# ASSESSMENT, DEVELOPMENT AND DEMONSTRATION OF ALTERNATIVES FOR FIVE EMERGING SOLVENTS

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# DISCLAIMER

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**TABLE OF CONTENTS**

## LIST OF FIGURES

**LIST OF TABLES**

# EXECUTIVE SUMMARY

More than 7,000 new chemicals enter the market each year. In spite of the fact that there is little toxicity information on many of these chemicals, they are gradually used in a variety of applications. Some of these emerging chemicals show evidence of toxicity but generally by the time this happens, they are used extensively. Workers, community members and consumers are exposed to these chemicals and they are at risk.

The Department of Health Services Hazard Evaluation System & Information Service (HESIS) is concerned about worker exposure to toxic chemicals. The Institute for Research and Technical Assistance (IRTA) is a nonprofit organization that focuses on safer alternatives, primarily in solvent applications. HESIS and IRTA collaborated on this project which is funded by an EPA Pollution Prevention Grant (NP-09012401-1) awarded to HESIS by EPA Region IX.. The aim of the project was to select five emerging solvents and to identify alternatives in several of the applications where they are used. Another aim of the project was to develop a template for evaluating alternatives for other similar emerging chemicals.

Solvents are most often used in dispersive applications where exposure is likely to be high. The five solvents selected by HESIS and IRTA for detailed focus are:

- decamethylcyclopentasiloxane or D5
- parachlorobenzotrifluoride or PCBTF
- n-propyl bromide or NPB
- 1,2-trans-dichloroethylene or DCE
- N-methyl pyrrolidone or NMP

D5 has caused cancer in laboratory animals. NPB is a reproductive and developmental toxin and causes nerve damage in workers and laboratory animals; it is currently being tested for carcinogenicity. NMP is a reproductive and developmental toxin. PCBTF and DCE are chlorinated solvents and are structurally similar to other chemicals with high toxicity.

The five solvents are used in a range of different applications. D5 is used as a dry cleaning agent, in repair and maintenance cleaning and in a variety of consumer products like antiperspirants, beauty creams and personal lubricants. PCBTF is used by the autobody industry in coatings, thinners and cleanup solvents. It is also used in repair and maintenance cleaning and consumer products like cosmetic stain removers and aerosol rust inhibitors. NPB is used in industrial and precision cleaning, in adhesive formulations used by foam fabricators and in aerosol cleaning products. DCE is used in precision cleaning applications and in aerosol cleaning products. NMP is used in consumer product paint strippers, furniture strippers and in various other general purpose stripping products. It is also used in precision cleaning, as a pharmaceutical penetration enhancer and in children's shampoo and bath concentrate.

In this project, IRTA identified and discussed safer alternatives for each of the emerging chemicals in all the applications that were studied. For many of the applications, IRTA presents case studies of companies that used the candidate chemical and converted to an alternative. In some instances, IRTA presents cost analyses and comparison of the candidate chemicals and their alternatives. Table E-1 summarizes the alternatives in the applications that were evaluated.

**Table E-1**
**Safer Alternatives for Candidate Solvents in Selected Applications**

| Chemical | Application | Alternative(s) |
|---|---|---|
| D5 | Dry Cleaning | water-based systems, carbon dioxide, hydrocarbons |
| | Repair and Maintenance Cleaning | water-based cleaners |
| | Consumer Products | IDNP, GD, DC, HP, various products |
| PCBTF | Autobody Coatings | various products |
| | Autobody Coating Thinner | various products, acetone and acetone blends |
| | Autobody Coating Cleanup | acetone, acetone/methyl acetate blend |
| | Repair and Maintenance Cleaning | water-based cleaners |
| | Cosmetic Stain Removal | various products, water-based cleaners, soy based cleaners, soy/acetone blends, glycol ether, glycol ether/acetone blend |
| | Aerosol Rust Prevention | various products, water-based products, vegetable based products |
| NPB | Industrial/Precision Cleaning | water-based cleaners, low solids flux, DCE blends, airless/airtight degreasers |
| | Adhesives | water-based products, acetone based products |
| | Aerosol Cleaning | water-based cleaners, cleaners with flash points, soy based cleaners, HCFC-141b, DCE blends |
| DCE | Vapor Degreasing | water-based cleaners, airless/airtight degreasers |
| | Aerosol Cleaning | water-based cleaners, cleaners with flash points, soy based cleaners, HCFC-141b |
| NMP | Consumer Product Paint Stripping | benzyl alcohol formulations |
| | Furniture Stripping | benzyl alcohol formulations |
| | Other stripping activities | various products/benzyl alcohol formulations |
| | Precision Cleaning | water-based cleaners, acetone, process changes |
| | Pharmaceutical Penetration Enhancer | various products |
| | Children's Shampoo and Bath Concentrate | various products |

Note: IDNP is isodecyl neopentanoate; GD is glycol distearate; DC is dicapryly carbonate; HP is hydrogenated polydecen.

The project findings indicate that safer alternatives to the five candidate chemicals are available in the applications that were targeted here. The cost of using most of the alternatives is lower than the cost of using the candidate chemical. In the cases where the cost of using the alternative is higher, it is not significantly higher.

Two of the solvents analyzed during the project, PCBTF and DCE, are used fairly extensively. They have not been tested for chronic toxicity and such data would be useful for better evaluating the risk they may pose.

# I. INTRODUCTION AND BACKGROUND

There are over 70,000 chemicals in commerce and more than 7,000 new chemicals enter commerce each year. The Toxic Substances Control Act (TSCA) was passed in 1976 and it was designed to give EPA better control over substances already in commerce and new substances entering commerce. It gave EPA the authority to require toxicity testing of new chemicals that EPA believed posed a risk to society. In spite of its promise, TSCA has not been very effective either because it has not been implemented as intended or because it does not provide EPA with adequate authority to implement it.

So-called emerging chemicals are becoming an increasing problem. A new chemical enters the market without adequate toxicity tests that could be used to verify its safety. The chemical begins to be used in a few applications and, as time goes on, it is used more extensively. The health and environmental regulations are not designed to control new chemicals. The Occupational Safety and Health Administration (OSHA), for instance, has not established appropriate workplace standards for existing chemicals and is not likely to establish standards for new chemicals until decades after they have been used. The Resource Conservation and Recovery Act (RCRA) regulates hazardous waste. It was passed in 1976 and it characterized wastes as listed wastes or characteristic wastes. The listed wastes were derivatives of chemicals that were in widespread use before 1976; new chemicals with characteristics similar to other listed wastes can never be added to the list. The Hazardous Air Pollutants (HAP) list was finalized in 1989 as part of the Clean Air Act Amendments. It listed only chemicals that were used extensively before that date. There is a provision for changing the list but the documentation supplied by EPA refers to delisting rather than listing any new chemicals.

Once the new chemicals are used by hundreds or thousands of companies and consumers, even if evidence of high toxicity becomes available, it is very difficult to prevent or control the use of the chemical. The economic well being of the companies that market it and use it is at stake. Any effort to restrict or control the use of the chemical, even when it is clearly toxic, becomes controversial.

This project was designed to focus on five emerging chemicals to highlight the problems with this issue. The purpose of the project is twofold. First, this project can serve as a template for the approach that can be used to gain and provide more information on emerging chemicals in general. Second, the project identifies and describes alternatives to the emerging chemicals that were targeted that should be useful to government agencies involved in regulation and outreach and to users of the chemicals who wish to identify and implement safer alternatives.

