Tert-Butyl Acetate: Safer Alternatives in Cleaning and Thinning Applications

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EXECUTIVE SUMMARY

In 2004, EPA listed tert-butyl acetate (TBAC) as a chemical that is exempt from Volatile Organic Chemical (VOC) regulations. Limited toxicity information is available for TBAC. The chemical forms a metabolite called tert-butyl alcohol (TBA) which has induced tumors in rats and mice. Use of TBAC should be considered to pose a potential cancer risk to humans.

TBAC, a solvent, is not widely used today. It is more expensive than other VOC solvents so these solvents are generally chosen by suppliers, formulators and users. There is a strong demand for exempt chemicals in areas like California where there are stringent VOC regulations. If TBAC were designated as exempt by the California air regulatory agencies, it could be used much more extensively.

The Institute for Research and Technical Assistance (IRTA) is a nonprofit organization with experience in identifying, developing, testing and demonstrating safer alternatives in solvent applications. EPA sponsored this project which was designed to evaluate TBAC in certain solvent applications where it could be used effectively and identify suitable safer alternatives.

The project focused on a range of different solvent applications where TBAC might be used. These include:

- batch loaded cold cleaning and handwipe cleaning;
- printed circuit board defluxing;
- coating application equipment cleaning;
- thinners for coatings;
- automotive aerosol cleaning;
- lithographic printing cleanup; and
- screen printing cleanup.

The approach involved some limited testing of TBAC in printing applications. IRTA used case studies in each of the application areas to analyze the performance and cost of using high VOC solvents, TBAC and safer alternatives.

IRTA identified effective alternatives in all of the applications and, in many cases, the case study companies have adopted them. A summary of the safer alternatives in each of the applications and types of companies is presented in Table E-1.

The table shows that the alternatives fall into three general categories: acetone and acetone blends; water-based cleaners; and soy based cleaners. Acetone is not classified as a VOC and it is lower in toxicity than most other organic solvents. Water-based cleaners are generally diluted in applications where they are used and many of them have low VOC content and low toxicity. Soy based cleaners, similarly, have low VOC content and low toxicity.

Table E-1
Safer Alternatives to High VOC and
TBAC Products in Cleaning and Thinning Applications

Cleaning Category	Case Study Company	Effective Safer Alternative(s)
Batch Loaded Cold Cleaning / Handwipe Cleaning	Machine Shop	Water-Based Cleaners
	Precision Contract Cleaning Company	Acetone
	Electric Motor Manufacturer	Acetone
Printed Circuit Board Defluxing	Data Acquisition Equipment Manufacturer	Acetone / IPA / D.I. Water
	Braking System Manufacturer	Acetone / IPA
Coating Application Equipment Cleaning	Wood Company	Acetone
	Architectural Contractor	Acetone
	Safe Manufacturer	Acetone
	Autobody Shop	Acetone
Thinners for Coatings	Wood Company	Acetone
	Architectural Contractor	Acetone
	Safe Manufacturer	Acetone
		Acetone / Soy
	Autobody Shop	Acetone / Soy
		Acetone / Glycol Ether
Automotive Aerosol Cleaners	Auto Repair Shops	Water-Based Cleaners -- Spray Bottles
		Water-Based Cleaners -- Aerosols
		Water-Based Cleaners -- Bulk
		Water-Based Cleaners -- Brake Cleaning Equipment
		Acetone, Acetone Blends -- Cannister Systems
		Acetone, Acetone Blends -- Aerosols
Lithographic Printing Cleanup	Poster Printing Company	Soy -- Roller Wash
		Acetone Blend -- Blanket Wash
	High Quality Independent Printer	Water-Based Cleaner -- Roller Wash
		Acetone / Glycol Ether Blend -- Blanket Wash
Screen Printing Cleanup	Textile Printer	Soy -- Recycle Cleanup
		Water-Based cleaner -- Recycle Cleanup
		Acetone Blend -- In-Process Cleanup
	Cosmetic Bottle Printer	Soy -- Recycle Cleanup
		Soy -- In-Process Cleanup

The results of the project are particularly important in California. The California Air Resources Board (CARB) and the South Coast Air Quality Management District (SCAQMD), the largest air district in California, have exempted TBAC in limited applications and they may exempt the chemical in additional applications in the future. The project findings indicate that there is no need to exempt TBAC in cleaning and thinning applications because safer alternatives are available and are demonstrated to be cost effective. Agencies in California do not generally exempt chemicals that pose a cancer risk unless they are controlled through toxic regulations. TBAC is not currently

listed on any toxic lists and CARB should list the chemical as a Toxic Air Contaminant so it cannot be used in an unconstrained way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

On November 29, 2004, U.S. EPA added tert-butyl acetate (TBAC) to the list of compounds that are exempt from Volatile Organic Compound (VOC) regulations. VOCs contribute to photochemical smog formation. TBAC is a solvent that is likely to be an effective cleaning or thinning agent for a variety of applications. It is used in limited applications today because it is more expensive than other VOC solvents. There is a demand for exempt chemicals in locations where VOC emissions are or will be increasingly restricted. Stringent VOC regulations in places like California, for example, could make TBAC an attractive alternative to VOC solvents even though it is more expensive.

TBAC forms a metabolite called tert-butyl alcohol (TBA) that is a carcinogen. If TBAC is used, TBA will be formed and workers and community members will face an increased cancer risk. Thus, even though use of TBAC could reduce VOC emissions and smog formation, it could be more toxic than many of the VOC or other exempt solvents used today.

The Institute for Research and Technical Assistance (IRTA) is a nonprofit organization established in 1989 to assist companies and whole industries in identifying, testing and demonstrating safer alternatives. IRTA's major focus over the last several years has been on solvents used in applications like cleaning, dry cleaning, stripping, adhesives and coatings. U.S. EPA Region IX sponsored this project and the aim was to find safer alternatives to TBAC in its existing and potential future cleaning and related applications.

This project was designed to focus on safer alternatives to TBAC. In some cases, TBAC is used currently in certain of the applications. In other cases, it may be used in the future in the applications of interest because it has been deemed exempt from VOC regulations. The project involved selecting applications where TBAC could be effective because of its physical characteristics, cleaning capability and solvent properties. In some instances, IRTA tested TBAC in a limited way to determine if it could be used effectively. The project also involved identifying, developing and testing alternatives that would be suitable in place of TBAC. Finally, it involved comparing the performance and cost of using the safer alternatives with the performance and cost of using TBAC.

The results of this project are particularly important in California and other locations where there are stringent VOC regulations. In locations where there are few VOC regulations, lower cost VOC solvents will be used in the applications of focus. Where there are regulations, however, the pressure to convert to exempt chemicals is greater even when the cost of the alternative is higher.

Section II of this report provides information on VOC exemptions in general, TBAC exemptions in California in particular. It briefly summarizes the toxicity information available on TBAC and TBA. Section III discusses the selection of the applications of focus for the project and describes in detail the feasibility and cost of using safer

alternatives in these applications. Case studies of companies that analyze using safer alternatives are presented. Section IV provides regulatory and toxicity information on TBAC and the alternatives. Finally, Section V summarizes the results of the analysis.

II. BACKGROUND

This section provides information on the process EPA and California agencies use in exempting chemicals from VOC regulations. It also describes the current status of TBAC in California. The toxicity information on TBAC and TBA, its metabolite, are presented.

BACKGROUND ON VOC EXEMPTIONS

The term VOC has a regulatory definition. Chemicals are assumed to be VOCs unless they are specifically designated as "exempt" from VOC regulations. Chemicals that break down in the lower atmosphere or troposphere in a short period of time are VOCs. EPA uses ethane as the standard and chemicals that form tropospheric ozone more readily than ethane are classified as VOCs. Before 1994, only chemicals that were more reactive than ethane on a per gram or a per mole basis were exempted from VOC regulations. Acetone is less reactive than ethane on a per gram basis but is more reactive than ethane on a per mole basis. In 1994, EPA exempted acetone from VOC regulations and, even though this action went against EPA policy, it opened the door for other chemicals that were more reactive than ethane on a per mole basis to also gain exempt status.

On January 17, 1997, ARCO Chemical Company submitted a petition to EPA requesting an exemption for TBAC. Although TBAC is more reactive than ethane on a per mole basis, it is less reactive than ethane on a per gram basis. The company cited the acetone exemption as an argument to exempt TBAC. EPA proposed the exemption of TBAC on September 1999 and finalized the exemption in December 2004.

When chemicals are deemed exempt, they have a market advantage which is particularly pronounced in areas like California where there are stringent VOC regulations. Distributors must meet regulatory requirements and non-VOCs are used to formulate products that meet them. Users must also comply with regulations and they seek out exempt chemicals with the appropriate properties for their needs. Even when the exempt chemical is more expensive than a VOC chemical, the regulations literally develop the market for exempt chemicals and virtually mandate their use.

EPA considers only the reactivity of a chemical when it grants an exemption from VOC regulations. For example, some chemicals that are carcinogens, like perchloroethylene and methylene chloride, are exempt. These chemicals, however, are regulated as toxic compounds in other regulations. Both chemicals are listed Hazardous Air Pollutants, for instance. When EPA exempted TBAC, the agency acknowledged the toxicity of the metabolite TBA and requested limited additional toxicity information on TBAC but does not regulate TBAC or TBA, the carcinogenic metabolite, in any other way.

In California, before a chemical can be classified as exempt, the California Air Resources Board (CARB) or the local air districts must exempt it. CARB has the authority to regulate consumer products in California and the local air districts have authority to

regulate stationary sources. Some air districts in California have regulations that automatically exempt chemicals that EPA has deemed exempt. Other air districts, like the South Coast Air Quality Management District (SCAQMD), which accounts for about half the chemical use in the state, do not have this automatic exemption. Some states also have this automatic exemption provision. Chemicals like TBAC that are exempted, however, will not have widespread use in most of these other states because they do not have the stringent VOC regulations that California does. The California market is very important to exempt chemical producers and suppliers because of the stringent VOC regulations that create a market for them.

CALIFORNIA TBAC EXEMPTIONS

CARB originally opposed the EPA TBAC exemption. CARB was concerned that the fact that TBA was a carcinogen could lead to unanticipated problems at a later date because of the experience with MTBE. MTBE is a gasoline additive that was used extensively in California. The chemical is a carcinogen and it ended up contaminating many groundwater basins. That problem was not anticipated before MTBE was used extensively.

Once EPA exempted TBAC, CARB conducted an environmental impact assessment of TBAC. The study involved examining certain applications where TBAC might be used and comparing the risks of TBAC (based on the cancer risk of TBA) and the risks of the continued use of the VOC chemicals it could replace. As part of this analysis, CARB asked the Office of Environmental Health Hazard Assessment (OEHHA), the State Water Resources Control Board (SWRCB) and the Department of Toxic Substances Control to weigh in on TBAC.

A memo to CARB regarding TBAC indicated that the SWRCB staff concluded that the potential impacts of TBAC emissions on water quality are uncertain based on the limited information available on the subject. OHEEA's memo to CARB included a detailed review of the health effects data for TBAC and TBA and discussed the toxicity of TBA. More discussion of the toxicity issues by OEHHA is presented below.

The CARB study recommended exempting TBAC in the California Consumer Products Regulations based on its low reactivity. It indicated that CARB staff would further evaluate the consumer product categories where TBAC might be used and determine whether use in these categories would pose an unacceptable risk. In the event that TBAC use did pose an unacceptable risk, CARB would propose mitigation measures in the regulations. CARB encouraged the local air pollution control agencies to consider whether or not TBAC poses an unacceptable risk in stationary source applications.

Over the last year, CARB has not yet proposed to exempt TBAC in any Consumer Product Regulation categories. Several categories are currently under regulatory evaluation, however, and CARB may propose exemptions in some of these categories by summer of 2007. In addition, CARB could propose exemptions in future rulemakings for other categories of consumer products.

CARB has exempted TBAC from VOC regulations in their Suggested Control Measure (SCM) for Automotive Refinish Coatings. The local air pollution control districts are responsible for regulating emissions from automotive coating operations. CARB provides technical support to the districts through development of SCMs. SCMs serve as models for districts when they adopt or modify regulations. Many of the air districts simply adopt the SCM but other districts develop an independent regulation.

The TBAC exemption in CARB's automotive coating regulation applies to all types of coatings and to materials used as cleanup solvents for the coating application equipment. Suppliers can formulate coatings and cleanup solvents based on TBAC to comply with the lower VOC standards.

SCAQMD amended their automotive coating regulation, Rule 1151, in December 2005. SCAQMD did not adopt the same exemptions for TBAC in the CARB SCM. Rather, the SCAQMD regulation exempts TBAC more narrowly, for use in primers, one type of coating used in the automotive industry. SCAQMD regulates coating application equipment cleaners in another regulation, Rule 1171. The District has indicated they have no plans to exempt TBAC for this application.

SCAQMD also amended their architectural coatings rule, Rule 1113, in 2006. Again, SCAQMD exempted TBAC in a narrow way, only for use in Industrial Maintenance (IM) Coatings. IM coatings are coatings that experience extreme environment conditions. Examples include coatings used at chemical plants and Publicly Owned Treatment facilities. CARB is currently developing an SCM for architectural coatings. They are not considering a full exemption for TBAC but may adopt an exemption for IM coatings as SCAQMD did.

<u>TOXICITY OF TBAC AND TBA</u>

As mentioned earlier, CARB requested information on the toxicity of TBAC from OEHHA. OEHHA's memo indicates that the toxicity information on TBAC are very limited. No chronic, developmental or reproductive toxicity data are available for the chemical. OEHHA also indicated that based on the absence of information on long-term exposure, birth defects and cancer, the agency could not assess the potential for adverse effects from exposure to TBAC.

OEHHA also provided information on the toxicity of TBAC's metabolite, TBA. The memo indicates that TBA has been shown to induce tumors in both rats and mice. OEHHA also stated in the memo that this raises a concern that exposure to TBAC may result in a cancer risk because of the metabolic conversion to TBA.

Several of the OEHHA staff published a paper entitled "Acute Toxicity and Cancer Risk Assessment Values for tert-Butyl Acetate." The paper indicates that TBAC is substantially metabolized to TBA and that TBA may cause oxidative DNA damage and has been shown to induce tumors in laboratory animals. The authors state that TBAC

should be considered to pose a potential cancer risk to humans because of the metabolic conversion to TBA.

PROJECT BASIS AND APPROACH

There is increasing pressure in many parts of the country, particularly California, to reduce VOC emissions to prevent the formation of photochemical smog. The air regulatory agencies rely on the availability of low-VOC alternatives and exempt chemicals to set lower standards for different types of products. For many years, EPA exempted chemicals based on whether or not they were as reactive as ethanol on a per mole basis. EPA mistakenly exempted acetone from VOC regulations because it is less reactive than ethanol on a per gram basis but is more reactive than ethanol on a per mole basis. This opened the door for producers of chemicals to submit petitions for other chemicals that are more reactive than ethanol on a per gram basis but not on a per mole basis.

The TBAC producers requested an exemption from EPA on this basis. Because of TBAC's metabolic conversion to TBA, a carcinogen, use of TBAC could pose a cancer risk to workers and community members. Even so, EPA granted the exemption. In California, CARB and the largest local air district, SCAQMD, have exempted TBAC in certain regulations and model rules. Because of the stringent VOC regulations in the state, a tightened VOC regulation with a simultaneous exemption for TBAC, the agencies are creating a market for TBAC. TBAC is more expensive than other VOC solvents so it would only be used where the low VOC standards virtually mandate its use. Although other low-VOC types of materials, like water-based materials for instance, might be used, formulators find it easier to use solvents in their products.

