicity data for the chemical ingredients in the typical adhesive formulations. Available testing data for the chemical ingredients were collected from the literature, with a focus on EPA-published toxicity data. In addition, occupational exposure standards and guidance levels were summarized.

Chemical exposures from day-to-day adhesives application operations were estimated for nearby residents and workers. Nearby residents can inhale airborne adhesive ingredients that leave the facility through the air. Worker exposure is possible by inhaling adhesive ingredients that become airborne from the application process and from skin contact with the adhesives. Fate and transport modeling was performed to estimate air concentrations for workplace and nearby resident exposures. Chemical concentrations estimated for the typical formulations were used to calculate dermal exposure to workers from adhesive use. These exposure results were then combined with chemical toxicity data to assess relative risk.

The risk characterization focused on chronic (long-term, repeated) exposure to chemicals that may cause cancer or have other toxic effects. Acute toxicity from brief exposures to chemicals, such as those that could occur from chemical fires or spills, was not assessed. The exposure assessment and risk characterization use a "model facility" approach, with characteristics of the model facility aggregated from site visit data and other sources. Therefore, this approach does not result in an absolute estimate or measurement of risk for any particular facility.

Potential public health risks were estimated for inhalation exposure for residents living near an adhesive-using facility. Public exposure estimates are based on three major assumptions. First, all volatile ingredients evaporate completely during application. Second, emissions are vented to the outside without any air pollution controls. Third, people may live as close as 25 meters from a facility. Table 2 presents results for nearby residents. The only chemical of concern for nearby residents is methylene chloride base on a potential cancer risk greater than one in one million.

Table 2. Summary of Chemicals of Concern for Nearby Residents

Adhesive Type	**Chemicals of Concern**[a]	**Data gaps**[b]
Methylene chloride adhesive (Baseline)	Methylene chloride	Irganox 1010
Acetone adhesive	None	Irganox 1010
Acetone/heptane adhesive	None	Heptane Irganox 1010
n-Propyl bromide adhesive	None	2-Bromopropane 1,2-Butylene oxide 1,3-Dioxolane Formaldehyde[c] Irganox 1010 n-Propyl bromide
Water-based latex adhesive	None	Chlorinated alkyl phosphates Cyanox 2246 Surfynol 440
Water-based latex/synthetic adhesive	None	Chlorinated alkyl phosphates Cyanox 2246 Surfynol 440 Chloroprene
Hot melt adhesive	None	Irganox 1010

[a] The chemicals for which the inhalation cancer risk is greater than one in one million.
[b] Exposure is possible, but toxicity data are lacking from the readily available literature. This applies to both cancer and noncancer risk estimates. For cancer, chemicals are listed as data gaps if they are considered probable or possible human carcinogens, but have no established cancer potency factor with which to estimate cancer risk. For noncancer, chemicals are listed if a hazard quotient could not be calculated.
[c] Possible degradation product of 1,3-dioxolane. A cancer potency factor is available, but the extent of degradation is unknown.

Health risks to adhesive application workers were estimated for inhalation exposures to volatile adhesive ingredients and for dermal absorption from skin contact with adhesive ingredients. The exposure assessment evaluated average and high-end scenarios with respect to adhesive use and ventilation using representative data for a model facility. Inhalation exposure estimates for workers are based on several assumptions, including that all of the volatile ingredients evaporate during the application process; the air in the process room is at steady state; and only general ventilation is used in the process area (without additional local ventilation, such as hoods). Table 3 presents a summary of worker health risk results from inhalation exposure.

Table 3. Worker Health Risks from Inhalation Exposure

Adhesive Type	**Chemicals of Concern**[a]	**Data Gaps**[b]
Methylene chloride adhesive (Baseline)	**Methylene chloride**	Irganox 1010
Acetone adhesive	**Acetone**	Irganox 1010
Acetone/heptane adhesive	Acetone Heptane	Heptane[c] Irganox 1010
n-Propyl bromide adhesive	2-Bromopropane **1,2-Butylene oxide** **n-Propyl bromide**	2-Bromopropane[c] 1,2-Butylene oxide 1,3-Dioxolane Formaldehyde[d] Irganox 1010 n-Propyl bromide[c]
Water-based latex adhesive	**Ammonia** **Latex**	Chlorinated alkyl phosphates Cyanox 2246 Surfynol 440
Water-based latex/synthetic adhesive	**Ammonia** Chloroprene **Latex**	Chlorinated alkyl phosphates Chloroprene Cyanox 2246 Surfynol 440
Hot melt adhesive	None	Irganox 1010