The Hazard Evaluation System & Information Service (HESIS) is part of the California Department of Health Services. HESIS was established to identify, evaluate, recommend protective standards for, and provide practical information on toxic chemicals and other workplace hazards. The Institute for Research and Technical Assistance (IRTA) is a nonprofit organization established in 1989 to assist companies and whole industries in identifying, testing, developing and demonstrating safer alternatives. IRTA's major focus over the last several years has been on solvents used in applications like cleaning, dry cleaning, paint stripping, adhesives and coatings. Under the Pollution Prevention Grants Program, EPA and HESIS sponsored a project on emerging chemicals. HESIS contracted with IRTA to perform the investigation of alternatives to five emerging chemicals and this report provides the results of the research. HESIS is evaluating the toxicity of the five candidate chemicals.

SELECTED EMERGING SOLVENTS

Five emerging solvents were selected for analysis in this project. These include:

- decamethylcyclopentasiloxane (D5)
- parachlorobenzotrifluoride (PCBTF)
- n-propyl bromide (NPB)
- 1,2-trans-dichloroethylene (DCE)
- n-methyl pyrrolidone (NMP)

Decamethylcyclopentasiloxane

Decamethylcyclopentasiloxane or D5 is a volatile methyl siloxane. In the mid 1990s, the producers began marketing some of the siloxanes in cleaning applications as alternatives to 1,1,1-trichloroethane (TCA) and CFC-113. Production of TCA and CFC-113 was halted in 1996 because the two chemicals contribute to stratospheric ozone depletion. The D5 producers submitted a petition to EPA requesting that the siloxanes be deemed exempt from VOC regulations. EPA granted the exemption and D5 and several other siloxanes were specified as exempt chemicals which means they are not defined as VOCs.

In 1993, under TSCA, EPA required the producers to submit information on 56 silicones. EPA and Dow Corning signed a Memorandum of Understanding (MOU) in 1996 and the MOU involved a request for new data development on six of the siloxanes including D5. Dow Corning conducted a two-year chronic toxicity/oncogenicity study and released the preliminary results in 2003. The results of the tests showed an increase in a malignant tumor. The final report on the chronic toxicity study was made available in 2006 and EPA and the Office of Environmental Health Hazard Assessment (OEHHA) in California are evaluating the results.

Over the last several years, D5 has been used increasingly in several applications where worker, community and consumer exposure is high. Taking into account the applications, IRTA and HESIS decided to focus on three uses of the chemical. First, D5 is used as a dry cleaning agent called Green Earth and it is marketed as a safer alternative to perchloroethylene (PERC). Second, D5 is used in repair and maintenance cleaning as an alternative to mineral spirits, particularly in locations where VOC regulations are stringent. Third, D5 is used in a variety of consumer products.

Parachlorobenzotrifluoride

Parachlorobenzotrifluoride or PCBTF was originally only used as an intermediate in the production of other chemicals; it was not used in dispersive applications. In the mid 1990s, the producer which was Occidental Chemical at the time, decided to begin marketing the chemical in solvent applications. This decision was based on the fact that the production of TCA was going to be banned and there was a large solvent market that PCBTF could penetrate. The producer submitted a petition to EPA requesting that EPA deem PCBTF exempt from VOC regulations. Some years later, EPA granted the exemption. The producer began marketing PCBTF in certain cleaning applications. Several years ago, Occidental Chemical sold off its intermediate business and no longer produces the chemical. Foreign producers now provide the chemical to suppliers in this country for use in several applications.

PCBTF has not been tested for chronic toxicity. Its structure is a benzene ring with a chlorine substituent. Other chemicals with a chlorinated benzene ring structure have high toxicity. PCBTF also contains fluorine; if it is manufactured without proper controls or if it is used in applications where it is reactive, it could form free fluorine which is an extremely toxic material. Because it is produced in other countries, there could be an issue with the quality of the material.

PCBTF is now used widely in dispersive applications. In some cases, the fact that it is not a VOC is a strong marketing point. With that in mind, IRTA and HESIS decided to focus on six applications. First, PCBTF is used in autobody coating formulations in California because it is not classified as a VOC. Second, the chemical is used in thinners for autobody coatings in California, again because it is not a VOC. Third, PCBTF is used in cleanup solvents for autobody coatings in California. Fourth, the chemical is used in repair and maintenance cleaning in California where the VOC limit on such cleaners is very low. Fifth, PCBTF is used as a cosmetic stain remover and Sixth, it is used as an aerosol rust inhibitor.

n-Propyl Bromide

1-Bromopropane or n-propyl bromide (NPB) is a brominated solvent. Producers began marketing the chemical in solvent applications when TCA and CFC-113 production was scheduled to be banned. One of the distributors submitted a petition to EPA requesting an exemption from VOC regulations. EPA has never exempted the chemical because of its short atmospheric lifetime so it is still classified as a VOC.

NPB is a reproductive and developmental toxin. It causes sterility in both male and female test animals, harms the developing fetus, and can cause nerve damage. The chemical is currently undergoing toxicity testing to determine if it is a carcinogen. HESIS issued a Health Hazard Alert for NPB in July 2003 and recommends that the workplace exposure to the chemical be set at about 1 ppm to protect against the reproductive and nerve toxicity. HESIS' proposal to Cal/OSHA is under consideration.

NPB producers and distributors have marketed the chemical aggressively over the last several years in applications where exposure of workers and community members can be high. With that in mind, IRTA and HESIS selected three applications for more detailed focus. First, the chemical is used in industrial and precision cleaning applications. Second, NPB is a component of adhesive formulations used in the foam fabrication industry. Third, the chemical is a component of aerosol cleaning formulations, so-called contact cleaners.

1,2-trans-Dichloroethylene

1,2-trans-Dichloroethylene or DCE is a chlorinated solvent. The chemical was originally used only as an intermediate in the production of other chemicals. The producer began marketing the chemical as a component in cleaning formulations in the mid-1990s when the ban on TCA and CFC-113 production was scheduled to be effective. Unlike other chlorinated solvents that are used widely, DCE has a flash point so it is generally combined with other chemicals without flash points so the blend does not have a flash point.

DCE has not been tested for chronic toxicity. It is structurally similar to other chlorinated solvents that are carcinogens. Its structure is similar to those of trichloroethylene (TCE) and PERC which cause cancer in animals and vinyl chloride which is an established human carcinogen.

The producer of DCE has not marketed the chemical extensively. Rather, it is marketed in combination with other materials that are used in high value applications. With that in mind, IRTA and HESIS selected two applications for more detailed focus. First, DCE is used in vapor degreasing, most often in precision cleaning applications. Second, DCE is used in aerosol contact cleaning products.

N-Methyl Pyrrolidone

N-Methyl pyrrolidone or NMP is a solvent that contains nitrogen. The producers of NMP began marketing the chemical for use in various applications when the ban on TCA was scheduled to become effective. It has also been marketed as a safer alternative to methylene chloride (METH) as METH, a carcinogen, has been increasingly regulated.

NMP is a developmental and reproductive toxicant in animals. Several years ago, EPA evaluated the toxicity of NMP. EPA reported that NMP is a reproductive and developmental toxin. NMP is listed as a developmental toxin under Proposition 65.

NMP is used in a variety of applications where workers, community members and consumers have high exposure to the chemical. It is marketed as a safe alternative. With that in mind, IRTA and HESIS selected six applications for more detailed analysis. First, NMP is used in consumer product paint strippers as a safer alternative to METH. Second, NMP is used in furniture stripping, again as a safer alternative to METH. Third, NMP is used in a variety of other formulations for stripping in a range of applications.

Fourth, NMP is used in precision cleaning. Fifth, the chemical is used in pharmaceutical formulations for penetration enhancement. Sixth, NMP is used in children's shampoo and bath concentrate.