TBAC use could increase significantly in the years to come if CARB and the other air districts in California exempt it in regulations that establish more stringent VOC standards. TBAC is not listed as a Toxic Air Contaminant (TAC) in California because CARB has not proposed to add it to the list. Thus there are no toxics regulations that might control its use. This indicates that suppliers will use it in formulations extensively and users will use it without any restraints. The Permissible Exposure Limit (PEL) set by the Occupational Safety and Health Administration (OSHA) is 200 ppm but this is not low enough to protect workers from a significant risk. The worker risk is discussed in more detail later in this document.

It is likely that there may be a much larger market for TBAC in the future in California if the air regulatory agencies continue to exempt the chemical in various applications. On that basis, EPA and IRTA thought it was important to identify potential applications for TBAC and describe and evaluate safer alternatives in those applications. TBAC is a fairly aggressive solvent and it has an intermediate vapor pressure which would offer a distinct advantage in cleaning and thinning applications. A Material Safety Data Sheet (MSDS) for the chemical is shown in Appendix A. The approach IRTA used in this project involved:

- identifying cleaning and thinning applications where TBAC could be used;

- selecting certain of the applications for further study;
- testing TBAC in a few of the potential applications;
- identifying safer alternatives to TBAC in these applications; and
- comparing the cost of using TBAC and the alternatives in the selected applications.

Selected Applications for Further Evaluation

IRTA considered all applications for further analysis where TBAC could be used for cleaning or thinning coatings. These applications included:

- dry cleaning;
- repair and maintenance cleaning;
- batch loaded cold cleaning and handwipe cleaning;
- printed circuit board defluxing;
- coating application equipment cleaning;
- thinners for coatings;
- automotive aerosol cleaning;
- lithographic printing cleanup; and
- screen printing cleanup.

TBAC would not be a suitable alternative in dry cleaning. The major solvent used in dry cleaning today is perchloroethylene (PERC). CARB and SCAQMD have adopted regulations that will phase out PERC over the next several years. There are a variety of alternatives available including hydrocarbon, Green Earth which is a silicone based solvent, Rynex which is a glycol ether, water-based cleaning processes and a carbon dioxide process. Hydrocarbon, Green Earth and the glycol ether all have flash points greater than 140 degrees F and equipment has been designed to accommodate this. A picture of the equipment designed for these solvents is shown in Figure 2-1. Fire departments will allow use of these alternatives if the flash points are greater than 140 degrees F. The flash point of TBAC is much lower than this, at 40 degrees F. This makes it highly unlikely that TBAC could ever be used in dry cleaning and IRTA did not consider this application further for that reason.

Repair and maintenance cleaning is conducted in parts cleaners and immersion cleaning systems that hold between 15 and about 50 gallons of solvent. Pictures of a parts cleaner and an immersion system are shown in Figures 2-2 and 2-3 respectively. Repair and maintenance cleaning is conducted by thousands of industrial and auto repair facilities. Fire departments likely would not allow use of this volume of TBAC because of the low flash point. For this reason, IRTA did not consider this application further.

Figure 2-1. Hydrocarbon Dry Cleaning Machine

Figure 2-2. Parts Cleaner

Figure 2-3. Immersion Parts Cleaner

TBAC could be used in some very small batch loaded cold cleaning operations with a volume of five gallons or less. The low flash point would prevent its use in large batch loaded cold cleaning operations. Industrial firms use batch loaded cold cleaners to clean various types of small parts by immersing the part in solvent for a period or dipping the part in the solvent. IRTA included batch loaded cold cleaning operations in the analysis. Handwipe cleaning is related to batch loaded cold cleaning and is generally conducted in industrial operations. Solvent is applied to a wipe cloth and the cloth is used to wipe the contaminants from large, medium sized and small parts. The solvent may be contained in a batch loaded cold cleaning unit. Flammability is not much of an issue in this application because such a small amount of solvent is used on each cloth. IRTA included handwipe cleaning operations in the analysis.

Flux is applied to printed circuit boards to facilitate solder flow and heat transfer. After the components are soldered to the board, the flux and other contaminants are cleaned from the boards. Many facilities that assemble boards use water-based cleaning equipment in a batch or conveyorized system to remove flux. TBAC could not be used in equipment like this because of its low flash point. During rework of boards, the most common method of removing flux after hand soldering is to use cleaners in small cleaning tanks or squeeze bottles to clean the flux from the boards. TBAC could be used in this application and IRTA included PC board rework in the analysis.

Solvents are used to clean coating application equipment like spray guns, brushes and rollers. A picture of several typical compressed air spray guns is shown in Figure 2-4. Some operations rely on spray gun cleaning systems which contain about five gallons of solvent to clean the equipment. In other operations, the workers clean the equipment in a bucket containing solvent. Solvents with low flash points are used today in these operations so IRTA included them in the analysis.

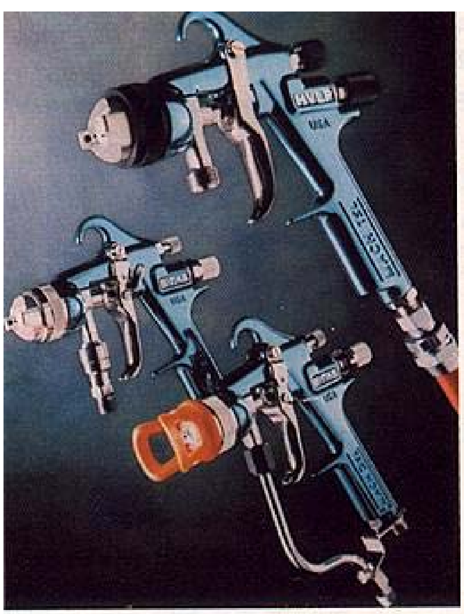

Figure 2-4. Compressed Air Spray Guns

Virtually all companies that apply coatings of various types use thinners to ensure the coatings have the proper consistency and flow characteristics. The thinners that are used today have low flash points so IRTA included thinning for a range of coating types in the analysis.

Aerosol cleaners of various types are used in automotive aerosol cleaning which includes brake cleaning, engine degreasing, general purpose degreasing and carburetor and fuel injection system cleaning. Solvents with low flash points are commonly used in these cleaners so IRTA included this application in the analysis.

Lithographic printing ink is commonly cleaned with solvents during printing. These printers use solvents in small squeeze bottles and wipe cloths for cleaning rollers and blankets on lithographic presses. In some cases, automated blanket and roller wash systems that contain large quantities of solvent are used for cleaning. IRTA did not include ink cleaning with automated systems in the analysis because the flash point of TBAC is too low for safe use in such systems. IRTA did include ink cleaning by hand in the analysis because only small quantities of the solvent are used in the squeeze bottles and on the wipe cloths.

Screen printers use solvents to clean screen ink from screens after and during printing. During printing, the solvents are applied on wipe cloths. Some printers, particularly textile printers, also clean the residual ink from the screens with solvent laden wipe cloths after printing when the screens are recycled. Other printers use solvents in parts cleaners or brush systems to clean the screens during recycling. Solvents with very low flash points cannot be used in parts cleaners so IRTA did not include such operations in the analysis. IRTA did include the wipe cloth processes in the analysis because solvents with low flash points are commonly used in these applications.

ALTERNATIVES EVALUATION

In some of the applications evaluated here, IRTA conducted limited testing to determine if TBAC could clean effectively. In lithographic printing and screen printing, the cleaner was tested for its capability in cleaning ink. In many of the other applications that were evaluated, IRTA relied on literature from the producer to determine whether TBAC would be a potential cleaning candidate. TBAC has not been deemed exempt from VOC regulations in California except in certain limited applications. It should be noted that in most of the applications where it was analyzed, it could not be used legally unless it were specifically exempted.

For the analysis IRTA had identified, tested, developed and demonstrated alternatives in previous projects. In those previous projects, IRTA analyzed the cost and performance of safer alternatives and compared it to the chemical of interest. In the earlier work, the chemicals of interest were generally high VOC content materials which are often also toxic. IRTA modified the earlier analysis to update the cost information and to include analysis of TBAC.

This document contains information on many case studies of companies that used the high VOC or toxic chemicals in various applications. In all of the case studies, IRTA elected to not identify the companies. This decision was based on the fact that the analysis was modified in certain instances to hypothesize that the company used a certain chemical when they did not. IRTA did not want to misrepresent the chemicals the companies used so their identity is protected.

Safer Alternatives

The safer alternatives that were evaluated varied depending on the application. For cleaning applications, IRTA evaluated water-based cleaners, soy based cleaners and acetone based cleaners. Water-based cleaners and soy based cleaners have very low VOC content. Acetone is exempt from VOC regulations and it is lower in toxicity than most other organic solvents. In the thinning applications, IRTA evaluated acetone, soy/acetone blends and glycol ether/acetone blends. The glycol ether that was tested is a propylene glycol ether which is low in toxicity and it is considered a Low Vapor Pressure (LVP) solvent in the CARB consumer product regulations. For purposes of that regulation, the glycol ether is not considered a VOC.

Cost Analysis and Comparison

Cost analysis is presented in all of the case studies. The cost of using the alternatives was compared with the cost of using the high VOC and toxic solvents and TBAC. In all cases, IRTA evaluated the cost components that changed with use of the alternatives. The types of costs that were evaluated in various case studies included:

- cost of capital equipment;
- material cost;
- labor cost;
- electricity cost; and
- disposal cost

The cost components were annualized in the cost analysis. In some of the case studies, new equipment was required to use the alternative. For all of the case studies, a reasonable and conservative life for the equipment was assumed and the cost of capital was assumed to be 5%. For the cleaner or thinner cost, IRTA used the cost paid by the facility. Costs of the alternative cleaners or thinners were those paid by the facility if they converted to the alternative or those charged by home improvement stores or by suppliers of the alternatives. IRTA obtained information on the cost of TBAC from a chemical supplier. He provided information on the price of the chemical in bulk, drums, five gallon containers and one gallon containers based on information from the supplier. The cost of electricity was assumed to be 12 cents per kWh. The disposal costs were those paid by the facilities or were estimated through conversations with waste haulers.

III. ANALYSIS OF ALTERNATIVES IN SELECTED APPLICATIONS

In the last section, the reasons for selecting the processes for analysis were discussed. This section describes the processes and compares the cost of using high VOC solvents, TBAC and the appropriate safer alternatives. The selected applications for which analysis was performed include:

- batch loaded cold cleaning and handwipe cleaning;
- printed circuit board defluxing;
- coating application equipment cleaning;
- thinners for coatings;
- automotive aerosol cleaning;
- lithographic printing cleanup; and
- screen printing cleanup.

BATCH LOADED COLD CLEANING AND HANDWIPE CLEANING

There are thousands of operations that use solvent in small containers up to five gallons in volume to clean parts. A batch loaded cold cleaner is simply a metal tank that holds the solvent. In some operations, the parts are placed in the liquid in the cold cleaning system for a period to remove contaminants like oil or particulates and then are removed and further processed. In other cases, the worker uses a brush or wipe cloth to clean the parts by hand in the cold cleaning system.

Handwipe cleaning is closely related to cleaning with batch loaded cold cleaners. In some cases, companies pour the solvent in a container or cold cleaning unit. They use a wipe cloth or rag to moisten the solvent which they then use to hand clean the part. In other cases, the solvent is poured in a small squeeze bottle container or plunger system. The wipe cloth is moistened with the solvent and is used to clean parts.

The types of operations that use solvents in batch loaded cold cleaners and handwipe processes include machine shops, various different types of metal fabricators, companies that paint parts, companies that have plating operations and companies that precision clean their parts. Case studies for three companies, a machine shop, a precision contract cleaning company and an electric motor manufacturer, are presented below.

Machine Shop

This company is a small machine shop that machines parts for aerospace applications. For many years, the firm used mineral spirits at 21 different stations to remove oil and chips from the machined parts so they can be inspected. The workers machined the parts, dipped them in a coffee can containing mineral spirits, held them over the machine and blew them off with compressed air. The oil used in the machines required dilution with mineral spirits and the excess mineral spirits on the parts during blow-off satisfied this requirement. The company also had two larger five gallon batch loaded cold cleaners that contained mineral spirits. These cleaning units were used to perform final cleaning

of the parts. The parts were placed in the unit, cleaned individually one by one and blown off with shop air by the workers.

IRTA worked with the company to find alternatives to mineral spirits, which is classified as a VOC, for the cleaning operations. IRTA provided a 30 gallon plastic parts cleaner to the company for testing. This approach worked well. A picture of this unit is shown in Figure 3-1. The company purchased the cleaning system and also purchased seven other smaller 15 gallon metal parts cleaners. A picture of one of the metal parts cleaners is shown in Figure 3-2.

Figure 3-1. Plastic Parts Cleaner

The company wanted to purchase a larger cleaning system to replace the two five gallon batch loaded cold cleaning units used for final cleaning. The aim was to minimize the labor spent during that step. After testing in a small tabletop unit, the company decided to purchase an ultrasonic water-based cleaning system. A picture of this system is shown in Figure 3-3.

Figure 3-2. Metal Parts Cleaner

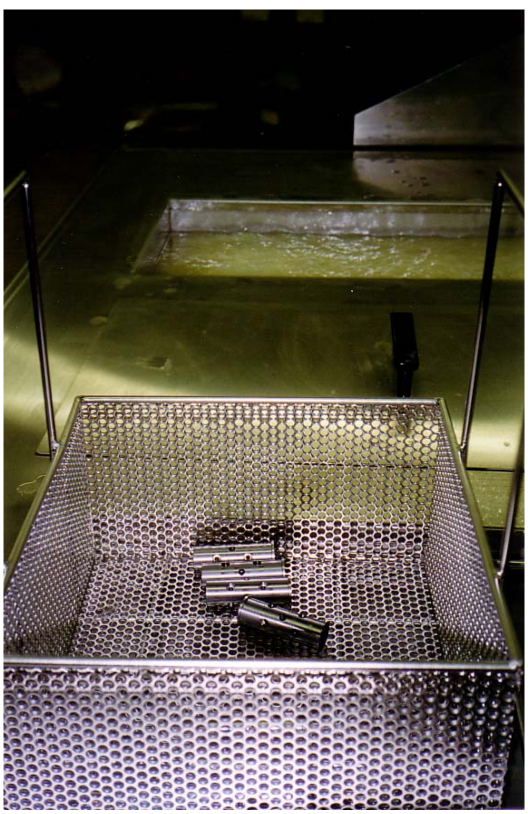
Figure 3-3. Ultrasonic Cleaning System

IRTA evaluated the costs of using the mineral spirits and the water-based cleaning systems that replaced the batch loaded cold cleaners. IRTA also evaluated replacing the mineral spirits with TBAC and continuing to use the coffee can containers at the work stations.

When the company used mineral spirits, they purchased 17 55 gallon drums of the solvent annually at a cost of $148.50 per drum. The total annual cost of the mineral spirits was $2,525. The shop had no disposal cost because, when the parts were blown off with air, the mineral spirits on them was simply added to the machines for dilution of the coolant.

The cost of the large water-based parts cleaner was $900 and the cost of the seven metal parts cleaners, which were second hand, together amounted to $900. The cost of the ultrasonic system for final cleaning was $19,008. Assuming a 10 year life for the equipment and a 4% cost of capital, the annualized equipment cost would amount to $2,185.