[a] The chemicals for which the inhalation cancer risk is greater than one in one million, the hazard quotient is greater than 1, or the estimated workplace air concentration exceeds an occupational exposure standard and/or guidance level. A chemical is shown in bold if its risk results indicated concern for both the average use/average ventilation scenario as well as the high use/worse-than-average scenario. Regular type indicates that risk results indicated concern only in the case of high adhesive use combined with worse-than-average ventilation.
[b] Exposure is possible, but toxicity data are lacking. This applies to both cancer and noncancer risk estimates. For cancer, chemicals are listed as data gaps if they are considered probable or possible human carcinogens, but have no established cancer potency factor with which to estimate cancer risk. For noncancer, chemicals are listed if a hazard quotient could not be calculated.
[c] Toxicity data were not sufficient to calculate a hazard quotient, but air concentrations could be compared to an occupational exposure standard and/or guidance level.
[d] Possible degradation product of 1,3-dioxolane. A cancer potency factor is available, but the extent of degradation is unknown.

Dermal exposure estimates are based on the assumption that workers do not routinely wear long sleeves or gloves, their hands and forearms are routinely in contact with spray adhesive, and chemicals applied to the skin are completely absorbed. Table 4 summarizes the risk results for worker skin contact.

Table 4. Summary of Chemicals of Concern from Worker Skin Contact

Adhesive Type	**Chemicals of Concern**[a]	**Data Gaps**[b]

Methylene chloride adhesive (Baseline)	Methylene chloride	Tackifying resin
Acetone adhesive	Acetone	Tackifying resin
Acetone/heptane adhesive	Acetone	Heptane Tackifying resin
n-Propyl bromide adhesive	None	2-Bromopropane 1,2-Butylene oxide 1,3-Dioxolane n-Propyl bromide Tackifying resin
Water-based latex adhesive	Ammonia Latex	Chlorinated alkyl phosphates Cyanox 2246 Surfynol 440 Tackifying resin
Water-based latex/synthetic adhesive	Ammonia Latex	Chlorinated alkyl phosphates Cyanox 2246 Surfynol 440 Tackifying resin
Hot melt adhesive	None	None

[a] The chemicals for which the hazard quotient is greater than 1.
[b] Exposure (skin absorption) is possible, but toxicity data are lacking. For noncancer, chemicals are listed if a hazard quotient could not be calculated.

Assumptions and uncertainties are a part of all risk assessments. Some of the major sources of uncertainty in this study included insufficient toxicity data for some chemical ingredients, uncertainty in the air concentration models used to estimate worker and nearby resident exposure, and uncertainty in estimating the amount of dermal absorption from worker skin contact with adhesive ingredients.

It should be noted that this is an interim draft of the CTSA risk evaluation report; the results presented here are based on preliminary toxicity data that were readily available from literature sources. Robust chemical toxicity summaries are being prepared by EPA for all of the adhesive ingredients, and any new or revised data will be incorporated into the final report.

Conclusions that can be drawn from this interim risk evaluation include the following:

- Use of METH-based adhesive can pose a significant cancer risk to workers and nearby residents, depending on adhesive use amount and other factors. Based on the available data, use of any of the evaluated adhesive alternatives would reduce or eliminate those cancer risks. If companies wish to continue using METH-based adhesives, they would have to purchase and install elaborate ventilation systems to protect workers. This measure, however, would not reduce the risk to the surrounding community and a control device to prevent community exposure would be necessary. On balance, it is doubtful these adhesives could be used safely.
- Although the toxicity data for nPB have not been fully analyzed, nPB-based adhesives could also pose important risks to workers and nearby residents.

Again, similarly to METH, users of the nPB-based adhesives should install ventilation systems and also control devices to protect workers and nearby residents.