## PROJECT APPROACH

IRTA's role in the project was to identify and evaluate alternatives to the five candidate chemicals in the selected applications. For some categories, IRTA collected new information on the uses of the candidate chemicals. For other categories, IRTA had identified, tested, developed and demonstrated alternatives in previous projects. In those previous projects, IRTA analyzed the cost and performance of the alternatives and compared it to the chemical of interest. In some instances, the chemical of interest was not one of the chemicals that are candidates for analysis in this project. Accordingly, IRTA modified the earlier analysis to include analysis of the candidate chemical. An example is the category of furniture strippers for NMP. IRTA's focus in the earlier project was to find, test and analyze alternatives to METH strippers. For this project, IRTA used the earlier analysis and included additional analysis and comparison with an NMP based stripping product. Another example is the category of vapor degreasing for NPB. IRTA included case studies from earlier projects where the facilities did not use NPB and the analysis was updated to include the chemical.

The document contains information on many case studies of companies that used the candidate chemical or other similar chemicals in the same application. 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 the candidate chemical when they really did not. IRTA did not want to misrepresent the chemicals the companies used so their identity is protected. IRTA did identify two furniture stripping firms that tested alternative strippers in another project.

### Cost Analysis and Comparison

Cost analysis is presented in some of the case studies. The cost of using the alternative was compared with the cost of using the candidate solvent. 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
- gas cost
- 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 the case studies except one, a reasonable and conservative life for the equipment was assumed and the cost of capital was assumed to be five percent. In one case study, IRTA used a four year amortization because that is the procedure used by the company. The life of the equipment in that case would be much longer than four years so it overestimates the capital cost over the four year period.

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 one case, energized electrical equipment cleaning, the potential alternatives all pose one type of problem or another. In this case, there is not now a clearly safer alternative.

In paint stripping applications, the alternative that is most effective is benzyl alcohol. Strippers based on this material should be safer than strippers based on METH or NMP. Benzyl alcohol has been tested and found to be negative in a carcinogenicity test. It does, however, exhibit the central nervous system toxicity of all organic solvents.

In dry cleaning, the alternatives to PERC and D5 include water-based cleaners, carbon dioxide and hydrocarbon cleaners. HESIS has evaluated the toxicity of the hydrocarbon cleaner used most widely in dry cleaning and indicates that it is lower in toxicity than either PERC or D5.

In adhesive applications, the alternatives to METH and NPB are water-based products and acetone based products. Again, acetone is lower in toxicity than most other organic solvents.

IRTA evaluated a variety of other smaller uses. In a few cases, aerosol rust inhibitors and cosmetic stain removers, IRTA has tested alternatives with industrial firms using these types of products. In other cases, pharmaceutical penetration enhancer, children shampoo and bath concentrate and various other consumer products, IRTA has not tested alternatives. In these cases, the approach IRTA took was to identify other similar products in the same category that did not contain the candidate chemical. Since the alternatives were not tested, they might not perform exactly as the products do that contain the candidate chemical. IRTA and HESIS could not evaluate the toxicity of the ingredients in all of the alternatives because it was beyond the scope of the project. In the ideal, this should be done to ensure that the alternatives provided here are indeed safer.

REPORT ORGANIZATION

Sections II, III, IV, V and VI of this report focus on D5, PCBTF, NPB, DCE and NMP respectively. For each of the candidate chemicals, a description of the selected uses is provided. For all uses, the safer alternatives are presented. As mentioned above, in many instances, case studies with a cost comparison of the alternative and the candidate chemical are included. Section VII summarizes the results of the project. Material Safety Data Sheets (MSDSs) and product sheets for the candidate chemicals and the alternatives are presented in the appendices.

## II. DECAMETHYLCYCLOPENTASILOXANE

### BACKGROUND

Decamethylcyclopentasiloxane or D5 is a volatile methyl siloxane. It is an oily liquid with a flash point. D5 has been deemed exempt from VOC regulations by EPA and in California. This indicates that it is not classified as a VOC. The chemical is relatively new to the market so it is not listed as a Hazardous Air Pollutant (HAP) by EPA or a Toxic Air Contaminant (TAC) by the California Air Resources Board (CARB).

In 1993, EPA requested data on 56 silicones under the Toxic Substances Control Act (TSCA). EPA and Dow Corning, one of the D5 manufacturers, signed a Memorandum of Understanding (MOU) in 1996. The MOU involved a request for new data development on six siloxanes including D5. Dow Corning conducted a two-year chronic toxicity/oncogenicity study and released the preliminary results in 2003. According to the Office of Environmental Health Hazard Assessment (OEHHA), the results of the tests showed a statistically significant increase in a malignant tumor (adenocarcinoma) due to D5. EPA published a fact sheet on D5 after the preliminary results of the testing were released. This fact sheet concluded that D5 may be a cancer hazard. The final report on the chronic toxicity study was made available in 2006 and EPA and OEHHA are currently evaluating the results.

Over the last few years, D5 has been used increasingly in solvent applications. It is used fairly extensively in dry cleaning as an alternative to perchloroethylene (PERC). For this application, it is marketed under the tradename Green Earth. It is also used in repair and maintenance cleaning and it is used fairly extensively in consumer products. HESIS and IRTA decided to focus the alternatives analysis in three applications:

- dry cleaning
- repair and maintenance cleaning
- consumer products
    - antiperspirants and deodorants
    - hair products
    - beauty creams
    - sunscreens
    - personal lubricants

The balance of this section includes a discussion of each of these applications. In all cases, it begins with a description of the application. Then it presents safer alternatives that are available to replace D5. For dry cleaning and repair and maintenance cleaning, case studies of companies that analyze the cost of using alternatives are presented.

### DRY CLEANING

PERC is the most widely used dry cleaning agent. The chemical is a carcinogen and it is classified as a HAP by EPA and a TAC by CARB. PERC is a contaminant at numerous dry cleaning sites and landlords are increasingly reluctant to allow cleaners to use the technology. In 2002, the South Coast Air Quality Management District (SCAQMD) substantially amended their dry cleaning regulation to include a complete phaseout of PERC by 2020. CARB is currently proposing to amend their California statewide regulation to phase out PERC by 2023. EPA has strengthened the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulation recently to phase out PERC in facilities co-located with housing. It does allow the continued use of PERC for other dry cleaners, however.

Alternatives in Dry Cleaning

Almost all dry cleaners lease their space and virtually all landlords require dry cleaners to use a PERC alternative on lease renewal. Because of the landlord positions and because of the more stringent regulations, cleaners are increasingly adopting alternatives to PERC. In California, in particular, where regulations will phase out the use of PERC, about one-third of the cleaners in the state have already converted to alternatives. The alternatives to PERC include:

- Hydrocarbon and a variation of the hydrocarbon process called Pure Dry
- Green Earth (the dry cleaning formulation trade name for D5)
- Rynex which uses a glycol ether
- Water-based technologies (traditional wet cleaning, icy water cleaning, Green Jet)
- Carbon dioxide

The hydrocarbon, Green Earth and Rynex processes, since the solvents have flash points, must be used in equipment designed to handle these materials. The machines generally contain nitrogen which can be used to suppress the flammability in the machine in the event of ignition. Some equipment, like the equipment used with PERC, has a refrigerated condenser and some does not. Distillation of the solvent must be performed in a vacuum in the equipment since the boiling points of the alternative solvents are higher than the boiling point of PERC. Hydrocarbons and the Rynex solvent are classified as VOCs whereas Green Earth is not. The solvent-based alternatives to PERC are preferred by dry cleaners because they are in-kind technologies which are technologies where substantial changes in practices are not required to use them. Most companies that have adopted alternatives to PERC have moved to hydrocarbons but many have also converted to Green Earth. There are only a few Rynex facilities in California. MSDSs for Green Earth, one of the hydrocarbons called DF-2000 and Rynex are shown in Appendix A.