The plastic parts cleaner operated for about seven months before it needed to be changed out. Assuming this unit and the other seven parts cleaner require changeout twice per year, the amount of cleaner required is 270 gallons. The company is using a 10% cleaner concentration. Thus, 27 gallons at a cost of $10 per gallon are required for a changeout. The spent cleaner and rinse water from the 30 gallon ultrasonic unit can be used as makeup in the parts cleaner so no additional cleaner needs to be used for this purpose. The total annual cost of the water-based cleaner for use in the parts cleaner is $270.

The 30 gallon ultrasonic cleaning unit uses the same cleaner at a 10% concentration. Assuming it requires changeout more often, every two months, the cost of the cleaning agent for changeout is $180 per year. An additional 10 percent of the cleaning agent is needed as makeup. On this basis, the cost of using the water-based cleaner in the ultrasonic system is $198 annually.

The company also uses a rust inhibitor in the rinse bath of the ultrasonic system. The price of the rust inhibitor is $11 per gallon. A concentration of 3% is required and the bath must be changed out every two months. An additional 10% of the rust inhibitor is required as makeup. The total annual cost of the rust inhibitor is about $66.

The company used compressed air to blow off the excess solvent after cleaning back into the machines. With the conversion to water-based cleaners, no solvent was being added to the machines. The coolant still requires some solvent for dilution and the amount is estimated at one drum every three months. At a price of $148.50 per drum, the total annual cost for the dilution solvent amounts to $594.

The electricity cost is higher with the water-based cleaning units. The shop owner estimates the electricity cost of using the large parts cleaner at $10 per month or $120 per year. He estimates the electricity cost of each of the seven smaller parts cleaners at $5 per month or $420 per year. The ultrasonic system has 1,200 watts of ultrasonic power in

the wash tank. Assuming the system is used one-half hour per day and an electricity cost of 12 cents per kWh, the electricity cost from using the ultrasonics is about $19 per year. The wash and rinse baths are heated and each of the heaters is 2,250 watts. These heaters are left on at night during the week and are turned off on the weekend. They are likely to be cycling on about one-fourth of the time they are operating. Again, assuming an electricity cost of 12 cents per kWh, the cost of running the heaters is $842 annually. The total electricity cost of all the cleaning units is $1,401 annually.

The spent water-based cleaner requires disposal. The company generates about four drums of waste per year. The cost of disposing of this waste is $46.75 per drum. The total annual cost of disposal is $187 per year.

The company estimates that the labor for cleaning with the mineral spirits and water-based parts cleaners is about the same. For the final cleaning area where the five gallon cleaning units were used, workers cleaned for about one hour per day. The ultrasonic cleaning unit is automated and the parts are cleaned in baskets instead of individually. The workers still have to blow off the parts. It is estimated that the ultrasonic cleaning system reduces the labor requirement to 40 percent of that required for the solvent cleaning. At a labor rate of $15 per hour, the labor cost for cleaning with the mineral spirits was $3,900 per year. With the ultrasonic system, the labor cost is $1,560 per year.

The company could use TBAC in place of the mineral spirits and the water-based cleaning systems if the chemical were exempt from VOC regulations. Assuming the same amount of TBAC as mineral spirits would be required, 17 drums of TBAC would be purchased annually. The cost of TBAC when purchased in drum quantities, is $10 per gallon so the cost of purchasing 17 drums would amount to $9,350 each year. The labor cost with TBAC would be the same as the labor cost with mineral spirits.

Table 3-1 shows the cost comparison for mineral spirits, water-based cleaning and TBAC. The figures show that the cost of using the mineral spirits and the water-based cleaners is comparable. Using TBAC would almost double the cost of cleaning.

Table 3-1
Annualized Cost Comparison for Machine Shop for Batch Loaded Cold Cleaning

	Mineral Spirits Cleaning	Water-Based Cleaning	TBAC Cleaning
Annualized Equipment Cost	-	$2,185	-
Cleaner Cost	$2,525	$398	$9,350
Rust Inhibitor Cost	-	$66	-
Oil Dilution Solvent Cost	-	$594	-
Electricity Cost	-	$1,401	-
Labor Cost	$3,900	$1,560	$3,900
Disposal Cost	-	$187	-
Total Cost	$6,425	$6,391	$13,250

Precision Contract Cleaning Company

This company provides precision cleaning services to the aerospace, semiconductor and medical industries. The company relies on an ultrasonic water-based cleaning system for cleaning most parts. Some parts, however, must be cleaned by hand.

IRTA worked with the company to find an alternative to isopropyl alcohol (IPA), a VOC, for routinely hand cleaning one type of part, gauges for Boeing. An MSDS for IPA is shown in Appendix A. IRTA and the company tested several alternatives including a soy based cleaner, a water-based cleaner, acetone and a few blends of acetone and IPA. After the gauges are cleaned, the company uses non-volatile residue (NVR) analysis to determine whether the gauges are clean. The lower the NVR, the cleaner the parts.

During the testing, IPA was used as the control. The findings indicated that the parts had a lower NVR when acetone and acetone/IPA blends were used than they had with the IPA used currently. The soy based cleaner and the water-based cleaner left a residue so the NVR levels were higher.

IRTA performed the cost analysis for acetone because it was the alternative that gave the lowest NVR level. An MSDS for acetone is shown in Appendix B. Although TBAC was not tested, it likely would be effective in cleaning but it is not known what the NVR level would be. Even so, IRTA also performed the cost analysis for TBAC.

The company receives the gauges three or four times a year and each job requires the use of two to three gallons of IPA. Assuming an annual use of IPA of 10 gallons for the cleaning and assuming a cost for electronics grade IPA of $7.27 per gallon, the annual cost of cleaning the gauges with IPA amounts to $73. If acetone were used instead of IPA, the company would require 10 percent more cleaner because acetone has a higher vapor pressure than IPA. The company pays $7 per gallon for electronics grade acetone. On this basis, the annual cost for purchasing acetone for cleaning the gauges is $77. The vapor pressure of TBAC is closer to the vapor pressure of IPA so only 10 gallons of TBAC would be required for the cleaning. IRTA did not have a price for electronics grade TBAC but the electronics grade for solvents is usually slightly more expensive than industrial grade material. Assuming the company purchased TBAC in drum quantities, the solvent cost would be $10 for industrial grade material. To be conservative, this price was used in the analysis. The cost of using TBAC would be $100 per year.

Table 3-2 shows the annual cost comparison for IPA, acetone and TBAC. The cost of using acetone is somewhat higher than the cost of using IPA. The cost of using TBAC is higher than the cost of using either IPA or acetone.

Table 3-2
Annualized Cost Comparison for
Contract Precision Cleaning Company for Handwipe Cleaning

	IPA	Acetone	TBAC
Cleaner Cost	$73	$77	$100
Total Cost	$73	$77	$100

Electric Motor Manufacturer

This company manufactures 100 motors per day. Many of the electric motors are used in food processing equipment. The electric motors are made of cast iron and aluminum. The company paints the motors after they have been assembled. In the past, prior to the coating process, the company used a brush and a cold cleaning system containing mineral spirits to remove dust and finger prints before the coating operation.

IRTA worked with the company to test alternatives for cleaning the parts. The company tested acetone as an alternative to the mineral spirits. It worked successfully and the company converted to the alternative and has been using it for a few years.

The company used about two gallons per day of the mineral spirits for cleaning the electric motors. Assuming the company operates five days a week and fifty-two weeks per year, 520 gallons of solvent would be required each year. The cost of purchasing the mineral spirits is $4 per gallon if it is purchased in drum quantities. On this basis, the annual cost of using mineral spirits is $2,080.

The cost of acetone, if purchased in drum quantities, is $7 per gallon. Assuming the same amount of acetone as mineral spirits would be required, the cost of using acetone is $3,640 annually. Although TBAC was not tested, it would likely be an effective solvent for cleaning the electric motors. The cost of TBAC, if purchased in drum quantities, is $10 per gallon. On this basis and assuming the same amount of TBAC would be required, the annual cost of using TBAC would amount to $5,200.

Table 3-3 shows the cost comparison for mineral spirits and the two alternatives. The cost of using acetone is 75% higher than the cost of using mineral spirits. The cost of using TBAC is 2.5 times as costly as using mineral spirits and 43% higher than the cost of using acetone.

Table 3-3
Annualized Cost Comparison for Electric Motor Manufacturer for Cold Cleaning

	Mineral Spirits	Acetone	TBAC
Cleaner Cost	$2,080	$3,640	$5,200
Total Cost	$2,080	$3,640	$5,200

PRINTED CIRCUIT BOARD DEFLUXING

Much of electronics cleaning is the cleaning of printed circuit boards (PCBs) or printed wiring assembles that are used in numerous aerospace and commercial devices. Flux is applied to the boards to facilitate solder flow and the components are soldered to the boards. The residual flux and other contaminants are then cleaned from the boards before they are shipped or used in assembly.

Flux is a polar material so the solvents used to clean flux always contain some alcohol which is effective in removing polar contaminants. Historically, PCBs were cleaned using 1,1,1-trichloroethane (TCA) and CFC-113 in formulations with alcohol. Production of TCA and CFC-113 was banned because the chemicals contribute to stratospheric ozone depletion. After the production ban went into effect, alternatives had to be adopted.

There are several types of flux that can be used to prepare for the soldering operation. First, some companies use low solids flux (sometimes called no-clean flux) that does not require removal with any cleaning agent. Conversion to low solids flux that does not have to be removed is one alternative method. Second, water soluble fluxes are widely available and are used routinely by many companies. This type of flux can be removed with plain deionized (D.I.) water. Third water-based cleaners called saponifiers can be used to remove traditional rosin based flux. The process involves using a formulated water cleaner and rinsing the boards with D.I. water. In both types of water cleaning, dryers are used to dry the boards after cleaning. A typical water cleaning conveyorized board cleaning system is shown in Figure 3-4.

Figure 3-4. Conveyorized Water Board Cleaning System

When TCA and CFC-113 production was banned, most PCB assemblers adopted water-based cleaning alternatives but some began using solvent alternatives like n-propyl bromide, HCFC-225, HFC43-10 and HFEs which are combined with alcohol and in some cases, with 1,2-trans-dichloroethylene. All of these chemical alternatives are used in vapor degreasers. TBAC is not a viable alternative for these solvents because it has a

flash point and could not be used in an open top vapor degreaser. It could, however, be used in an airless/airtight degreaser. Since such degreasers are very expensive, IRTA did not evaluate TBAC use in equipment for PCB assembly.

During the PCB assembly process, some of the boards fail during the quality control tests and they must be reworked. In some cases, PCBs that have been used in devices in the field fail and they need to be reworked. Other electronic devices like hybrid circuits, relays and various other assemblies have parts that are soldered and they may need to be reworked during manufacture or use. Rework operations are commonly conducted by hand. After soldiering the components to the electronic device, workers either immerse the board in a small batch loaded cold cleaner or use wipe cloths with a small squeeze bottle to remove the flux. When water soluble flux is used, the most effective way to remove the flux is with plain water but some companies use IPA. When rosin flux is used, the common solvent of choice is IPA although some other solvents are also used.

TBAC could be used in the rework process but would probably have to be combined with alcohol to effectively remove polar rosin flux. Because of the flash point, the chemical cannot be used in large quantities in equipment. In rework operations, however, the chemical could be used in small batch loaded cold cleaners and squeeze bottles for hand cleaning.

IRTA analyzed and compared the cost of using a high VOC material, a safer low-VOC alternative and TBAC for two companies that perform rework. The first is a data acquisition equipment manufacturer using water soluble flux and the second is a brake system manufacturer using rosin flux.

Data Acquisition Equipment Manufacturer

This company builds data acquisition equipment and supporting ground data processing stations for airlines and airports. The systems must have very high reliability.

The company subcontracts out the assembly of their PCBs. The company does a small amount of additional assembly on the boards when they arrive in-house. A few of the boards fail quality control and they are reworked and cleaned by hand. In addition, the customer repair department does a large amount of rework. The boards are assembled using a water soluble flux. The company has a water-based cleaning system with D.I. water. This system is used in a few cases for cleaning the flux after rework. In other cases, the company used plain IPA for some of the cleaning and a blend of 50% IPA and 50% D.I. water in an aerosol package for the rest of the cleaning.

IRTA tested a variety of alternatives with the company to replace the IPA which is a VOC and the IPA/D.I. water blend. The alternatives that were tested included plain D.I. water, acetone, a saponifier and different blends of acetone, D.I. water and IPA. All of the cleaners that were tested provided visually clean boards but the worker who was performing the testing did not like the high acetone content cleaners or the saponifier because he believed it left a residue. The remaining three cleaners, a material called

Ionix, plain D.I. water and a blend of 85% D.I./5% IPA/10% acetone, were further tested to determine the ionic contamination left on the boards after cleaning. All three cleaners resulted in low ionic contamination levels. The company decided to adopt the blend of D.I. water, acetone and IPA.

The company used about 12 gallons per year of IPA for rework. At a cost for electronics grade IPA of $12.25 per gallon, the annual IPA cost amounted to $147. The company also used 18 aerosol cans per year of the 50% IPA/50% D.I. water blend. At a cost of $8 per can, the cost of this cleaning agent was $144 per year. The total cost of cleaning with these materials was $291 annually.

For the alternative, it was assumed that usage would be the same, 12 gallons plus 96 ounces or 12.75 gallons. According to the company, for the new blend, the cost of acetone would be $25 per gallon and the cost of IPA would be $15 per gallon. On this basis, the total annual cost for purchasing the alternative blend is $41.

TBAC could be used in place of the new blend. IRTA did not have a price for electronics grade TBAC but it is more expensive than industrial grade chemicals. Because so little cleaner is used by the company and to be conservative, IRTA used the price of $20 per gallon assuming the company would purchase the cleaner in five gallon containers. The TBAC would likely have to be combined with alcohol to clean effectively. Assuming the blend would be composed of 95% TBAC/5% IPA and using the price of $15 per gallon for IPA, the annual cost of using the TBAC blend would be $252.

Table 3-4 shows the cost comparison for the cleaning methods. The cost of using the TBAC blend is lower than the cost of using the original cleaner but is more than six times higher than the cost of the current cleaning method.

Table 3-4
Annualized Cost Comparison for
Data Acquisition System Manufacturer for Flux Cleaning

	IPA and Aerosol	Acetone/IPA/ D.I. Water Blend	TBAC/IPA Blend
Cleaner Cost	$291	$41	$252
Total Cost	$291	$41	$252

Braking System Manufacturer

This company is an aerospace subcontractor that manufactures braking systems, pumps and airlocking devices. The company also does repair work on the pumps used in military and commercial aircraft like the C-130 transport and the C-17.

As part of the operations, the company assembles PCBs. In some cases, the boards do not pass quality control and they need to be reworked. The rework process is done by hand and IPA is used to clean the flux from the boards after the components have been

soldered to them. The company uses a rosin based flux because of existing aerospace contracts that require it.

IRTA and the company worked on two alternatives for the rework operation. It takes place in the same room as the main assembly operations. For assembly, the boards are cleaned in a high pressure spray system with a water-based saponifier. One option is to clean the boards that have been reworked in this machine. The machine cycle is about 20 minutes long and the workers that clean with IPA do the cleaning in a few minutes. Although cleaning with the water-based cleaning system is an option, the costs were not analyzed.

The second alternative that was investigated was using blends of IPA and acetone for the rework hand cleaning. The company tested a blend of 92% acetone/8% IPA. The workers used this blend for a period of time and it seemed to work well for removing the flux.