- All of the evaluated spray adhesives can result in exposures to at least one ingredient with risks above concern levels, although risks are generally higher for solvent-based adhesives than for water-based.
- Among the solvent-based adhesives, risk results are generally higher for METH- and nPB-based adhesives, and lower for acetone- and acetone/heptane-based adhesives. Ventilation systems must be used for acetone and acetone/heptane adhesives because of their flammability. Companies using these adhesives are required to follow the directives of their local fire departments for storing and using the products safely.
- A number of spray adhesive ingredients, even trace ingredients, result in workplace air concentrations higher than occupational exposure standards and/or guidance levels.
- There are worker sensitization concerns from the use of latex and inhalation and dermal problems from ammonia in the water-borne adhesives.
- Significant inhalation or dermal exposure is not expected from the routine use of hot melt adhesives.
- There are several chemical ingredients without sufficient toxicity data or existing occupational exposure standards or guidance levels to evaluate hazards, although exposure to these chemicals is possible, especially to adhesive workers.

Process safety issues for adhesive workers were evaluated based on information from representative adhesive MSDSs. Hazardous properties include eye and skin irritation (for all adhesive types) and flammability (for acetone- and acetone/heptane-based adhesives). In addition, most adhesive chemical formulations can decompose under specific conditions to form potentially hazardous chemicals (especially of concern are the chlorine- and bromine- containing formulations). Work-related injuries from equipment, improper use of equipment, bypassing equipment safety features, failure to use PPE, and physical stress that may appear gradually as a result of repetitive motion are also potential process safety hazards to workers. Appropriate training can help reduce the number of work-related accidents and injuries for any adhesive type.

VII. CHOOSING AMONG ALTERNATIVES

In the foam fabrication sector, some companies are still using METH-based adhesives. The alternatives for this sector include water-based adhesives, acetone adhesives, acetone blend adhesives and nPB adhesives. The costs of the different adhesive systems are roughly comparable. From the health and environmental standpoint, water-based adhesives appear to pose less risk. Use of water-based latex and water-based latex/synthetic adhesives requires process changes. The adhesive must be applied to both pieces of foam that are bonded and the adhesive supply must be elevated and gravity fed. Foam fabricators that have successfully adopted water-based adhesives have adapted to these process changes and have, in most cases, reduced their costs through optimization of the new system.

Acetone-based adhesives are comparable in cost and performance for foam fabricators. They appear to pose a lower risk than the other solvent-based adhesives. The conversion from METH adhesives to acetone adhesives is straightforward because the properties of the two chemicals are similar. Because of the flammability of the acetone, however, companies must install ventilation systems. Acetone blends are also available but the other ingredients in the blend are generally VOCs and some may be toxic. Companies should take that into account when they consider acetone blends.

nPB-based adhesives have been adopted by several smaller foam fabricators; the larger manufacturers have generally not adopted nPB adhesives because of concern for toxicity. nPB is a VOC and a reproductive toxin and companies should take this into account when they are considering alternatives. If companies decide to use these adhesives, they should be used with extreme caution and users should make an effort to purchase nPB that contains as low a concentration of 2-BP as possible. Ventilation systems are required to reduce the worker exposure. nPB adhesives are more expensive than the other types of adhesives and system costs may increase if these adhesives are selected as an alternative.

In the upholstered furniture sector, the option that appears to pose the least risk from the health and environmental standpoint is hot melt adhesives. These adhesives have been adopted by many companies in this sector, particularly office chair manufacturers. Selection of this option requires the company to implement process changes. Some companies may need to install automated application systems and others must purchase special hot melt spray guns. Water-based adhesives are comparable in terms of cost and performance and some home furniture manufacturers are now using these adhesives. From the health and environmental standpoint, water-based adhesives appear to pose much less risk than solvent-based adhesives although there are some concerns. Process changes will also be necessary for companies using water-based adhesives. They must be applied to both surfaces that are bonded and they may have to be gravity fed. Acetone and acetone blend adhesives are another choice for this sector but companies must implement measures to deal with the flammability of the new adhesives. This generally means that ventilation systems will have to be installed. The risks from acetone-based adhesives appear to be much lower than the risks from methylene chloride-based adhesives.

In the mattress manufacturing sector, the option that appears to pose the least risk from a health and environmental standpoint is hot melt adhesives. Companies using METH-based adhesives that decide to use these adhesives must change their process considerably. Special spray guns are required or, in some cases, automated systems will be required to apply the adhesives. Another very good option that may be appropriate for some of the companies in this sector is sewing; this method eliminates the need for adhesive altogether. A few companies in this sector may decide to adopt acetone or acetone blend adhesives. For this choice, companies must take care to minimize the threat of flammability and this generally means they must install ventilation systems.