The water-based technologies rely on water, conditioners, degreasers and detergents for cleaning garments. Traditional wet cleaning has been used for more than 10 years in the U.S. and it is an aggressive cleaning method. Humidity controlled dryers are used to dry the garments. Special finishing equipment, called tensioning equipment, must be used when the garments still contain a small amount of residual moisture. There are only a few icy water shops in California. The vendors claim this technology results in less shrinkage than traditional wet cleaning and requires less finishing labor. The Green Jet technology is generally used in conjunction with another technology. The garments are not immersed in water but, rather, are sprayed with a water/detergent mixture in one machine that both cleans and dries the garments. The Green Jet technology is a gentle cleaning method that can be used only for lightly soiled garments. There are some exclusive wet cleaners in California but most of the industry has not accepted the water-based technologies because they require substantial changes in practices.

The carbon dioxide technology relies on liquid carbon dioxide used in a machine that is pressurized to about 700 psi. Carbon dioxide is a fairly gentle cleaning method and the detergents are not aggressive. The equipment is very expensive compared to PERC equipment and other alternative equipment and it is used by cleaners in high end areas where consumers can be charged higher prices. Most cleaners have not accepted carbon dioxide because of the high cost of the equipment and because the technology requires substantial changes in practices.

IRTA conducted a project on alternatives to PERC in dry cleaning that was sponsored by CARB as part of their regulatory development and EPA because the agency is interested in pollution prevention. The report, which analyzed the cost and performance of all the alternatives, is called "Evaluation of New and Emerging Technologies for Textile Cleaning" and was published in August 2005. In the report, IRTA presented 14 case studies of cleaners; nine of these had converted from PERC to alternatives and five had started up facilities with alternatives. Although the report analyzed alternatives to PERC, the other alternatives are obviously alternatives to Green Earth as well. Some of the relevant information from the report that relates to alternatives to PERC and therefore Green Earth is presented here.

Table 2-1 summarizes the results of the cost analysis in the PERC alternatives document. It compares the annualized cost for 12 cleaners using various alternatives to PERC. The first column identifies the facility; in this case, the facility name is not given and they are identified by number. The second column specifies the technology used by the cleaner. The third column gives the pounds of garments cleaned by the facility per year. The fourth column gives the total cost of using the technology for each facility. To normalize the costs for all facilities, the fifth column presents the total annual cost per pound of garments cleaned. Finally the last column presents the annual operating cost per pound of garments cleaned for each facility. The values in the last column exclude the cost of the equipment.

The values of Table 2-1 show that one of the cleaners using Green Earth, # 12, has the highest cost per pound of any facility. The second Green Earth cleaner, # 4, has a much lower cost per pound. The water-based technologies have lower costs per pound than # 12 but higher costs per pound than # 4 with the exception of # 1 which uses the icy water technology in one machine and PERC in a second machine. The carbon dioxide cleaners have higher costs per pound than # 4 but lower costs per pound than # 12. The hydrocarbon technology, used by # 2 and # 3, has a lower cost per pound that the two Green Earth facilities.

**Table 2-1**
**Annualized Cost Comparison for Dry Cleaners**

| Facility | Technology | Pounds Per Year | Total Cost | Total Cost Per Pound | Operating Cost Per Pound |
|---|---|---|---|---|---|
| # 1 | PERC/icy water | 312,000 | $202,188 | $0.65 | $0.63 |
| # 2 | hydrocarbon | 168,000 | $122,956 | $0.73 | $0.69 |
| # 3 | hydrocarbon | 254,800 | $259,384 | $1.02 | $0.99 |
| # 4 | Green Earth | 54,000 | $59,372 | $1.08 | $0.98 |
| # 5 | Rynex | 46,800 | $53,545 | $1.14 | $1.06 |
| # 6 | Pure Dry | 31,200 | $36,646 | $1.17 | $1.05 |
| # 7 | carbon dioxide | 117,000 | $143,073 | $1.22 | $1.12 |
| # 8 | Green Jet | 31,200 | $38,099 | $1.22 | $1.18 |
| # 9 | wet cleaning | 31,200 | $39,015 | $1.25 | $1.20 |
| # 10 | wet cleaning | 39,000 | $51,545 | $1.32 | $1.23 |
| # 11 | carbon dioxide | 104,000 | $145,647 | $1.40 | $1.29 |
| # 12 | Green Earth | 78,000 | $181,656 | $2.33 | $2.32 |

The water-based technologies and carbon dioxide are the preferred alternatives from an overall health and environmental standpoint. The costs per pound of these technologies is generally high. The cost per pound of the hydrocarbon technology is relatively low. The disadvantage of the hydrocarbon is that it is classified as a VOC. In another project performed by IRTA for Cal/EPA's Department of Toxic Substances Control (DTSC), IRTA investigated the hydrocarbon technology in more detail. As part of the project, HESIS reviewed the MSDSs and evaluated the toxicity of the hydrocarbon solvents that are used in dry cleaning. In general, the HESIS review indicated that the hydrocarbons are lower in toxicity than PERC. HESIS indicates for this current project that the toxicity of the hydrocarbons are also lower in toxicity than Green Earth. The toxicity of the solvent used in the Rynex process has not been evaluated so it is not clear whether it could serve as a safer alternative to Green Earth. It can be concluded that water-based, carbon dioxide and hydrocarbon technologies are available as safer alternatives to both PERC and Green Earth in dry cleaning.

## REPAIR AND MAINTENANCE CLEANING

Repair and maintenance cleaning is performed by auto repair facilities and certain types of industrial facilities. Auto repair facilities use cleaners to clean oil and grease from parts they are repairing and replacing in vehicles. Industrial facilities use cleaners to clean parts they are rebuilding or machining. Most repair and maintenance cleaning is performed using parts cleaners. Other types of cleaning units called immersion units are also used to some extent. In the South Coast Basin in California which includes four counties--Los Angeles, Orange, Riverside and San Bernardino--there are an estimated 40,000 parts cleaners and immersion units used for repair and maintenance cleaning. About 25,000 of these cleaning units are in auto repair facilities and 15,000 are in industrial facilities.

In 1999, a SCAQMD regulation for repair and maintenance cleaning required that cleaners used for this purpose have a VOC content of 50 grams per liter or less. Later, this limit was reduced further, to 25 grams per liter VOC.  Prior to the regulation, nearly all repair and maintenance cleaning was performed using mineral spirits.  After the regulation became effective, nearly all of the repair and maintenance cleaning in the South Coast Basin was performed with water-based cleaners.  A typical parts cleaner which is sometimes called a sink-on-a drum that uses a water-based cleaner is shown in Figure 2-1.  The water-based cleaner is stored in the drum below the sink and it is pumped into the sink for cleaning.  The sink contains a drain and the water-based cleaner flows through the drain to the drum below.

Figure 2-1.  Typical Parts Cleaner

Some of the auto repair and industrial facilities did not want to use water-based cleaners and a large service provider offered them a few chemical alternatives.  Because the regulation required cleaners to have a very low VOC content, only chemicals exempt from VOC regulation would be suitable.  The large service provider offered D5 and another chemical discussed in this document later, parachlorobenzotrifluoride or PCBTF as alternatives.  PCBTF, like D5, is exempt from VOC regulations.  An MSDS for the D5 material, called QSOL 300 Cleaning Solvent, that is sold for use in repair and maintenance cleaning is shown in Appendix A.  D5 and PCBTF had to be used in equipment that was very different from the equipment used for water-based cleaners.  A picture of the equipment used with D5 is shown in Figure 2-2.  Like a parts cleaner, the equipment has a sink.  Because the D5 is an expensive material, the equipment includes a distillation unit.  This unit is operated periodically or after the shop is closed and it reclaims the liquid D5 for reuse and leaves the contaminants in a sludge for pickup and disposal as hazardous waste.