The company currently uses 55 gallons per month of IPA for the rework operation. The price of the IPA is $5.01 per gallon so the annual cost of using the IPA is $3,307. If the company converted to the acetone/IPA blend, the cost of using this cleaner would be $2,845 per year, based on a price for the blend of $4.31 per gallon. If TBAC were used, it would likely be combined with IPA to clean effectively. Assuming the blend would be 92% TBAC/8% IPA, the same amount of cleaner would be required, and a price of $10 per gallon for drum quantities of TBAC, the annual cost of using the TBAC blend would amount to $6,336.

Table 3-5 shows the cost comparison for the different cleaners. The cost of using the acetone/IPA blend is 29% lower than the cost of using IPA. The cost of using TBAC is more than twice the cost of using the acetone/IPA blend.

Table 3-5
Annualized Cost Comparison for Braking System Manufacturer for Flux Cleaning

	IPA	Acetone/IPA Blend	TBAC/IPA Blend
Cleaner Cost	$3,307	$2,845	$6,336
Total Cost	$3,307	$2,845	$6,336

COATING APPLICATION EQUIPMENT CLEANING

Many companies that have coating operations use spray guns to apply the coatings. An electric spray gun is shown in Figure 3-5. The spray gun has a cup where the coating is poured and it is delivered to the part in a high volume low pressure spray. In most cases, the coating operation is performed in a spray booth. A typical spray booth in a wood furniture manufacturing operation is shown in Figure 3-6. The booths contain filters that capture the particulates generated in the painting operation.

Figure 3-5. Electric Spray Gun


Figure 3-6. Typical Spray Booth at Wood Coating Operation

Some smaller industrial operations and many contractors use brushes or rollers to apply the coatings. Consumers applying coatings at home also generally use brushes or rollers but might also use spray guns. Most brush and roller operations do not have spray booths. A typical brush used to apply coatings is shown in Figure 3-7 and a roller is shown in Figure 3-8.

Figure 3-7. Typical Brush

Figure 3-8 Typical Roller

Cleanup solvents are used after the painting operation to clean the application equipment. Some companies have spray gun cleaning systems that are used to clean spray guns. A typical spray gun cleaner is shown in Figure 3-9. The reservoir of the cleaning system holds about five gallons of cleanup solvent and companies purchase the solvent from home improvement stores or suppliers. The spray gun is placed in the system and the top of the system is closed. The inside and outside of the spray gun are cleaned with the solvent which is pumped from the reservoir. The used solvent runs back into the reservoir for reuse. Some companies with spray gun cleaning systems change out the solvent themselves when it is too contaminated for further use. The spent solvent is shipped off-site as hazardous waste. Other companies contract with a service provider who changes out the unit periodically and disposes of the spent cleaner as hazardous waste.

Figure 3-9. Typical Spray Gun Cleaning System

Some companies that use spray guns use a bucket or other small container to clean the spray gun after the coating operation. Solvent is used to clean the cup of the gun and the outside of the gun, particularly the tip. Solvent is put into the cup and the gun is sprayed into the bucket to clean the inside of the gun. Companies, contractors and consumers who use brushes and rollers generally clean them in a container with cleanup solvent.

Solvents used currently for cleanup of application equipment include lacquer thinner, paint thinner, mineral spirits, toluene, xylene, hexane, methyl ethyl ketone (MEK) and

methyl isobutyl ketone (MIBK). All of these solvents are VOCs and many of them are also toxic. The most commonly used solvents for cleanup are lacquer thinner and paint thinner.

Lacquer thinner is a term used for a blend of different solvents of various types. Three MSDSs or product sheets for lacquer thinner products are shown in Appendix A. The first product, offered by AWC, is a blend of toluene, MEK and MIBK. The second product, DTL10 Lacquer Thinner, is composed of acetone, toluene, glycol ether acetates, isopropyl alcohol and petroleum distillates. The third product, Parks Lacquer Thinner, contains methanol, MEK, toluene and various other ingredients.

Paint thinner is a term used for petroleum based solvents. Three MSDSs for paint thinner are shown in Appendix A. The first product, Dunn-Edwards Paint Thinner (Bortz), is petroleum distillates. The second product, E-Z Paint Thinner, is Stoddard Solvent which contains trace quantities of 1,2,4-trimethylbenzene. The third product, Allpro Paint Thinner (Metal) is mineral spirits which also contains trace quantities of 1,2,4-trimethylbenzene.

Lacquer thinner and paint thinner are widely used by consumers and companies for cleaning up their coating application equipment. They are sold in one or five gallon containers at hardware, home improvement and paint supply stores. They are also sold in one gallon, five gallon and drum quantities by chemical suppliers.

Four case studies for companies that clean or cleaned their application equipment with high VOC solvents are presented below. These include a furniture stripper and refinisher, an architectural contractor, a safe manufacturer and an autobody shop.

Wood Company

This company strips and refinishes wood furniture, doors and other items. The company also performs contracting services for homes and offices to strip and refinish cabinetry on-site.

About three years ago, the company converted from lacquer thinner to acetone for cleanup of the spray guns used to apply coating in the facility and the spray guns and brushes used to apply coating at home and office sites. The owner of the facility purchased the lacquer thinner and now purchases the acetone from a paint supply store. He estimates that he uses roughly the same amount of acetone for cleanup as lacquer thinner, 52 gallons per year. The cost of the lacquer thinner is $54 per five gallon container; on this basis, the annual cost of using the lacquer thinner was $562 per year. The cost of the acetone is also about $54 gallons per five gallon container so the cost of using acetone for cleanup also is $562 per year.

The company could substitute TBAC for acetone in the cleanup operation. A supplier estimates the cost of TBAC in five gallon quantities at $20 per gallon or $100 per five

gallon container. Assuming that 52 gallons of TBAC would be required for cleanup each year, the annual cost of purchasing the TBAC for cleanup would amount to $1,040.

Table 3-6 shows the cost comparison for using the high VOC lacquer thinner, acetone and TBAC. The cost of using TBAC would be about twice the cost of using the lacquer thinner or acetone.

Table 3-6
Annualized Cost Comparison for Wood Company for Cleanup Materials

	Lacquer Thinner	Acetone	TBAC
Cleanup Solvent Cost	$562	$562	$1,040
Total Cost	$562	$562	$1,040

Architectural Contractor

This company performs work on commercial buildings. The operation involves coating steel beams and rails used in the construction of the buildings. The contractor uses a solventborne red oxide primer for coating the metal beams and rails. An MSDS for this coating, Shopkote Metal Primer, is shown in Appendix A. Figure 3-10 shows a picture of steel beams after coating with the primer.


Figure 3-10. Steel Beams Coated by Architectural Contractor

The contractor applies the coating to steel beams with a roller and uses a spray gun for applying the primer to the rails. The company currently uses paint thinner purchased from a home improvement store to clean the rollers and spray guns.

The contractor purchases 90 gallons per year of paint thinner for cleanup of the spray guns and rollers. IRTA tested plain acetone as an alternative cleanup material with the company. According to the painter, the acetone worked a little better than the paint thinner for the cleaning operation. TBAC could also be used in place of paint thinner for the cleanup operations.

The cost of the paint thinner at a home improvement store is $6.38 per gallon. The annual cost of using the thinner for cleanup is $574. The cost of acetone at a home improvement store is currently $13.97 per gallon. Assuming the same amount of acetone as paint thinner would be required, the annual cost of using acetone for cleanup would amount to $1,257. A supplier estimates the price of TBAC purchased in one gallon quantities at $25 per gallon. On this basis, assuming the same amount of TBAC as paint thinner and acetone would be required, the annual cost of using TBAC would be $2,250.

Table 3-7 shows the annual cost comparison for the three cleanup solvents. The cost of using acetone is more than twice as high as the cost of using the high VOC paint thinner. The cost of using TBAC is much higher than the cost of using either the paint thinner or acetone.

Table 3-7
Annualized Cost Comparison for Architectural Contractor for Cleanup Materials

	Paint Thinner	Acetone	TBAC
Cleanup Solvent Cost	$574	$1,257	$2,250
Total Cost	$574	$1,257	$2,250

Safe Manufacturer

This company manufactures burglary, fire protection and gun safes and is the largest security safe manufacturer in the country. As part of the manufacturing process, the company paints the safes. MSDSs for certain of the coatings used by the company are shown in Appendix A. These include a gray primer, an activator for the urethane topcoat, a black urethane topcoat and a burgundy urethane topcoat.

Several years ago, the company used lacquer thinner in a spray gun cleaning system for cleaning the spray guns that are used to apply the coatings. The company wanted to reduce their overall VOC emissions and they tested acetone. This chemical worked well and the facility converted to the alternative. IRTA analyzed the costs of using lacquer thinner, acetone and TBAC.

The company purchased 10 gallons of lacquer thinner per day for cleaning the spray guns. Assuming the company operates five days per week and 52 weeks per year, the total annual purchases of the solvent amounted to 2,600 gallons. The cost of lacquer thinner, purchased in five gallon containers from a paint supplier, is $54 or $10.80 per gallon. The cost of using the lacquer thinner was $28,080 per year.

When the company converted to acetone the same amount was used. The cost of purchasing acetone in five gallon containers is the same as the cost of purchasing lacquer thinner. The annual cost of using acetone is $28,080.

The cost of TBAC purchased in five gallon containers is $20 per gallon. On this basis, and assuming the same amount of TBAC would be used, the annual cost of using TBAC would amount to $52,000.

Table 3-8 shows the annual cost comparison for using lacquer thinner, acetone and TBAC. The cost of using TBAC is almost twice the cost of using acetone.

Table 3-8
Annualized Cost Comparison for Safe Manufacturer for Cleanup Materials

	Lacquer Thinner	Acetone	TBAC
Cleanup Material Cost	$28,080	$28,080	$52,000
Total Cost	$28,080	$28,080	$52,000

Autobody Shop

This company owns a spray gun cleaning system that is used routinely to clean the application equipment. A picture of the spray gun cleaner is shown in Figure 3-11. The company originally used lacquer thinner in the cleaning unit.

Figure 3-11. Spray Gun Cleaning System at Autobody Shop

IRTA tested acetone as an alternative to the lacquer thinner. IRTA provided five gallons of acetone to the company and the workers indicated it performed very well. IRTA compared the cost of using lacquer thinner and acetone. The company could also use TBAC and IRTA also included the cost comparison for that chemical.

The company used about five gallons of lacquer thinner, purchased from a home improvement store, every quarter. Assuming the price of lacquer thinner is $13.47 per gallon, the annual cost of purchasing lacquer thinner amounts to $269. The company converted to acetone after the testing. Assuming the same amount of acetone would be required and the price of acetone is $13.97 per gallon at a home improvement store, the

annual cost of using acetone is $279. The price of TBAC, if purchased in one gallon quantities, is estimated by a supplier at $25 per gallon. Assuming the same amount of TBAC as acetone would be required, the annual cost of using TBAC would be $500.

Table 3-9 shows the cost comparison for using lacquer thinner, acetone and TBAC. The values indicate that the cost of using TBAC is much higher than the cost of using acetone.

Table 3-9
Annualized Cost Comparison for Autobody Shop for Cleanup Materials

	Lacquer Thinner	Acetone	TBAC
Cleanup Material Cost	$269	$279	$500
Total Cost	$269	$279	$500

THINNERS FOR COATINGS

As discussed above under cleanup materials for coating application equipment, many companies apply coatings as part of the production process. A number of companies use powder coatings or waterborne coatings. For example, most metal product manufacturers use powder coatings and architectural contractors use latex coatings which are waterborne coatings for the majority of their applications. No thinners are used for powder coating and plain water is used to thin waterborne coatings. Some metal product manufacturers use solventborne coatings and contractors often use solventborne coatings for painting metal trim. Virtually all companies that use solventborne coatings for all or part of their operations thin the coatings.

The same solvents or blends of solvents that were described earlier under cleanup solvents are used to thin solventborne coatings. The weather can affect the consistency of the coating. Thinners are generally used to thin the coating so it can be applied properly. Only operations where spray guns are used would require thinner. Some thinners, which are also called reducers or retarders, are classified as slow, medium or fast. Depending on the conditions, painters and consumers dilute the paint with thinner which can range in concentration in the blend from about 10% to 50% depending on the application.

IRTA conducted a project that involved developing and testing low-VOC safer alternatives for the currently used thinners. The alternatives that were most effective in some of the applications are discussed below. In all case studies which include a wood stripper and refinisher, a contractor, a safe manufacturer and an autobody shop, IRTA compares the cost of using the high VOC solvents, the safer alternatives and TBAC.

Wood Company

This company strips and refinishes wood furniture, doors and other items. The company also performs contracting services for homes and offices to strip and refinish cabinetry on-site.

The company uses a variety of different coatings and an MSDS for the coating used for the thinning tests, Valspar Black NAA1252, is shown in Appendix A. The company generally applies four coats of the lacquer. The lacquer was thinned with lacquer thinner (called a retarder by the facility) in a 75% lacquer/25% lacquer thinner blend.

The company and IRTA tested plain acetone as an alternative thinner. The acetone was used in the same proportions as the routinely used thinner. Four coatings of lacquer thinned with lacquer thinner were applied to four oak panels and four coatings of lacquer thinned with acetone were applied to four oak panels. A picture of the panels is shown in Figure 3-12.

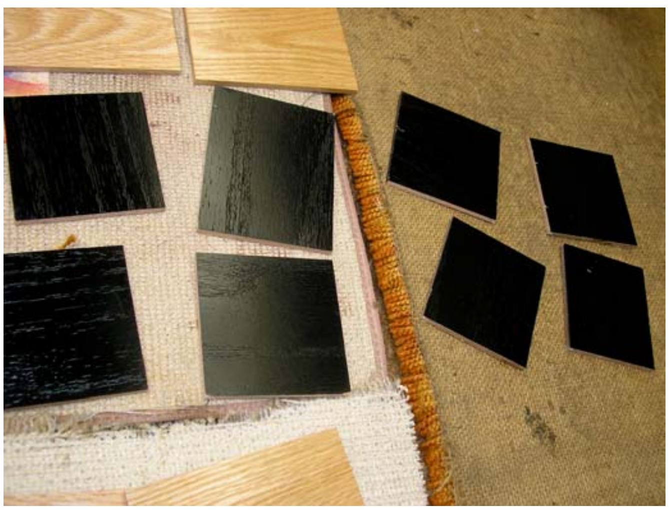

Figure 3-12. Panels Coated at Wood Company

The owner visually inspected the panels after the coatings had dried and found no difference between the panels thinned with lacquer thinner and the panels thinned with acetone. He also indicated that the drying time for the eight panels was the same. Because of the successful tests, the company decided to convert to acetone and has been using it exclusively for over a year.

The company used 130 gallons of lacquer thinner per year as a thinner. The company now uses the same amount of acetone thinner. The company could use TBAC in place of acetone as a thinner as well. The cost of the acetone and lacquer thinner are the same, $54 per five gallon container. On this basis, the cost of using both of the thinners is $1,404 per year. The cost of TBAC in a five gallon container is $20 per gallon. Assuming the same amount of TBAC would be required, the annual cost of using TBAC as a thinner would be $2,600.

Table 3-10 shows the cost comparison for the three different thinners. The cost of using TBAC as a thinner is 85% higher than the cost of using lacquer thinner or acetone.