Figure 2-2. D5 Cleaning System

Alternatives for Industrial Facilities

In an earlier project, sponsored by SCAQMD, IRTA worked with an industrial facility that rebuilds electric motors to assist them in converting from mineral spirits to a low-VOC alternative to comply with the regulation. The company decided to convert to D5 but IRTA evaluated and compared the costs of using mineral spirits, D5 and a water-based cleaner. Other electric motor rebuilders might also use D5 for their repair and maintenance cleaning. The case study from the earlier project is presented below.

Case Study for Electric Motor Rebuilder. Company A is a small company with 17 employees located in South El Monte. The company rebuilds electric motors that have been in the field, sometimes for years. Motors are received at the facility and they are disassembled. If the windings on the electric motors are still good, they clean them without removing the protective varnish. The metal parts are cleaned in a spray cabinet that uses a water-based cleaner.

Company A historically cleaned the windings in a mineral spirits parts cleaner. IRTA tested two alternatives with the company. IRTA provided the company with a water-based parts cleaner. The water-based cleaner is an alkaline cleaner with virtually no VOC. It performed effectively on the cleaning but Company A was reluctant to use it because oven baking would be necessary for the parts cleaned in the water-based cleaner. IRTA also tested a soy based cleaner which did not perform well on the parts. A service provider brought Company A a parts cleaner with a distillation unit that relied on D5 and the company decided to adopt the D5 system.

IRTA analyzed and compared the costs of the mineral spirits used by the company originally, the D5 used currently and the water-based cleaning alternative. If Company A were to use the water-based cleaner, a heated parts cleaner similar to the unit shown in Figure 2-1would be required. The cost of the unit is about $1,500. Assuming a useful life for the parts cleaner of 10 years and a cost of capital of five percent, the annualized cost would be $158.

Company A leased a mineral spirits parts cleaner from a service provider who supplied the cleaning unit and the mineral spirits and provided maintenance and disposal services. The annual cost of the service was $1,300. Company A also leases the D5 unit and the service includes maintenance and disposal costs but the company purchases the D5 separately. The cost of the D5 service is $1,188 annually.

The cost of the D5 is $35 per gallon. Company A uses the distillation unit to recycle the solvent and the company purchases five gallons every six months. The total annual cost of the D5 is $350. The cost of the water-based cleaner is $10 per gallon. If a 30 percent concentration of the cleaner were required for the 30 gallon parts cleaner, then the cost of replacing the bath would amount to $90. The cleaner would require replacement every three months. The annual cost for purchasing the water-based cleaner would be $360.

The mineral spirits parts cleaner had a one-fourth horse power pump which ran four hours per day. The annual electricity cost was $42. The D5 unit has the same pump but also has a still that is run at the end of the day. The still uses 5 kW of electricity and runs for a two hour cycle. Assuming an electricity cost of 12 cents per kWh and that the still operates for 260 days per year, the electricity cost for the D5 unit is $354 annually. The water-based parts cleaner has the same pump as the other two units and it has a 2 kW heater that cycles on and off. Assuming the parts cleaner is used four hours per day, that it cycles on half the time, that it is used for 260 days per year and that the electricity cost is 12 cents per kWh, the annual electricity cost of the water-based cleaner is $167.

If Company A were to adopt a water-based cleaner, most of the parts would be air dried. The oven the company already owns would be used to dry the electrical windings. There would be no extra cost for drying the windings because they could be put through the oven with other parts that have been coated.

The disposal costs for the mineral spirits and the D5 are included in the servicing cost. For the water-based cleaner, it was assumed that the disposal cost would amount to $2 per gallon. The disposal of the 120 gallons annually would cost $240.

Table 2-2 shows the cost comparison for Company A. The cost of using the D5 is 41 percent higher than the cost of using the mineral spirits. The cost of using the water-based cleaner is lower than the cost of using either of the solvent alternatives even with the drying cost included in the analysis.

**Table 2-2**
**Annualized Cost Comparison for Company A for Electric Motors**

| | Mineral Spirits | D5 | Water-Based Cleaner |
|---|---|---|---|
| Annualized Capital Cost | - | - | $158 |
| Servicing Cost | $1,300 | $1,188 | - |
| Cleaner Cost | - | $350 | $360 |
| Electricity Cost | $42 | $354 | $167 |
| Disposal Cost | - | - | $240 |
| Total Cost | $1,342 | $1,892 | $925 |

Alternatives for Auto Repair Facilities

Some auto repair facilities are using D5 for repair and maintenance cleaning. The types of auto repair facilities that would most likely not want to use water-based cleaners and would, instead use D5 are shops that clean complex components like transmissions, carburetors or fuel injection systems. In earlier projects, IRTA worked with a few transmission shops, one carburetor rebuilder and a shop that specialized in repairing sensors and fuel injectors. All of these shops used mineral spirits and successfully converted to water-based cleaners. This demonstrates that water-based cleaners are suitable for the more complex auto repair cleaning applications. A case study of a fuel injector shop that shows the cost comparison for using mineral spirits and a water-based cleaner is shown below. The case study has been updated to include the cost of using D5.

Case Study for Company B. Company B repairs vehicle diesel engines and fuel injection systems. This facility replaced a mineral spirits unit with an ultrasonic cleaning unit that uses a water-based cleaner. IRTA analyzed and compared the cost of using the mineral spirits and the water-based cleaner in an earlier study. For this project, IRTA analyzed the cost to the facility of using D5 since facilities with similar operations might use the chemical.

Company B purchased a large ultrasonic cleaning system for cleaning the fuel injection system parts for $9,300. Assuming a five year life for the equipment and a five percent cost of capital, the annualized cost of the system is $1,953.

The company leased a mineral spirits unit and the service cost, which includes leasing, chemical and disposal costs, was $1,680 per year. If the company leased the same kind of D5 system used by Company A above which includes the distillation system, the servicing cost would be the same as that of Company A, $1,188 annually. Note that the servicing cost for the D5 does not include the cost of the chemical.

Company A spends $350 annually to purchase D5; the same assumption will be made for Company B. The concentration of the water-based cleaner in the ultrasonic system is 10 percent. The 60 gallon bath is changed out six times a year and an additional 10 percent cleaner is required for makeup. The price of the cleaner is $15 per gallon. The annual cost for purchasing the water-based cleaner is $594.

The mineral spirits parts cleaner must be manually operated. The same is true for the D5 unit. When the company used mineral spirits, one worker spent 50 weeks per year cleaning with the unit at a labor cost of $350 per week. The annual labor cost amounted to $17,500. This same labor cost would be incurred with the D5 unit. The water-based ultrasonic system is automated and requires only 10 percent of the labor required for cleaning with the other two units. The annual labor cost for using the water-based system is $1,750.

The electricity cost for the mineral spirits unit is $5 per month or $60 per year. Because the D5 unit has a distillation system, the electricity cost is higher. Assuming the same electricity cost as for Company A, Company B's electricity cost for operating the D5 unit would be $354 annually. Using electricity bills for the facility, the electricity cost for operating the water-based ultrasonic system is $684 annually.

Disposal of the mineral spirits and the D5 is included in the servicing cost. The water-based cleaning bath requires change out six times a year at a price of $200 per drum. Assuming one drum per disposal, the annual disposal cost of the water-based cleaner is $1,200.

Table 2-3 shows the cost comparison for the mineral spirits system, the D5 system and the water-based ultrasonic system. The cost of using the water-based cleaner is less than one-third the cost of using mineral spirits or D5, primarily because of the labor savings. It's worth noting that other shops that may be using D5, carburetor and transmission shops, would also be likely to use an ultrasonic system which automates the cleaning. Their savings in using a water-based cleaner could be comparable to the savings for Company B.