Table 3-10
Annualized Cost Comparison for Wood Company for Thinners

	Lacquer Thinner	Acetone	TBAC
Thinner Cost	$1,404	$1,404	$2,600
Total Cost	$1,404	$1,404	$2,600

Architectural Contractor

This contractor is the same contractor discussed above under coating application equipment cleaning. The company coats steel beams and rails used in construction of commercial buildings. An MSDS for the primer that requires thinning, Shopkote Metal Primer, is shown in Appendix A. The red oxide primer is currently thinned with paint thinner.

IRTA tested two alternative thinners with the company. The first alternative was acetone and the second alternative was a blend of 99% acetone/1% soy. An MSDS for Soy Gold 2500, the component of the thinner, is shown in Appendix B.

The owner inspected the coatings and indicated that the coatings thinned with the alternatives had a good appearance. He did indicate, however, that the coating thinned with acetone/soy did not dry as quickly as the coatings thinned with paint thinner and acetone. This would not necessarily be a disadvantage since the beams and rails are shipped the following day and the drying time currently is about 30 minutes. The acetone thinned coating dried quickly.

The company uses 90 gallons of paint thinner for thinning the coatings per year purchased from a home improvement store. The cost of the paint thinner is $6.83 per gallon. The annual cost of using the thinner is $574. The cost of acetone from a home improvement store is $13.97 per gallon. Assuming the same amount of acetone would be required, the annual cost of using acetone as a thinner would be $1,257. TBAC is not currently sold in one gallon quantities in home improvement stores. One chemical supplier estimates the price of one gallon quantities at $25 per gallon. On this basis and assuming the same amount of TBAC would be used, the annual cost of using TBAC as a thinner would amount to $2,250.

Table 3-11 shows the annual cost comparison of the three different thinners. The cost of using acetone is more than double the cost of using paint thinner. The cost of using TBAC is almost four times the cost of using paint thinner and is 80% higher than the cost of using acetone.

Table 3-11
Annualized Cost Comparison for Architectural Contractor for Thinners

	Paint Thinner	Acetone	TBAC
Thinner Cost	$574	$1,257	$2,250
Total Cost	$574	$1,257	$2,250

Safe Manufacturer

IRTA tested alternative thinners with the same safe manufacture discussed above under cleanup of coating application equipment. MSDSs for the activator for the urethane topcoat and two urethane topcoats are shown in Appendix A. The company currently used three different types of thinners (called reducers) for the topcoats. These include slow, medium and fast reducers which are selected by the painter based on the weather. MSDSs for the three reducers are provided in Appendix A. The company generally blends about 15% of the reducer with the topcoat.

IRTA conducted two sets of tests with the company. The first set of tests gave results that were used to design the second set of tests. In the second set of tests, four panels were prepared by coating with the primer. Then the topcoat was applied to the four panels and was thinned with four different thinners. They included:

- the company's current thinner (slow reducer);
- plain acetone;
- 99% acetone/1% soy; and
- 99% acetone/2% soy.

A picture of the four panels with the burgundy topcoat are shown in Figure 3-13. The first two panels dried in a reasonable period of time and the third and fourth panels took longer to dry. All of the panels had a good appearance.

IRTA conducted the cost analysis for the current thinner, the acetone thinner and the 99% acetone/1% soy thinner. IRTA also included a cost analysis for TBAC used as a thinner. The company purchases about 140 gallons of slow, medium and fast reducer each year. The total cost of the thinners is $1,598 annually. IRTA obtained an estimated from a supplier who indicated he would supply five gallon containers of acetone at $42 per five gallons. The cost of purchasing acetone, assuming the same amount is used, would be $1,176 per year. The same supplier would provide five gallon containers of the soy/acetone blend for $45 for a five gallon container. The annual cost of using the blend would be $1,260 annually. The supplier indicated he would provide a five gallon container of TBAC for $100. On this basis and assuming the same amount would be required, the annual cost of using TBAC would be $2,800.

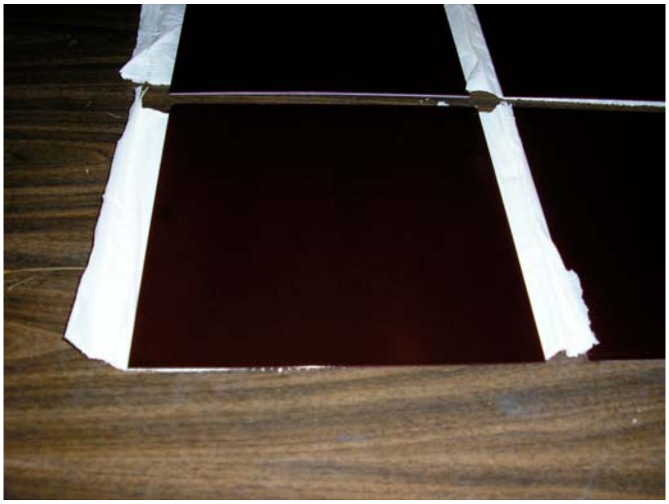

Figure 3-13. Burgundy Panels Coated at Safe Manufacturer

Table 3-12 shows the cost comparison for the four thinners. The cost of using acetone is 26% lower than the cost of using the current thinner. The cost of using the acetone/soy blend is 21% lower than the cost of using the current thinner. The cost of using TBAC is 75% higher than the cost of using the current thinner and 2.4 times the cost of using plain acetone.

Table 3-12
Annualized Cost Comparison for Safe Manufacturer for Thinners

	Current Thinner	Acetone	Acetone/ Soy Blend	TBAC
Thinner Cost	$1,598	$1,176	$1,260	$2,800
Total Cost	$1,598	$1,176	$1,260	$2,800

Autobody Shop

IRTA worked with a small autobody shop to test alternative thinners. The shop purchases solvent for thinning from a paint supply company. IRTA tested three alternative thinners with the company. These were plain acetone, a blend of 99% acetone/1% soy and a blend of 97.5% glycol ether/2.5% acetone. An MSDS for the glycol ether, called DPM, is shown in Appendix B. The company routinely uses a combination of 50% coating and 50% thinner for the base or color coat. IRTA used the same proportions in the alternatives testing.

The painter applied primer to a scrap part to prepare for the testing. The base coat and the current thinner were mixed and applied to the part. The three alternative thinners were mixed with the base coat and applied to the part. The plain acetone thinner did not give a very good finish but the two other thinners gave a good finish, according to the painter. A clear topcoat was applied over all of the color coats. All of the coatings, including the coating thinned with acetone, gave a good finish after the clear topcoat was applied.

IRTA analyzed the cost of using the high VOC thinner used today and the soy/acetone, the soy/glycol ether and TBAC thinners. The shop uses 54 gallons per year of the thinner for thinning coatings. The cost of the thinner is $8.17 per gallon. On this basis, the cost of using the current thinner is $441 annually, According to one supplier, the cost of purchasing the acetone/soy blend or the acetone/glycol ether blend in a five gallon container would amount to $45. The cost of using either blend would be $486 annually. If TBAC were used as a thinner, the same supplier would provide a five gallon container for $100. The cost of using TBAC as a thinner would be $1,080 per year.

Table 3-13 shows the cost comparison for the four thinners. The cost of using the two alternative acetone based thinners is 10% higher than the cost of using the current thinner. The cost of using TBAC as a thinner is more than twice the cost of using the other three thinners.

Table 3-13
Annualized Cost Comparison for Autobody Shop for Thinners

	Current Thinner	Acetone/Soy Blend	Acetone/Glycol Ether Blend	TBAC
Thinner Cost	$441	$486	$486	$1,080
Total Cost	$441	$486	$486	$1,080

AUTOMOTIVE AEROSOL CLEANING

Many different types of solvents are used in automotive aerosol products. In California, CARB regulates these products and the VOC limit for the cleaners currently is 45%. CARB recently passed a regulation that will reduce the allowed VOC content to 20% in 2008 and 10% in 2010. The regulation was based on work IRTA had performed for CARB and the Hazard Evaluation System & Information Service (HESIS) on alternative low-VOC, low toxicity aerosol cleaners. IRTA also recently completed a project, sponsored by Cal/EPA's Department of Toxic Substances Control (DTSC), that focused on both aerosol and non-aerosol alternatives.

Technicians in auto repair facilities use automotive aerosol products for brake cleaning, general purpose degreasing and carburetor and fuel injection system cleaning. Car washes and detailers use automotive aerosol cleaners for engine degreasing. Most of the automotive aerosol cleaning products used in California currently have a VOC content of 45%. In Southern California, some of the dealerships are using automotive aerosol products that have 2.5% VOC content so they are very low VOC materials. A SCAQMD regulation restricts usage of the higher VOC products.

Older vehicles manufactured in the 1980s and before have drum brakes on both the front and the back. Before about 1995, vehicles were manufactured with disc brakes on the front and drum brakes on the back. In the last 10 years, vehicles have been manufactured with disc brakes on both the front and the back. Figure 3-14 shows a picture of a vehicle

with the tire removed and the drum brakes exposed. Drum brakes are cleaned when the technician repairs or replaces parts like brake pads or brake cylinders. The major contaminant removed is dust. When technicians inspect or adjust brakes, they often do not clean them. Disc brakes include a caliper, which is the brake mechanism, and a rotor, which is the steel disc. Technicians clean the caliper when a repair is necessary. Contaminants can include dust and, if there is a leaky seal, brake fluid. The rotor is always cleaned. Some technicians remove the rotor and clean it with soap and water in a sink. If the rotor needs to be machined, the technician cleans the particulate contaminants before reinstalling it. Other technicians use a brake cleaner to remove dust, oil or fingerprints.

Figure 3-14. Vehicle with Drum Brakes.

General purpose degreasing is performed when a part needs to be replaced or repaired. Technicians often spray the part with an aerosol cleaner to remove any dirt, grease or oil so they can examine the part and replace or repair it as necessary. Figure 3-15 shows a technician performing general purpose degreasing.

Figure 3-15. Technician Performing General Purpose Degreasing.

Many auto repair facilities purchase an aerosol carburetor cleaner which they consider to be fast evaporating. Most new automobiles sold today have fuel injection systems rather than carburetors. Some older cars on the road still have carburetors. Most of the carburetor cleaner used today is used for cleaning throttle body valves.

Many consumers use the services of car washes and detailers to degreaser their engines. Most of these companies do not use aerosol products. Rather they use bulk water-based cleaners to clean the engine, which is then rinsed with plain water. Automotive supply stores, however, do sell solvent based engine aerosol degreasers and consumers purchase them to degrease their engines themselves.

Alternatives for Automotive Aerosol Cleaning

As mentioned above, some Southern California dealerships are using low-VOC aerosol automotive cleaners. These are generally based on acetone. IRTA obtained water-based cleaners from vendors and these were packaged in aerosol cans. IRTA also developed and tested low-VOC, low toxicity solvent aerosol automotive cleaners. Several water-based aerosol cleaners were demonstrated to perform well for engine degreasing. Another cleaner that performed well is a water-based cleaner for brake cleaning and general purpose degreasing. IRTA developed two acetone based cleaners that performed well for brake cleaning and general purpose degreasing. Finally, IRTA developed a carburetor cleaner based on acetone and soy that was an effective cleaner.

One facility IRTA worked with decided to stop using aerosol cleaners altogether. The shop decided to use a water-based cleaner in spray bottles instead of aerosol products. This alternative has been used for over a year.

In Southern California, many auto repair shops use water and/or water-based cleaners in small brake cleaning equipment. Pictures of one type of brake cleaning system is shown in Figure 3-16. In general, these systems are on wheels so they can be moved easily under a car to do a brake job. They have a small reservoir containing the water-based cleaner. The cleaner is pumped to a sink area with a brush which is used to wet down the dust and clean the brakes. The water cleaning systems are considered an alternative to solvent aerosol brake cleaning.

Suppliers have developed a different type of delivery system called a cannister. An example of a cannister system tested by IRTA is shown in Figure 3-17. The cannister system uses a carbon dioxide propellant and in Southern California, the regulations restrict the VOC content in these devices to 25 grams per liter or about 2.5% VOC. The cleaning agent in the cannister systems is virtually 100% acetone although a small amount of other VOC solvents could be blended with the acetone. Some auto repair facilities have adopted this cannister system as an alternative to aerosol cleaners.

Figure 3-16. Brake Cleaning System

Figure 3-17. Cannister System Tested at Dealerships.

These alternatives are summarized in Table 3-14. Both aerosol and non-aerosol cleaning methods are included.

Table 3-14
Alternative Low-VOC, Low Toxicity Cleaning Methods

Method	Description	Approximate VOC Content
Engine Degreasing	Water-Based Aerosols	10%
	Bulk Water-Based Cleaners	<25 g/L
Brake Cleaner/General Purpose Degreaser	Water-Based Aerosol	10%
Brake Cleaner /General Purpose Degreaser	Mineral Spirits/Acetone Aerosol	10%
Brake Cleaner/General Purpose Degreaser	Glycol Ether/Acetone	2.5%
Carburetor/Fuel Injection System Cleaner	Soy/Acetone Aerosol	0.6%
Spray Bottles	Water-Based Cleaner--Non-Aerosol	<25 g/L
Brake Cleaning Systems	Water-Based Cleaners--Non-Aerosol	<25 g/L
Cannister Systems	Acetone and Acetone Blends--Non-Aerosol	<25 g/L

Note: g/L is grams per liter.

<u>Cost Comparison of Cannister Systems</u>

IRTA analyzed the cost of using the cannister system in place of high VOC aerosol cleaners for two different types of facilities. The analysis also includes a comparison of the cost of using TBAC in the cannister systems. The first facility type is a large dealership and the second is a smaller general automotive repair shop.

The dealership uses 65 cases or 780 cans of aerosol cleaners per month. The cost of the aerosol cans is $1.80 each. On this basis, the annual cost of using the aerosol cleaners is $16,848. Assuming each can contains one pound of product, the dealership uses 9,360 pounds of cleaner per year.

The alternative cannister system holds 20 pounds of cleaner and is propelled by carbon dioxide. The dealership converted to the cannister systems several months ago. They used 39 of the systems throughout the facility in a six week period. The supplier changes out the tanks after six weeks and the cost of the servicing is $27 per unit. The annual cost of using the cannister systems amounts to $9,126. The amount of cleaner used by the dealership with the cannisters is 6,760 pounds per year. This is 28% lower than the amount of cleaner used with the aerosol cans.

A small general auto repair facility uses one case per week of brake cleaner and pays $1.75 per can. The annual cost of using the brake cleaner is $1,092. The facility also uses one case of carburetor cleaner every two weeks at a cost of $1.80 per can. The

annual cost of using the carburetor cleaner is $562. The total cost to the small facility of using the aerosol cans is $1,654 annually. The amount of cleaner used by the shop each year is 936 pounds assuming that each can contains a pound of product.

Even though the dealership uses 28% less cleaner with the cannister system, to be conservative, it was assumed that the small shop uses the same amount of product in the cannister system as in the aerosol cans. Since the cannister systems contain 20 pounds of product, the shop would need about 46.8 cannisters per year. At a cost of $27 per unit, the annual cost amounts to $1,264.

TBAC could be used in the cannister system in place of acetone. The cost of TBAC if purchased in drum quantities is $10 per gallon. The cost of acetone purchased in drum quantities is lower, at $7 per gallon. There is no way of knowing how much of the $27 per cannister changeout is a function of the raw materials cost of the solvent and how much is attributable to the labor expended during the changeout. The raw materials cost is unlikely to account for more than 25% of the total cost. Under this assumption, the changeout cost per cannister for acetone is $27 and the changeout cost per cannister for TBAC would be about $3 higher, at $30. The cost of using TBAC cannister systems for the large dealership would be $10,140 annually. The cost of using TBAC cannister systems for the small general automotive shop would be $1,404 annually.