**Table 2-3**
**Annualized Cost Comparison for Company B for Fuel Injection Systems**

| | Mineral Spirits | D5 | Water-Based Cleaner |
|---|---|---|---|
| Annualized Capital Cost | - | - | $1,953 |
| Servicing Cost | $1,680 | $1,188 | - |
| Cleaner Cost | - | $350 | $594 |
| Labor Cost | $17,500 | $17,500 | $1,750 |
| Electricity Cost | $60 | $354 | $684 |
| Disposal Cost | - | - | $1,200 |
| Total Cost | $19,240 | $19,392 | $6,181 |

CONSUMER PRODUCTS

Silicones, including D5, were introduced for use in cosmetics and toiletries applications in the 1950s and are now so widely used that more than half the consumer skin care products contain some silicone. More recently, silicone products have begun to be used in pharmaceutical preparations. A Danish study estimates that 60 percent of the silicones used for cosmetics, toiletries and pharmaceutical preparations are used in hair, skin and other personal care products in the U.S. The same study estimates that 32 percent of these silicones are used in stick antiperspirants. Some specific applications where D5 is used include:

- antiperspirants and deodorants
- hair care products
- skin care products like beauty creams
- sunscreens
- personal lubricants

D5 is used in the cosmetics and toiletries industry under the trade name cyclomethicone. In general, cyclomethicone is a mixture of D5 and another silicone material called D4. In this project, IRTA focused on the D5 (or cyclomethicone) used in the applications listed above. More specifically, IRTA focused on D5 use in antiperspirants/deodorants, sun screen, beauty creams, shampoos/conditioners and personal lubricants. The Danish study indicates that the typical content of the siloxanes in cosmetics and toiletries is less than two percent of the final product but the content can vary between 0.5 and 40 percent depending on the product.

Siloxanes have some very good properties which make them attractive for use in the cosmetics and toiletries applications. For lotions and skin creams, the siloxanes can give the product a smooth and soft feeling on the skin without being greasy. The silicones function as emollients, antifoaming agents, agents that control viscosity, antistatic agents, binders, film formers, surfactants, emulsifying agents, humectants, antioxidants and additives. In hair styling products, the silicones give a reduced tack, reduced drying time and a transitory shine. Other characteristics of silicones that are attractive is that they are generally not sticky, not oily, not irritating and do not make marks on clothing.

In the five product categories defined above, IRTA identified several specific products that used cyclomethicone. IRTA did not perform a thorough analysis of each product type and the alternatives that are available because it was beyond the scope of the project. To demonstrate that alternative products are available, IRTA also identified specific products in the same category as examples that do not contain cyclomethicone. The products that contain D5 and do not contain D5 are identified by an MSDS, a description from the National Institutes of Health National Library of Medicine Specialized Information Services data base (NIH data sheets) or product sheets. IRTA also relied on the recent Danish study mentioned above to determine potential alternatives for cyclomethicone. In what follows in this section, IRTA first presents the alternatives identified in the Danish study as potential alternatives for cyclomethicone in general.

Then, alternative specific products that do and do not contain cyclomethicone are presented.

General Alternatives

One alternative identified in the Danish study for cyclomethicone in conditioners, lotions and creams and perhaps also shampoos and cream soaps is isodecyl neopentanoate (IDNP). The material has high spreadability and gives a soft feeling like cyclomethicone. It can function both as a solvent and an emulsifier. IDNP is about twice the cost of cyclomethicone.

The second alternative for cyclomethicone in cream soaps and related products is glycol distearate (GD). This material does not impart exactly the same properties as cyclomethicone. GD gives the product a milk like appearance and contains wax which gives shine and smooth feeling to cream soaps, shower gels and shampoos. Cyclomethicone gives a more distinct feeling of softness but the GD has similar properties. The price of products containing GD is about half the price of products containing cyclomethicone.

The third alternative for cyclomethicone in creams and lotions is various vegetable oil components like dicapryly carbonate (DC). In this case, as was true for GD, the DC does not have exactly the same properties as cyclomethicone. DC does give softness and spreadability to the products but it does not have the foam reducing effect of cyclomethicone. DC is slightly less expensive than cyclomethicone.

The fourth alternative for cyclomethicone when it is used in conjunction with paraffin oils in creams and lotions is hydrogenated polydecen (HP). The HP can substitute for both the cyclomethicone and paraffin oil in a product. It gives some of the same soft feeling to the skin and does not feel greasy. It does not, however, give the extra soft feeling imparted by cyclomethicone.

Alternatives in Antiperspirants and Deodorants

In this category, four representative products, Right Guard Sport, Secret Wide Solid Antiperspirant & Deodorant, Secret Aerosol Antiperspirant LYD and Sure Roll-On Antiperspirant & Deodorant IR, that contain D5 or cyclomethicone were identified. The NIH data sheets or MSDSs for the products are shown in Appendix A. Two of the products are aerosol and two are solid. The data sheets and MSDSs indicate that three of the products contain cyclomethicone and one contains D5.

IRTA found two representative alternative products, Ban Roll On Deodorant and Old Spice Classic Stick Deodorant, that do not contain cyclomethicone or D5. The MSDS and data sheet for the two products are shown in Appendix A. One product is a stick deodorant and the other is a roll-on.

Alternatives in Hair Care Products

IRTA identified two representative hair care products, Suave for Men 2 in 1 Shampoo & Conditioner and Halo Curl Conditioner, that contain cyclomethicone or D5. MSDSs for these two products are shown in Appendix A.

IRTA found three alternative hair care products, Suave Naturals Fresh Mountain Strawberry Shampoo, Head & Shoulders Classic Clean 2-in-1 Anti-Dandruff Shampoo and Infusium 23 Maximum Body Shampoo, that do not contain cyclomethicone or D5. MSDSs for these products are shown in Appendix A. Note that the Head and Shoulders product contains dimethicone but dimethicone does not contain D5.

Alternatives in Skin Care Products

IRTA identified one skin care product called JOEY New York Correct-A-Line that contains D5. A product sheet for this skin cream is shown in Appendix A.

IRTA found two skin care products that do not contain D5 or cyclomethicone. MSDSs for the two products, Herbal Essences Facial Moisturizer and Noxzema Sensitive Skin Cream, are shown in Appendix A. Note that the Noxzema product contains one of the general alternatives, glycol distearate, discussed above.

Alternatives in Sunscreens

IRTA identified three sun screen products that contain D5 in the form of cyclomethicone. Product sheets for the three products, Glytone Wellskin--Sunscreen SPF 25, Pedinol Ti-Screen Sunscreen SPF 23 and Vanicream Sunscreen Sport SPF 35, are shown in Appendix A.

Alternatives that do not contain D5 or cyclomethicone include GoJo Sunscreen SPF 15, Total Solutions Sunscreen Wipes, Solarepel Sunscreen SPF 25, Stoko UV SPF 30+ Lotion and SunVantage Sunscreen SPF 30+. MSDSs and a product sheet for these products are shown in Appendix A.

Alternatives in Personal Lubricants

IRTA found two representative personal lubricants that contain D5. Product sheets for these two products, called Herbal Enhance Life Sexual Stimulant Gel and System Jo Silicone Lubricant, are shown in Appendix A.

IRTA identified five alternative personal lubricants that do not contain D5 or cyclomethicone. Four product sheets that describe K-Y Personal Lubricant Jelly, Emerita--Personal Lubricant, Nature’s Personal Lubricant, Astroglide Gel are shown in Appendix A. One MSDS for an additional product called Veena Slida is also shown in Appendix A.

# III. PARACHLOROBENZOTRIFLUORIDE

## BACKGROUND

The structure of parachlorobenzotrifluoride or PCBTF is a benzene ring with a chlorine substituent. Many other chemicals with this general structure have very high toxicity.

PCBTF has been marketed for at least the last decade but there are currently no U.S. producers of the chemical. Because PCBTF is relatively new to the market, it has not been tested for chronic toxicity and it is not on the HAP, TAC or Proposition 65 lists. EPA and most states exempted the chemical from VOC regulations so it does not contribute to photochemical smog formation. As a consequence of its exemption, it is used extensively in California in particular in several different types of formulations to meet the state's stringent VOC limits.

Several years ago, the SCAQMD adopted a regulation for the autobody industry that relied on the availability of PCBTF. The District established low VOC limits for coatings used in that industry. In 1999, a SCAQMD regulation that set low VOC limits on repair and maintenance cleaning materials became effective and some facilities began using PCBTF to comply. More recently, SCAQMD adopted a regulation that set lower VOC limits for coating application equipment cleanup and many autobody facilities are using PCBTF formulations to comply. PCBTF is also used in certain consumer products. IRTA and HESIS selected several areas of focus in light of the applications where PCBTF is used. They include:

- autobody coating
- autobody coating thinning
- autobody coating application equipment cleaning
- repair and maintenance cleaning
- cosmetic stain removal
- aerosol rust prevention

The first four uses of PCBTF occur in industrial facilities and the last two are consumer product categories. The balance of this section describes the uses of PCBTF in these applications and discusses the safer alternatives that are available.

## AUTOBODY COATING

In the South Coast Basin, there are approximately 3,500 businesses that use automotive coatings and 1,730 of these apply automotive coatings on a routine basis. There are likely to be about twice as many facilities in California. These businesses include autobody repair/paint shops, production autobody paint shops, new car dealer repair/paint shops, fleet operators repair/paint shops, custom-made car fabrication facilities and truck body builders. Autobody shops apply coatings to vehicles to protect and enhance the appearance of exterior surfaces. The coatings are applied to a vehicle as part of a repair process following accidents to rectify damage.

Refinishing may be done on a spot, a panel or the entire vehicle. Spot repair and paint work is generally performed on a small damaged area. Panel repair is similar except that the work area is larger and may include a hood or a door, for instance. The entire vehicle could be repainted because the paint is faded or a different color is requested. The repair work would generally include the physical repair of the damaged area, conditioning of substrate and application of undercoats and topcoats. Two views of a typical spray booth in an autobody shop are shown in Figure 3-1 and Figure 3-2.

Figure 3-1. Outside of Typical Spray Booth

Figure 3-2. Inside of Typical Spray Booth

Undercoats include primers, primer surfacers and primer sealers which prepare the exterior surfaces by providing corrosion resistance, adhesion and a smooth foundation for topcoats. Topcoats are applied to provide color, gloss and a protective finish. In many cases, the first topcoat is called a base coat which contains the pigmentations and metallic flakes that provide the final color and color effects. The second topcoat is a non-pigmented clear coat that provides hardness and durability to the final finish.

Virtually all autobody shops use air dry coatings or coatings that are cured using infrared lamps or by forced-air spray booths. Refinishing shops cannot use high temperature ovens because the high temperature could damage other components in the vehicle. As a result, automotive refinishing coatings are formulated for fast drying times.

Over the last several years, in California in particular, autobody shops have been required to meet regulations that have low VOC limits for the primers, base (or color) coats and topcoats. Coating suppliers reformulated the coatings that are currently in widespread use with PCBTF because it was exempt from VOC regulations. MSDSs for two autobody primer products, called PCL Euroseal Non-Sanding Urethane Catalyst and PCL Euroseal Non `Sanding Primer Sealer White, that contain PCBTF are shown in Appendix B. An MSDS for a typical basecoat, called Western Dimension 2.8 VOC H.S. Urethane System, containing PCBTF is also shown in the appendix. MSDSs for two clearcoats, called High Solid 3 Minute Clearcoat and Bondo 4.3 Ultra High Image Clear, containing PCBTF are shown in Appendix B.

Alternative Autobody Coatings

There are alternative coatings offered by several suppliers on the market today that do not contain PCBTF. IRTA identified alternative primers, basecoats and topcoats that contain solvents with primarily known, acute toxicity that could serve as alternatives to the PCBTF coatings. IRTA found three alternative primers, called PCL Polyprimer Surfacer White, PCL Aquaprimer W/B Primer Surfacer White and Sherwin Williams Water-reducible Primers, that meet the current VOC limits and do not contain PCBTF. IRTA identified two alternative basecoats, called PCL Enviro-Finish Polyurethane Coating (Part A & B) and Sherwin Williams Waterborne Basecoat System, that do not contain PCBTF. IRTA also found three alternative topcoats, called Sherwin Williams Ultra One Stage Turbo 3.5 System, Sherwin Williams Acrylyd H.S. 3.5 VOC System and Bondo Ultra High Image A/U Clear, that do not contain PCBTF. MSDSs for these products are provided in Appendix B.

ARB adopted a Suggested Control Measure (SCM) for Automotive Refinishing Coatings in October of 2005. The SCM is not a regulation but rather is a guideline for the air districts in California that develop the regulations. In December of 2005, SCAQMD adopted a regulation for the industry that was similar to the SCM adopted by CARB. The SCAQMD regulation, which covers about half the autobody shops in the state, substantially reduced the allowed VOC content of coatings that could be used by the industry. Both the SCM and the SCAQMD regulation established VOC limits based on waterborne coatings that are available in Europe. The European Union is implementing waterborne technology in 2007 as part of the European Parliament directive to reduce VOC emissions from coatings and solvents. The lower SCAQMD limits are scheduled to become effective in 2008 and 2009 for most coatings. Other local air districts in California will likely adopt the SCM or regulations similar to the SCAQMD regulation over the next several years.

The new coatings that are being developed and tested for the industry are not yet available from the suppliers. They will begin to be tested in several autobody shops in 2007. MSDSs for the coatings are not available at this time since the coatings are still being formulated. If they are based on the waterborne technology used in Europe, they are not likely to contain PCBTF. Even if some of the coatings do contain PCBTF, it is likely that some products that do not contain PCBTF will be available. Before the more stringent regulations become effective in SCAQMD and before regulations are adopted in the rest of the state, autobody shops in California can use the alternative solventborne coatings listed above that contain solvents of known, primarily acute toxicity, and that do not contain PCBTF.

AUTOBODY COATING THINNER

Autobody shops apply their coatings most often with spray equipment. A typical spray gun used in an autobody shop is shown in Figure 3-3. At certain times of the year, when the weather is cold, for instance, the coating does not flow through the equipment as easily. Thinners are used by all autobody shops to thin the coatings so they flow properly during application. Thinners are also referred to as reducers or retarders. Some companies supply slow, medium and fast retarders that are used at different times of the year depending on the weather.

Figure 3-3. Typical Spray Gun

Some of the thinners for this industry are formulated with PCBTF since the coatings often also have PCBTF as a component. An MSDS for a typical thinner that contains PCBTF, called PCL Slow Universal Exempt Reducer, is shown in Appendix B.

Alternative Thinners

There are a variety of alternative thinners that do not contain PCBTF as a component. MSDSs for two typical products, PCL Medium Urethane Reducer and Bondo Virgin Lacquer Thinner are shown in Appendix B.

IRTA is currently conducting a project sponsored by DTSC that is focusing on testing alternative low-VOC, low toxicity thinners and cleanup materials for consumer product coatings. IRTA is testing alternative thinners with the autobody industry. The alternatives that are being tested are acetone, a soy/acetone blend and a glycol ether/acetone blend. Acetone is not a VOC and soy has a very low VOC content. These materials are low in toxicity. Acetone can be purchsed from hardware and home improvement stores and soy and glycol ether based materials are available from suppliers.