Table 3-15 summarizes the cost comparison for the high VOC aerosol cleaners, the acetone cannisters and the TBAC cannisters. The cost of using the cannisters with TBAC is lower than the cost of using the high VOC aerosol cleaners but is higher than using acetone cannisters.

Table 3-15
Annualized Cost Comparison for Aerosol Cleaners and Cannister Systems

System Type	Dealership	General Auto Repair Shop
High VOC Aerosol Cleaners	$16,848	$1,654
Acetone Cannisters	$9,126	$1,264
TBAC Cannisters	$10,140	$1,404

Cost Comparison of High VOC and Alternative Aerosol Cleaners

Some of the auto repair facilities IRTA worked with on other projects used a 45% VOC product offered by Granitize. According to the MSDS, which is shown in Appendix A, this cleaner contains acetone, toluene and methanol. Some of the dealerships IRTA worked with were using a commercial very low-VOC aerosol cleaner offered by Granitize that contains acetone and a small amount of heptane. An MSDS for this low-VOC product is shown in Appendix B. IRTA tested various other low-VOC products that are not yet commercial. These included an acetone/mineral spirits blend, an acetone/glycol ether blend, an acetone/soy blend and a water-based cleaner as shown in Table 3-14.

Because some of the products were not commercial, they do not have a price. IRTA performed a cost analysis based on comparison of the raw materials costs of the alternative cleaners to the raw materials costs of the commercial cleaners based on bulk chemical purchases. Table 3-16 shows the raw materials costs which were obtained from a chemical supplier and cost estimates from an earlier project. The raw materials cost of TBAC is also included in the table. It is based on a supplier's estimate of a price of $8.57 per gallon for bulk chemical purchases and a density for TBAC of 7.2 pounds per gallon. The TBAC cleaner has the highest raw materials cost of the cleaners in the table.

Table 3-16
Raw Materials Cost for Aerosol Cleaners

Product	Description	Raw Materials Cost (cents per pound)
Granitize High VOC	Acetone/Toluene/Methanol	55
Granitize Low-VOC	Acetone/Heptane	52
Alternative Brake Cleaner #1	Acetone/Mineral Spirits	52
Alternative Brake Cleaner #2	Acetone/Glycol Ether	52
Kyzen Degreaser 11	Water-Based Cleaner	54
Alternative Carburetor Cleaner	Acetone/Soy	61
Brake/Carburetor Cleaner	TBAC	62

IRTA obtained the costs of packaging aerosol cans from packagers. If the products were commercialized, they would likely be packaged in very large quantities. The cost of packaging 100,000 16 ounce cans including the propellant amounts to 79 cents per can. The price for the Granitize products that are already commercial is $1.80 per can. The markup by the manufacturer for the high VOC product is 46 cents or about 26% of the total product price and the markup for the low-VOC product is 49 cents or about 27% of the product price. The markup for the two low-VOC alternative products, Brake Cleaner #1 and Brake Cleaner #2, is the same as the markup of the low-VOC Granitize product. The markup for the water-based cleaner, Kyzen Degreaser 11, is about the same as the markup for the High VOC Granitize product. This analysis demonstrates that the two alternative brake cleaners and the water-based cleaner could be priced the same as the Granitize products and the profit would be acceptable to the manufacturer.

Some of the auto repair shops that participated in IRTA's projects purchase a Granitize product that is a carburetor cleaner. The price the facilities pay for this product is $2 per can. The raw materials price of the soy/acetone blend, which is used for carburetor cleaning, is 61 cents per pound. This is 7 cents per pound higher than the Granitize high VOC brake cleaning blend and 9 cents higher than the Granitize low-VOC brake cleaner. The supplier of the alternative soy/acetone cleaner could make a profit of 60 cents per can if the cans were priced at $2 per can or about 30% of the total product price.

The TBAC cleaner has a raw materials cost of 62 cents per pound. If the product were priced at $2 per can, the profit would be 59 cents or about 30% of the total product price.

The TBAC could be priced lower, at $1.93 per can, if the supplier wanted to make a 27% profit. The TBAC could be used for brake and carburetor cleaning and the price would be higher than the price of other brake cleaners based on acetone but roughly the same in price as high VOC carburetor cleaners.

Cost of Water-Based Brake Cleaning Equipment

One of the dealerships that participated in the project has 50 technicians that represent 10 teams of five technicians each. The facility uses a total of 65 cases per month or 780 cases per year of aerosol cleaners. Two-thirds of the aerosol cleaners or 520 cases per year are used for brake cleaning. The cost of the aerosol brake cleaner is $1.80 per can. On this basis, the cost of purchasing brake cleaner aerosols is $11,232 annually. This is the cost of using any of the acetone based brake cleaning aerosols discussed above.

If the company purchased TBAC brake cleaning aerosols, the price of the cans would be $1.93 based on the analysis above. If the shop required 520 cases per year, the annual cost of using the TBAC aerosols for brake cleaning would amount to $12,043.

For the analysis, it was assumed that each team would require one water-based brake cleaning system so the dealership would have to purchase 10 units. The capital cost of the units is $10,000. Assuming a cost of capital of four percent and a 10 year useful life for the equipment, the annualized cost of the 10 units is $1,050. Each of the brake cleaning systems holds eight to ten gallons of cleaner. They are used with about one gallon of cleaner concentrate and the remainder is water. A company services the units which involves cleaning them out and refilling them with cleaner concentrate and water and disposing of the spent cleaner as hazardous waste. Most dealerships require the servicing on an eight to 12 week schedule and the cost of the servicing is $150. Assuming the dealership requires a ten week service for the 10 units, the annual cost of servicing the brake cleaning systems amounts to $7,800. The total cost of using the brake cleaning systems is $8,850 per year.

Table 3-17 shows the annualized cost comparison for the dealership. The cost of using the brake cleaning systems 21% lower than the cost of using acetone based aerosols. The cost of using the TBAC aerosols is 7% higher than the cost of using the acetone based aerosols and 36% higher than the cost of using the water-based brake cleaning system.

LITHOGRAPHIC PRINTING CLEANUP

The number of lithographic printers in the U.S. is estimated at about 54,000. Most of the printing companies are located in six states, one of them California. The state has about 8,300 lithographic printers and many of them are located in southern California. There are approximately 2,000 newspapers in California and many of them also use the lithographic printing process.

Table 3-17
Annualized Cost Comparison for Dealership for Brake Cleaning Systems

	Acetone Brake Cleaning Aerosol	TBAC Brake Cleaning Aerosol	Brake Cleaning Systems
Annualized Equipment Cost	-	-	$1,050
Cleaner Cost	$11,232	$12,043	-
Servicing Cost	-	-	$7,800
Total Cost	$11,232	$12,043	$8,850

Lithographic printing is often referred to as offset printing and it is based on the fact that oil and water do not mix. The ink is offset from the plate to a rubber blanket on an intermediate cylinder and from the blanket to the substrate--which could be paper, plastic or metal--on an impression cylinder. On the plate, the printing areas are oil or ink receptive and water repellent and the non-printing areas are water receptive and ink repellent. When the plate, mounted on a cylinder, rotates, it contacts rollers that have been wet by water or dampening solution and rollers wet by ink. The dampening solution wets the non-printing areas of the plate, which prevents the ink from wetting these areas. The ink wets the image areas and these are transferred to the blanket cylinder. As the substrate passes between the blanket cylinder and impression cylinder, the inked image is transferred to the substrate.

Some of the lithographic presses used by the industry are sheet fed where the image is printed on sheets of a substrate and some are web presses where the image is printed on a continuous web. Sheet fed presses are used for printing products like advertising, books, catalogs, greeting cards, posters, labels, packaging and coupons. Web presses, which print on rolls of paper, are used for printing business forms, newspapers, inserts, long-run catalogs, books and magazines.

Three types of inks are used in lithographic printing today. First, many printers use traditional solventborne inks. Second, some printers use soy based ink. Third, a few printers use ultraviolet (UV) curable ink which contains photoinitiators and the ink is cured with light. Solvents are used to clean the ink from the rollers and blankets both during printing and after printing when the ink type or color is changed. The solvents used for cleaning include mineral spirits, toluene, xylene, MEK, glycol ethers, heptane and hexane. All of these solvents are VOCs and many of them are toxic.

IRTA conducted some limited tests designed to determine if TBAC would be a suitable cleaner for lithographic printing inks. IRTA applied solventborne, soy based and UV curable ink to a blanket. IRTA used wipe cloths to clean the ink with TBAC. TBAC cleaned all three inks well. Although the tests are limited because they did not involve testing at a lithographic printing business, the results suggest that TBAC does solubilize ink well.

Some printers use automated blanket and roller wash systems to clean the blankets and rollers on the presses. Other printers clean both rollers and blankets by hand. Automated cleaning systems should use cleaners that have flash points above about 105 degrees F. For that reason, the case studies presented here are for printers that clean by hand.

SCAQMD modified their cleaning regulation, Rule 1171, to set more stringent VOC limits for cleaners used in lithographic printing cleanup. Currently, most of the industry must use cleaners with 500 grams per liter VOC and on January 1, 2008, the industry must convert to cleaners with a VOC content of 100 grams per liter. IRTA conducted two projects, one sponsored by SCAQMD and the other sponsored by DTSC, to identify, test, develop and demonstrate safer cleaning alternatives that would meet the 100 gram per liter VOC limit. IRTA tested and found alternatives for several lithographic printing facilities in the South Coast Basin.

IRTA presents two case studies of lithographic printers for the analysis. The first facility uses soy based ink and is typical of many medium sized lithographic printers who print posters and flyers. The second facility is a large printer that uses both solventborne and UV curable ink for printing high quality products.

Poster Printing Company

This company has four sheet fed four color presses and a picture of one of these is shown in Figure 3-18. The company prints high quality posters and flyers; 90 percent of the paper for the products is coated and 10 percent is uncoated. Soy ink is used for all of the printing.

The company, like most other companies, uses high VOC cleaning agents. An MSDS for the product used for both roller and blanket cleaning, called Step #2 Roller Wash, is shown in Appendix A. IRTA tested a variety of alternatives with the company including water-based cleaners, soy based cleaners and acetone cleaners. The company participated in an extended testing program and used the best performing alternatives for more than three months.

The roller wash that worked best for the company is a soy based cleaner called Soy Gold 2500. This product was designed to rinse easily and it can be rinsed with one water rinse. An MSDS for this cleaner is shown in Appendix B. The alternative that worked best for blanket cleaning is a high acetone content cleaner called Rhosolv 7248. An MSDS for this blanket wash is shown in Appendix B.

The company uses one drum per month or 660 gallons per year of the high VOC cleanup solvent. The company owner estimates that about one-third of the solvent or 220 gallons is used for roller wash and two-thirds or 440 gallons is used for blanket wash. The cost of the cleaner is $525 per drum or $9.55 per gallon. On this basis, the annual cost of the roller wash is $2,101 and the annual cost of the blanket wash is $4,202. The total annual cost of the cleaner amounts to $6,303.

Figure 3-18. Four Color Press at Poster Printing Company

During the extended testing, the workers indicated they used about the same amount of the alternatives as the high VOC solvent. The cost of the Soy Gold 2500 roller wash is $8.93 per gallon based on purchases of drum quantities. Assuming 220 gallons are used annually, the cost of the new roller wash is $1,965 per year. The cost of the Rhosolv 7248 blanket cleaner, again based on purchases of drum quantities, is $5.96 per gallon. Assuming 440 gallons are used per year, the annual cost of the alternative blanket wash is $2,622 per year.

The cost of TBAC is $10 per gallon if purchased in drum quantities. Assuming the TBAC is used as both a roller and blanket wash, and assuming the same amount would be used as the high VOC cleaner, the cost of using the TBAC as a roller wash would be $2,200 per year and the cost of using the chemical as a blanket wash would be $4,400 per year.

Table 3-18 summarizes the cost comparison for the company. The cost of using the soy and acetone based cleaners is lower than the cost of using either the high VOC solvent or TBAC. The cost of using TBAC is about 5% higher than the cost of using the high VOC cleaner.

Table 3-18
Annualized Cost Comparison for Poster Printing Company

	High VOC Cleaner	Soy and Acetone Cleaners	TBAC
Blanket Cleaner Cost	$4,202	$2,622	$4,400
Roller Cleaner Cost	$2,101	$1,965	$2,200
Total Cost	$6,303	$4,587	$6,600

High Quality Independent Printer

This company is a high quality independently owned printer with three facilities in California. IRTA tested alternatives with the company at one of the locations which has

five sheet fed eight color presses and three full web presses. This analysis focuses on the testing for one of the sheet fed presses that uses UV curable ink.

The company uses a cleaner called 396 U.V. Wash as a blanket and roller wash for the UV press. An MSDS for this cleaner is shown in Appendix A. IRTA tested alternatives with the company and the cleaner that worked most effectively as a roller wash was a water-based cleaner called Magic UV and the cleaner that performed best as a blanket wash was a blend of 92% acetone and 8% DPM, a glycol ether. MSDSs for Magic UV, acetone and DPM are shown in Appendix B.

The company tested the alternatives for a few weeks. The pressman indicated that the blanket wash was as effective as the high VOC blanket wash and the same amount of the alternative blanket wash was required. He also indicated that the alternative roller wash cleaned effectively but that more was required. He estimated that the alternative cleaner would be used up in 5.5 days whereas the high VOC cleaner would be used up in seven days. This indicates that 27% more of the alternative was required for roller cleaning.

The company purchases one drum per month of the high VOC cleaner for on-press cleaning at a cost of $500 or $9.09 per gallon. Three-fourths of a drum or 41 gallons is used for blanket cleaning and one-fourth or 14 gallons is used for roller cleaning. The annual cost of the blanket cleaner is $4,472 and the annual cost of the roller cleaner is $1,527.

The cost of the alternative acetone/DPM blanket wash is $6.85 per gallon if purchased in drum quantities. Assuming the company would use 41 gallons of the cleaner per month, the annual cost of the alternative blanket wash would be $3,370. The cost of the alternative roller wash, the Magic UV, is $20 per gallon. Assuming 18 gallons per month or 216 gallons per year of the roller wash would be required, the annual cost of purchasing the roller wash would be $4,320.

The company could use TBAC as both a roller and a blanket wash. According to a supplier, the cost of TBAC if purchased in drum quantities is $10 per gallon. There is no information on whether more or less TBAC would be required for the cleaning. Assuming the same amount of TBAC as the high VOC solvent would be required, the cost of purchasing the TBAC as a blanket wash would be $4,920 annually and the cost of purchasing the TBAC as a roller wash would be $1,680 per year.

Table 3-19 shows the annual cost comparison of using the high VOC cleaner, the safer alternative cleaners and TBAC. The cost of cleaning with the safer alternative cleaners is 28% higher than the cost of cleaning with the high VOC cleaner used currently. The cost of using TBAC is 10% higher than cleaning with the high VOC solvent but is lower than the cost of using the safer alternative.

Table 3-19
Annualized Cost Comparison for Lithographic Printer Using UV Curable Ink

	High VOC Cleaner	Alternative Cleaner	TBAC
Blanket Wash Cost	$4,472	$3,370	$4,920
Roller Wash Cost	$1,527	$4,320	$1,680
Total Cleaner Cost	$5,999	$7,690	$6,600

SCREEN PRINTING CLEANUP

The printing industry is one of the largest manufacturing industries in the United States. The industry is dominated by small and medium sized businesses, most of them with fewer than 20 employees. In 2002, according to the Bureau of Census, approximately 83 percent of the screen printing industry was comprised of small businesses. The Info USA Power Business Database estimates the number of screen printers in 2002 in the U.S. at 16,341. California has 1,886 screen printing establishments.

Screen printing is a short-run process that prints on almost any substrate including fabric, paper, leather, metal, glass, wood, ceramic and plastics. It is used for printing art prints, posters, greeting cards, labels, menus, program covers, wallpaper and textiles such as clothing, tablecloths, shower curtains and draperies. Some screen printing is done by hand with very simple equipment consisting of a table, screen frame and squeegee. Most commercial printing is performed on automated presses. One type of automated press uses flat screens that move in an indexed manner so that ink of different colors can be applied. Another type uses rotary cylindrical screens with the squeegee mounted inside the cylinder. The ink is pumped in automatically.

Screens are prepared before printing by the screen printers. The screens can be various sizes and they are generally made of polyester material with a wood or metal frame. A light sensitive emulsion is put onto the screen and it is cured with light. The emulsion forms a so-called stencil, which serves as the pattern for printing. During printing, ink is forced through the screen and a pattern is printed on the substrate. The emulsion masks part of the screen so the ink cannot pass through. Some companies also use a material called blockout to touch up the emulsion.

Most companies save the screens after a printing run so they can be used next time the customer orders a job. The emulsion is not removed from these screens and the screens are stored for future use. Some companies remove the emulsion each time the screen is used for printing.

Four types of inks are commonly encountered in screen printing. One type of ink is solventborne ink which is used by many printers. Another type of ink, called Plastisol ink, is used in textile printing applications; this ink is also solventborne. Textile printers account for about two-thirds of screen printers. Some screen printers use UV curable ink. Finally, a few screen printers use waterborne inks.

IRTA conducted some limited tests designed to determine if TBAC would be a suitable cleaner for screen inks. IRTA applied solventborne, Plastisol and UV curable screen ink

to a test screen. IRTA used wipe cloths to clean the screen ink with TBAC. TBAC cleaned all three inks well. Although the tests are limited because they did not involve testing at a screen printing business, the results suggest that TBAC does solubilize ink well.

There are two places in the process where solvents are used to clean ink from the screens. During printing, many companies clean the screens periodically when the ink builds up. After printing when the screens are recycled or completely cleaned, solvents are used to remove the ink from the screens. VOC solvents have commonly been used to remove ink from the screens during and after printing. Commonly used cleaners include lacquer thinner, mineral spirits, MEK, toluene, xylene, terpenes, heptane and hexane. Many of these solvents are also toxic in various ways.

SCAQMD modified their cleaning regulation, Rule 1171, to set stringent more VOC limits for screen printing cleaners. Currently, the industry must use cleaners with 500 grams per liter VOC and on January 1, 2008, the industry must convert to cleaners with a VOC content of 100 grams per liter. IRTA conducted two projects, one sponsored by SCAQMD and the other sponsored by DTSC, to identify, test, develop and demonstrate safer cleaning alternatives that would meet the 100 gram per liter VOC limit. IRTA tested and found alternatives for several screen printing facilities in the South Coast Basin.

IRTA based the analysis presented here on two case studies of screen printers involved in the earlier projects. IRTA updated the case studies to include a cost comparison of using the original high VOC cleaners, the safer alternatives and TBAC. IRTA used one case study of a textile printer since two-thirds of the industry is composed of printers of this type. IRTA also used a case study of a company that prints on cosmetic bottles with UV curable ink. The analysis is presented below.

Textile Printer

Much of the work performed by this printer involves printing on T-shirts. The company also prints on woven shirts, sweaters, activewear, headwear, outerwear and accessories like backpacks and aprons. The company is a typical textile printer. A picture of an automated press used in textile printing is shown in Figure 3-19.

Figure 3-19. Automated Press for Textile Printing

When IRTA began working with this textile printer, the company used paint thinner purchased from a home improvement store for in-process cleaning during printing and after printing. The solvent was applied by workers with wipe cloths that are shipped off-site to an industrial laundry after they have been used. After IRTA began the testing, the company purchased a parts cleaner that uses a VOC solvent. A picture of the parts cleaner is shown in Figure 3-20.


Figure 3-20. Parts Cleaner at Textile Printer

IRTA tested a variety of alternatives with the company. For the in-process cleaning, IRTA tested a blend of 60 percent white oil, 30 percent acetone and 10 percent VM&P, a

mineral spirit. MSDSs for the white oil, acetone and VM&P are shown in Appendix B. The operator indicated that the paint thinner worked a little better but that the alternative did perform acceptably. The evaporation rate of the alternative in-process cleaner was judged by the operator to be just right.

Two alternatives were successfully tested for cleaning after printing. One of these was a soy based cleaner called Soy Gold 2000. An MSDS for this cleaner is shown in Appendix B. IRTA provided the facility with a parts cleaner and the soy cleaner was tested in the parts cleaner and also for handwipe cleaning. An extra step was required to rinse the soy. The second alternative cleaner was a water-based cleaner called Ardrox 405-V; an MSDS is shown in Appendix B. This cleaner was tested in a parts cleaner at a 50 percent concentration with water and it was heated to about 105 degrees F.

IRTA analyzed and compared the cost of using the paint thinner, the new VOC cleaner, TBAC and the alternative blend for cleaning during printing and the soy and water-based alternatives for cleaning after printing. The soy cleaner was evaluated for cleaning in the parts cleaner and by hand.

The printer used about 30 gallons per month or 360 gallons per year of the paint thinner. The shop owner estimates that 95 percent of the cleaner was used at the end of the cleaning process and five percent was used for in-process cleaning. On this basis, 342 gallons of the cleaner were used after printing and 18 gallons were used during printing each year. The cost of the paint thinner at hardware stores is $6 per gallon. On this basis, the annual cost of purchasing the paint thinner was $108 for in-process cleaning and $2,052 for cleaning after printing.

The new VOC cleaner is used in a parts cleaner with a 30 gallon capacity for cleaning after printing. The company purchased the parts cleaner at a cost of $1,500. Assuming a useful life for the parts cleaner of 10 years and a cost of capital of 5%, the annualized cost of the parts cleaner amounts to $158. IRTA estimates that the parts cleaner would require changeout every three months. The company would also need 18 gallons of the cleaner each year for in-process cleaning. The cost of the cleaner is $10.50 per gallon. The cost of purchasing the cleaner for in-process cleaning is $189 annually and after printing cleaning is $1,260 annually. The unheated parts cleaner would use electricity for the pump and IRTA estimates this cost at $50 per year.

Workers at the company spend eight hours per day cleaning. Assuming a five day week and 52 weeks per year and adopting the company's labor rate of $8 per hour, the labor cost of the cleaning activities is $16,640 annually.

For the in-process cleaning, IRTA estimated the cost of the alternative based on the raw materials cost of the components purchased in small quantities. The cost of the white oil is $16.50 per gallon. The cost of acetone is $13.97 per gallon and the cost of the VM&P is $6 per gallon. On this basis, the cost of the blend is $14.69 per gallon. Assuming the company would purchase 18 gallons per year of the blend, the annualized cost amounts to

$264. The labor cost would remain the same for the alternative in the in-process cleaning.

For cleaning after printing, it was assumed that the soy cleaner would be used for hand cleaning in the same manner as the paint thinner. The cost of the soy is $9 per gallon. Assuming 342 gallons would be required, the annual cost of purchasing the soy is $3,078. In this scenario, the labor would increase because the screens would require rinsing to remove the soy. The increased labor is estimated at one-half hour per day. On this basis, the increase in the labor cost would be $1,040 annually for a total labor cost of $17,680.

For cleaning after printing, IRTA also analyzed the cost of using the soy cleaner or the water-based cleaner in the parts cleaner. The water-based cleaner needs to be heated to clean effectively. If the company purchased a heater for the parts cleaner, it would cost $400. Making the same assumptions as for the parts cleaner, the annualized cost for the heater would be $42. The parts cleaner with the added heater would use more electricity at a cost of $466 annually based on a usage rate of eight hours per day.

Based on the cleaning tests with the parts cleaner, the soy and the water-based cleaner would require changeout every three months. Assuming a capacity of 30 gallons for the parts cleaner and a cost of $9 per gallon for soy, the annual cost of soy for the parts cleaner would amount to $1,080 per year. The cost of the water-based cleaner is $7.50 per gallon for drum quantities and the cleaner is used at 50 percent concentration. On this basis, the annual cost of purchasing the water-based cleaner for the parts cleaner would be $450. No additional labor would be required for cleaning with the water-based cleaner.

TBAC is not currently sold in hardware stores. One supplier provided a cost for the cleaner if it were purchased in one gallon quantities at $25 per gallon. The TBAC would be used for hand cleaning; the low flash point would not allow the cleaner to be used in a parts cleaner. Assuming the cleaner would be used in both in-process cleaning and cleaning after printing and that the same amount of TBAC as paint thinner would be required, the annual cost of purchasing the TBAC for in-process cleaning would amount to $450 and the annual cost of purchasing the chemical for cleaning during recycling would be $8,550 The labor for using this cleaner would be the same as the labor for using the paint thinner.

The company currently pays $45 per week for sending the soiled rags to an industrial laundry and receiving fresh rags. The annual cost of this service amounts to $2,340. Use of the soy cleaner and TBAC for hand cleaning would have the same cost. Use of the VOC solvent, the soy cleaner and the water-based cleaner in the parts cleaner would require disposal of two drums of waste per year. The cost of disposal is estimated at $200 per drum for an annual cost of $400. Use of the parts cleaner would reduce the cost of the service for the rags. Assuming that five percent of the cleaning is in-process cleaning which would be performed with rags, the cost of the rag service with the parts cleaner would be $117 annually.

Table 3-20 compares the cost of six scenarios;

- paint thinner cleaning by hand;
- VOC solvent cleaning in parts cleaner;
- TBAC cleaning by hand;
- soy cleaning by hand;
- soy cleaning in parts cleaner; and
- water-based cleaning in parts cleaner

The scenarios assume that the alternative in-process cleaning, the blend, is used for the last three cases. The cleaner used after printing is referred to as Cleaner A in the table and the in-process cleaner is called Cleaner B.

Table 3-20
Annualized Cost Comparison for Textile Screen Printer

	Paint Thinner Hand	VOC Solvent Parts Cleaner	TBAC Hand	Soy Hand	Soy Parts Cleaner	Water-Based Parts Cleaner
Capital Cost	-	$158	-	-	$158	$200
Cleaner A Cost	$2,052	$1,260	$8,550	$3,078	$1,080	$450
Cleaner B Cost	$108	$189	$450	$264	$264	$264
Labor Cost	$16,640	$16,640	$16,640	$17,680	$17,680	$16,640
Electricity Cost	-	$50	-	-	$50	$466
Disposal Cost	$2,340	$517	$2,340	$2,340	$517	$517
Total Cost	$21,140	$18,814	$27,980	$23,362	$19,749	$18,537

The lowest cost option in Table 3-20 is use of the water-based cleaner in a parts cleaner. The cost of this option is about 12 percent lower than the cost of the baseline option, use of paint thinner by hand. The cost of using the VOC solvent in a parts cleaner is also lower than the cost of the baseline option by about 11%. The cost of using the soy in a parts cleaner is also lower than the cost of the baseline option, by 7%. The cost of using TBAC for hand cleaning is the highest cost option; it is 32% higher than the cost of the baseline option. The cost of hand cleaning with soy is also higher than the cost of the baseline option.

Cosmetic Bottle Printer

This company manufactures plastic cosmetic bottles for various types of products like shampoo and other personal products for a number of customer. The firm has several extrusion and blow molding machines that are used to make the bottles. The bottles are made of a range of plastic materials including HDPE, PET, LDPE, PVC and polypropylene. The bottles have a variety of shapes such as cylinders and ovals.

The company has several automated in-line decorating machines that are used to screen print on the plastic bottles. For a number of years, the firm has exclusively used UV curable inks. The machines apply one color of ink to the bottle as it passes through the

ink delivery system. Some of the bottles require five colors so they pass through five screens in the machine, each with one color. The bottles pass under a screen and squeegees applied to the top of the screen force the ink through the screen to color the pattern on the bottles. After the ink is applied, the bottles pass through a UV light which cures the ink. A picture of one of the machines is shown in Figure 3-21.

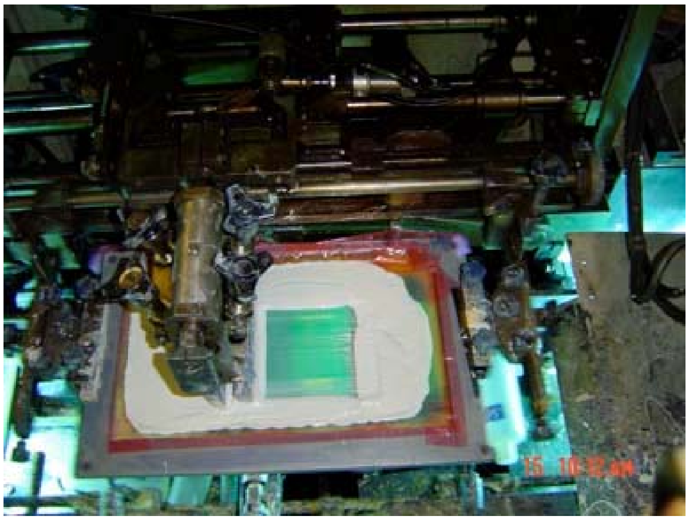

Figure 3-21. Cosmetic Bottle Printing Machine

The company performs two types of cleaning. First, workers monitor the screens at the machines. Periodically, when the screens are contaminated, the worker uses a cleaner on a rag to wipe the excess ink from the lower part of the screen; this is in-process cleaning. Second, after the run, the screens are removed from the machine, workers remove the ink from the top and bottom of the screens and they are processed further so they can be reused.

In preliminary tests, IRTA found that soy based cleaners cleaned the ink well. IRTA performed scaled up testing of one of the cleaners, Soy Gold 2000, and the company later decided to convert to a similar soy based cleaner. The cleaner is water rinseable so the screens can be cleaned and rinsed in the recycling process. An MSDS for the cleaner is shown in Appendix B. The new cleaner protects the emulsion which forms the pattern on the screen better than the high VOC cleanup solvent used in the past. The workers also like the new cleaner better because it does not have the strong odor of the high VOC cleaner.

The company uses 15 gallons of cleaner per week under normal production conditions and the company purchases the cleaner in five gallon containers. The cost of the high VOC cleaner was $13 per gallon. On this basis, the cost of using the high VOC cleaner was $10,140 annually. The cost of the new soy based cleaner is lower, at $10.90 per gallon. The annual cost of using this cleaner is $8,502. The cost of TBAC purchased in five gallon quantities is estimated at $20 per gallon by a chemical supplier. On an annual basis, the cost of using TBAC would amount to $15,600.

Table 3-21 shows the cost comparison for using the high VOC cleaner, the soy based cleaner and TBAC. The cost of using the soy based cleaner is lower than the cost of using the high VOC cleaner or TBAC.

Table 3-21
Annualized Cost Comparison for Cosmetic Bottle Screen Printer

	High VOC Cleaner	Soy Based Cleaner	TBAC
Cleaner Cost	$10,140	$8,502	$15,600
Total Cost	$10,140	$8,502	$15,600

IV. POTENTIAL USE OF TBAC AND TOXICITY OF TBAC AND ALTERNATIVES

This section presents IRTA's estimates of the amount of TBAC that could be used statewide in the applications analyzed here if the chemical were granted an exemption from VOC regulations. Section II of this document provided some information on the toxicity of TBAC and its metabolite TBA. This section presents additional information on the toxicity of the two chemicals and the risks the use of TBAC poses to workers. The section also briefly discusses the toxicity of the safer alternatives that were discussed for the applications of interest.

POTENTIAL TBAC USE

TBAC use in California is currently very limited since the chemical is more expensive than alternative VOC and non-VOC chemicals. If the chemical were exempted from VOC regulations throughout California, its use could be significant. Lyondell, the manufacturer of TBAC, estimates potential use of the chemical in California at 10 tons per day (tpd) if the chemical were exempt. CARB estimated the potential use of TBAC in certain applications assuming an exemption at 33 to 54 tpd. The CARB analysis assumed that much of the substitution of TBAC would be as a component in solventborne coatings which IRTA did not analyze in this project.

IRTA estimated the potential use of TBAC in California for the applications considered in this report. Table 4-1 presents these estimates. The estimates are based on the assumption that TBAC would be deemed exempt in California in all of the applications and that low VOC limits would be established throughout the state.

Table 4-1
Estimates of Potential TBAC Use in California

Application	Potential Use (tons per day)
Batch Loaded Cold Cleaning/Handwipe Cleaning	6
Printed Circuit Board Defluxing	1
Coating Application Equipment Cleaning	5.5
Thinners for Coatings	12
Automotive Aerosol Cleaning	5
Lithographic Printing Cleanup	2
Screen Printing Cleanup	1.5
Total	33

SCAQMD estimates that VOC emissions from batch loaded cold cleaning amounted to 6 tpd in the South Coast Basin in 1999. Since then, SCAQMD has established lower VOC limits but the estimate provides a reasonable basis for assuming that solvent use in batch loaded cold cleaning amounted to 6 tpd at that time. The jurisdiction of the SCAQMD is about half the state. In this light, solvent use for the state would amount to 12 tpd in this

application. Many companies have converted to alternatives because of the more stringent regulations. Some of these companies would continue using the low-VOC products they have adopted and some would convert to TBAC if it were exempted. Assuming one-fourth of the industry would adopt TBAC, the use of TBAC in batch loaded cold cleaning would be 3 tpd. There are no estimates for use of cleaners in handwipe applications. IRTA's best judgement would suggest that handwipe use of TBAC would be about equal to batch loaded cold cleaning use of TBAC. Under this assumption, the potential use of TBAC in both batch loaded cold cleaning and handwipe applications would be 6 tpd.

No data are available on the use of cleaners in rework of printed circuit boards. IRTA's best judgement is that the amount of cleaner used for these purposes is no more than 2 tpd. Assuming that one-half of the users converted to TBAC, the use of TBAC in this application might amount to 1 tpd.

SCAQMD estimates the VOC emissions from cleanup of coating application equipment for stationary sources at about 10 tpd in the South Coast Basin. Making the same assumption as before, the emissions statewide would amount to 20 tpd. In the consumer products categories, CARB estimates VOC emissions from the category "spray gun cleaner and solvent" at 0.012 tpd and emissions from the category "multi-purpose solvent and remover at 1.937 tpd. The sum of these estimates is about 22 tons per day. Assuming one-fourth of the market would use TBAC, use of TBAC for cleaning coating application equipment would amount to 5.5 tpd.

CARB estimates VOC emissions from a consumer product category called "lacquer thinner" at 13.271 tpd and emissions from another category called 'paint thinners and reducers" at 10.731 tpd. There are no estimates of the emissions from industrial users who purchase thinners from suppliers rather than from home improvement and hardware stores that sell consumer products. IRTA estimates that the emissions from industrial users are roughly the same as the emissions from the two CARB consumer product categories. Solvent use of thinners on this basis amounts to 48 tpd. Assuming one-fourth of the market would go to TBAC, the use of TBAC in thinners would amount to 12 tpd.

CARB recently reduced the VOC limits for automotive aerosol cleaners and estimated emissions from the category at about 10 tpd. In this case, it is likely TBAC would garner a higher percent of the market, at 50%. On this basis, the TBAC use in automotive aerosol cleaners could potentially be 5 tpd.

Several years ago, before SCAQMD regulated the VOC content of cleaners used in lithographic and screen printing, the agency estimated that emissions from these sources amounted to 4 tpd and 3 tpd respectively. Assuming SCAQMD accounts for half the emissions in the state, emissions of cleaners in California from lithographic printing equipment cleanup would be 8 tpd and from screen printing cleanup equipment would be 6 tpd. Assuming TBAC could take one-fourth of the market, potential use of the chemical in lithographic printing cleanup would be 2 tpd and screen printing cleanup would be 1.5 tpd.

The potential market for TBAC, according to the figures in the table, could be 33 tpd. This is the potential increase in use that could be realized in the cleaning and thinning applications examined here if TBAC were exempted from VOC regulations and the categories were further regulated.

TOXICITY OF TBAC AND TBA

CARB requested information from OEHHA on the toxicity of TBAC when the agency was evaluating whether or not to exempt the chemical from VOC regulation. The OEHHA memo provides an assessment of the existing toxicity information for TBAC and TBA.

This memo, dated March 20, 2000, indicates that the health effects information for TBAC is limited. The review indicated that TBAC has low acute inhalation, oral, dermal and ocular toxicity. OEHHA found no chronic, developmental or reproductive toxicity data for the chemical. Neither did OEHHA find any information on TBAC's genetic toxicity or carcinogenicity. OEHHA states that, because of the limited data, it is not possible to assess the potential adverse effects from prolonged exposure. This does not mean that TBAC is not toxic; it simply means there are no toxicity data that would allow an assessment of its toxicity.

OEHHA's review, however, did reveal that TBAC is substantially metabolized to TBA in rats which raises a concern with TBA exposure. OEHHA indicates that the TBA genetic toxicity data are mixed but that information from the positive genotoxicity study for TBA suggests that the chemical may cause DNA damage; the assays used in the negative studies are insensitive to oxidative DNA damage so these studies cannot be used to draw conclusions. OEHHA did indicate that TBA has been shown to induce tumors in both rats and mice and the agency calculated a cancer potency factor for TBAC and an air unit risk value of 4×10^{-7} per microgram per meter cubed.

Several of the OEHHA staff, as mentioned earlier, submitted an article to the journal Regulatory Toxicology and Pharmacology in November of 2003. The article, which was available online in August of 2004, focused on TBAC and TBA. The journal article indicates that, because TBA causes cancer in rats and mice, TBAC "should be considered to pose a potential cancer risk to humans because of the metabolic conversion to TBA."

Risk of TBAC

HESIS conducted a workplace risk assessment based on CARB's research document that evaluated the environmental impact of TBAC. The Permissible Exposure Limit (PEL) for TBAC established by the Occupational Safety and Health Administration (OSHA) is 200 ppm. On this basis, the assessment assumed a working lifetime exposure at the PEL level of 200 ppm. Using OEHHA's cancer unit risk number for TBAC, HESIS calculated a lifetime cancer risk of 380,000 in a million or 0.38. HESIS calculated the working lifetime cancer risk based on a worker inhaling 10 meters cubed per day, 250

days per year for 40 years. This leads to a working lifetime cancer risk of 74,000 in a million or 0.074.

To place this risk in context, consider methylene chloride, a carcinogen used in paint stripping, automotive aerosol cleaning and other cleaning applications. OEHHA's unit risk value for methylene chloride is 1×10^{-6} per microgram per meter cubed which is higher than the air unit risk value of 4×10^{-7} per microgram per meter cubed for TBAC determined by OEHHA. The PEL for methylene chloride is 25 ppm. Using OEHHA's unit risk value and making the same assumptions for the worker as before, the working lifetime cancer risk for a worker using methylene chloride at the PEL is about 23,000 in a million or 0.023. Using different quantitative risk assessment methods, the working lifetime risk at 25 ppm calculated by OSHA is 3,600 in a million or 0.004.

The lifetime cancer risk for a worker using methylene chloride at the PEL, based on either the OEHHA unit risk value or OSHA's quantitative risk assessment, is more than three times lower than the lifetime cancer risk for a worker using TBAC at the PEL. Methylene chloride is on EPA's Hazardous Air Pollutant (HAP) list, is considered a Toxic Air Contaminant (TAC) in California and is listed on Proposition 65. The chemical is heavily regulated by CARB and the local air districts. CARB has prohibited the use of methylene chloride in automotive aerosol applications and is proposing a prohibition of use in other consumer product categories.

In contrast, TBAC is not regulated by CARB or the local air districts. In fact, as discussed earlier, CARB has exempted the chemical from VOC regulations in the automotive SCM. SCAQMD has exempted TBAC from VOC regulations in their automotive coatings regulation for use in primers and in their architectural coating regulation for use in industrial maintenance coatings. CARB may exempt TBAC for use in some consumer product regulations and SCAQMD may exempt it in other regulations in the future. It is not clear why these agencies stringently regulate a carcinogen like methylene chloride which poses a lower risk to workers than TBAC and at the same time encourage and promote the use of TBAC in some applications. Since TBAC is not regulated as a toxic, it is much more likely to be used in an unrestrained way in applications where it is exempt.

TOXICITY OF ALTERNATIVES

The purpose of this project was to evaluate the potential uses of TBAC and to assess the feasibility and cost of using safer alternatives in cleaning and thinning applications. IRTA identified and tested alternatives in all of the applications that were considered. Alternatives generally included soy based products, acetone and water-based cleaners.

In other projects conducted by IRTA, HESIS staff evaluated the MSDSs of certain products and reported on the toxicity. HESIS examined the MSDS for Soy Gold 2500, one of the soy based products tested as an alternative in lithographic printing cleanup. Based on the MSDS for the product, HESIS indicated that the product contains fatty acid esters and there are no hazardous ingredients listed on the MSDS. Fatty acid esters have

low volatility and they are lower in toxicity than other organic solvents. In past projects, HESIS has also indicated that acetone is lower in toxicity than other organic solvents.

Whether or not water-based cleaners have toxicity problems obviously depends on the ingredients they contain. IRTA focuses on testing water-based cleaner that do not have solvent additives or that have very low levels of solvent additives. These water-based cleaners are generally diluted with plain water before use. The water-based cleaners tested by IRTA have no hazardous ingredients listed on the MSDSs. In past projects, HESIS has indicated that certain of the cleaners are low in toxicity.

V. RESULTS AND CONCLUSIONS

TBAC forms a metabolite called TBA that is a carcinogen. OEHHA evaluated the toxicity of TBA and indicates that TBA has been shown to induce tumors in both rats and mice. The agency concluded that TBAC should be considered to pose a potential cancer risk to humans because it metabolically converts to TBA.

TBAC is not currently used in most applications today. It is much more costly than other VOC solvents so formulators of cleaning and thinning products do not use the material. If TBAC were exempted in California by CARB or the local air districts, it would probably be used extensively, particularly in cases where there are stringent VOC limits. An exemption for the chemical combined with a lower VOC limit literally creates a market for TBAC.

TBAC has been designated by EPA as exempt from VOC regulations. In areas like California where stringent VOC regulations are necessary, suppliers, vendors and users rely on exempt chemicals to a large extent for compliance. CARB regulates consumer products in California and the agency must specifically exempt chemicals from VOC regulations before they can be used in products as a non-VOC. Local air districts similarly must exempt chemicals for products used in stationary source applications before they are considered non-VOCs. CARB has exempted TBAC in one SCM for the autobody industry and SCAQMD has exempted TBAC for use in primers used in the autobody industry and in industrial maintenance coatings used in the architectural coating industry. Both CARB and SCAQMD may exempt TBAC for use in other applications in the future.

IRTA conducted this project to demonstrate that safer alternatives TBAC are available and they can be used in cleaning and thinning applications. Several selected applications were evaluated. These include:

- batch loaded cold cleaning and handwipe cleaning;
- printed circuit board defluxing;
- coating application equipment cleaning;
- thinners for coatings;
- automotive aerosol cleaning;
- lithographic printing cleanup; and
- screen printing cleanup.

Case studies of companies using high VOC products, safer alternative products and TBAC were presented. The costs of using these materials in each application was compared.

Table 5-1 summarizes the alternatives that were found to be effective substitutes for both high VOC materials and TBAC. The table shows that the alternatives that were tested and, in many cases, adopted by the companies were generally acetone, acetone blends, water-based cleaners and soy based cleaners. Acetone and soy are lower in toxicity than

most other organic solvents and water-based cleaners are generally safer than other materials.

Table 5-1
Safer Alternatives to High VOC and
TBAC Products in Cleaning and Thinning Applications

Cleaning Category	Case Study Company	Effective Safer Alternative(s)
Batch Loaded Cold Cleaning / Handwipe Cleaning	Machine Shop	Water-Based Cleaners
	Precision Contract Cleaning Company	Acetone
	Electric Motor Manufacturer	Acetone
Printed Circuit Board Defluxing	Data Acquisition Equipment Manufacturer	Acetone / IPA / D.I. Water
	Braking System Manufacturer	Acetone / IPA
Coating Application Equipment Cleaning	Wood Company	Acetone
	Architectural Contractor	Acetone
	Safe Manufacturer	Acetone
	Autobody Shop	Acetone
Thinners for Coatings	Wood Company	Acetone
	Architectural Contractor	Acetone
	Safe Manufacturer	Acetone
		Acetone / Soy
	Autobody Shop	Acetone / Soy
		Acetone / Glycol Ether
Automotive Aerosol Cleaners	Auto Repair Shops	Water-Based Cleaners -- Spray Bottles
		Water-Based Cleaners -- Aerosols
		Water-Based Cleaners -- Bulk
		Water-Based Cleaners -- Brake Cleaning Equipment
		Acetone, Acetone Blends -- Cannister Systems
		Acetone, Acetone Blends -- Aerosols
Lithographic Printing Cleanup	Poster Printing Company	Soy -- Roller Wash
		Acetone Blend -- Blanket Wash
	High Quality Independent Printer	Water-Based Cleaner -- Roller Wash
		Acetone / Glycol Ether Blend -- Blanket Wash
Screen Printing Cleanup	Textile Printer	Soy -- Recycle Cleanup
		Water-Based cleaner -- Recycle Cleanup
		Acetone Blend -- In-Process Cleanup
	Cosmetic Bottle Printer	Soy -- Recycle Cleanup
		Soy -- In-Process Cleanup

The results of the analysis indicate that there is no reason to provide exemptions from VOC regulations for TBAC in a wide variety of cleaning or thinning applications. There is no dispute that TBA is a carcinogen and there are alternatives to TBAC that are safer. Other chemicals that are exempt and also pose a cancer risk are heavily regulated by the air agencies in California. This puts limits on their use. In contrast, a TBAC exemption would lead to unrestrained use of the chemical. HESIS calculated the lifetime cancer risk

to a worker using TBAC at the current OSHA PEL level and it is very high, 74,000 in a million. To protect workers and community members, IRTA recommends that CARB add TBAC to the list of Toxic Air Contaminants in the state. IRTA also recommends that CARB and the local air districts not provide additional exemptions for the chemical.

VI. REFERENCES

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