AUTOBODY COATING APPLICATION EQUIPMENT CLEANING

Many companies that paint and apply adhesive use solvents to clean coating and adhesive application equipment. The application equipment can be a spray gun or rollers or brushes. Autobody shops apply their coatings using spray guns and the companies often use solvents containing PCBTF to remove the coating residue from the spray equipment at the end of the day or when they are changing the type or color of the coating. An MSDS for a typical autobody coating application equipment cleaner that contains PCBTF, called 25 gms/L Compliant Cleaning Solvent, is shown in Appendix B.

Some smaller autobody shops clean the spray guns in buckets containing the solvent cleaner. Many autobody shops use spray gun cleaning systems that are designed to funnel solvent through the inside of the spray gun and spray the outside of the spray gun. The cleaning solvent is in a five gallon container which is part of the system. The spray gun is placed in a chamber at the top of the system and turned on. The solvent cleans the gun and the spent solvent drains back into the five gallon container. A picture of a typical spray gun cleaning system used by autobody shops is shown in Figure 3-4.

Figure 3-4.  Typical Spray Gun Cleaning System

Alternative Application Equipment Cleaners

IRTA conducted projects sponsored by SCAQMD and EPA a few years ago that involved identifying, testing and demonstrating alternative low-VOC, low toxicity cleaners for coating and adhesive application equipment cleaning. IRTA worked with several facilities that applied coatings and adhesives in a variety of different industries. Two of the facilities that participated in the projects were autobody shops. Based on the results of the projects, SCAQMD lowered the allowed VOC content of cleaners used in cleaning coating and adhesive application equipment to 25 grams per liter.

IRTA tested acetone based cleaners with the two autobody shops. In one case, pure acetone worked effectively in the spray gun cleaning system. In the second case, IRTA tested a blend composed of 80 percent acetone and 20 percent methyl acetate and it worked effectively. Methyl acetate, like acetone, is exempt from VOC regulations. IRTA conducted a cost comparison for the companies to compare the cost of their high VOC solvent and the cost of the alternatives IRTA tested. The case studies are described below and they demonstrate that alternatives that do not contain PCBTF are effective.

Case Study for Autobody Shop #1. Autobody Shop #1 is located in Santa Monica, California. It is one of a chain of 10 body shops located in Southern California. Like other body shops, the company repairs cars and paints them as part of their process. The company uses High Pressure Low Volume (HVLP) spry guns and the guns are cleaned in an enclosed spray gun cleaning unit leased by Autobody Shop #1. A picture of the gun cleaner is shown in Figure 3-5. A service provider maintains the equipment, supplies the cleaning solvent and disposes of the waste. It is likely that the company was using a solvent containing PCBTF in the cleaning operation.


Figure 3-5. Spray Gun Cleaner at Autobody Shop #1

During preliminary laboratory testing, IRTA cleaned the spray gun contaminated with the coatings with acetone with only marginal success. IRTA was able to clean the gun with a blend of 80 percent acetone and 20 percent methyl acetate. IRTA provided five gallons of plain acetone and five gallons of the acetone/methyl acetate blend to the company for scaled up testing in the cleaning system. The plain acetone did not work effectively but the acetone/methyl acetate blend did work well.

The cleaning unit used by the shop currently is leased from the solvent provider. If the autobody shop converted to the acetone/methyl acetate blend, the company would have to purchase an enclosed spray gun cleaning unit to use the solvent. Such units cost about $1,050. Assuming a 10 year useful life for the equipment and a cost of capital of five percent, the annualized cost of the unit would be $110.

The autobody shop's service provider does the maintenance on the leased spray gun cleaner. The servicing cost, which includes maintenance, the cost of leasing the unit, the cost of the solvent, the change out cost and the disposal cost, amounts to $2,290 annually. If the company converted to the new blend, the workers would have to devote about 30 minutes to change out of the cleaner. Currently the cleaner is changed out once a month. Assuming the new blend would also have to be changed out once a month and assuming a labor cost of $10 per hour, the maintenance/change out cost would be $60 per year.

The cost of the cleaner is currently included in the total service cost. If the company converted to the new blend, the cost of the cleaner would be $7.21 per gallon if the company purchased the solvent in drum quantity. The annual cleaner cost would amount to $1,082.

The disposal cost is presently included in the servicing cost. If the autobody shop converted to the new cleaner, the company would have to dispose of 60 gallons of hazardous waste each year. Assuming a disposal cost of $2 per gallon, the annual disposal cost would amount to $120 per year.

Table 3-1 shows the costs for the current and new cleaner for the autobody shop. The figures show that the company could reduce their cost by 40 percent by converting to the alternative.

**Table 3-1**
**Annualized Cost Comparison for Spray Gun Cleaning for Autobody Shop #1**

| | Current Cleaner | Acetone/Methyl Acetate Blend |
|---|---|---|
| Annualized Capital Cost | - | $110 |
| Servicing Cost | $2,290 | - |
| Maintenance Cost | - | $60 |
| Cleaner Cost | - | $1,082 |
| Disposal Cost | - | $120 |
| Total Cost | $2,290 | $1,372 |

Case Study for Autobody Shop #2. Autobody Shop #2, like Autobody Shop #1, is located in Santa Monica, California. The company repairs cars and, as part of that activity, they paint them. The shop uses an enclosed spray gun cleaner that belongs to the facility to clean the HVLP spray guns that are used to apply the coatings. A picture of this spray gun cleaner is shown in Figure 3-6. The cleaner used by the company is lacquer thinner which would not comply with the VOC limit for cleaners today.


Figure 3-6. Spray Gun Cleaner at Autobody Shop #2

IRTA performed preliminary testing on Autobody Shop B's coatings. The results indicated that the coatings could be cleaned with acetone or an 80 percent blend of acetone and methyl acetate. IRTA conducted scaled up testing at the shop with plain acetone and, after testing it for a few months, the workers indicated that it was an effective cleaner.

To make the conversion to acetone, the company could use the new cleaner in their spray gun cleaner so no capital investment in equipment would be required. Autobody Shop #2 uses about five gallons of lacquer thinner each quarter. At a cost of $11.05 per gallon at a home improvement center, the total annual cost for purchasing the lacquer thinner is $221. The cost of acetone is $13.95 per gallon if it is purchased at a home improvement center. Assuming the same amount of acetone would be used, the annual cost of the acetone would be $279. Disposal costs for the 20 gallons of spent acetone or spent lacquer thinner would amount to $40 annually.

Table 3-2 shows the cost comparison of the cleanup solvents for the autobody shop. The cost of using the acetone cleaner is 22 percent higher than the cost of using the lacquer thinner.

**Table 3-2**

**Annualized Cost Comparison for Spray Gun Cleaning for Autobody Shop #2**

| | Lacquer Thinner | Acetone |
|---|---|---|
| Cleaner Cost | $221 | $279 |
| Disposal Cost | $40 | $40 |
| Total Cost | $261 | $319 |

Other Commercial Application Equipment Alternative Cleaners

Because of the more stringent SCAQMD regulation, many vendors now offer low-VOC cleanup materials. Since PCBTF is exempt from VOC regulations, many of the suppliers offer formulations based on PCBTF. As demonstrated by the case studies, however, plain acetone or a blend of acetone and methyl acetate is a very suitable and effective cleanup material for this industry. MSDSs for two low-VOC cleaning products that do not contain PCBTF are shown in Appendix B. One of the products, a blend of acetone and methyl acetate is called No VOC Universal Solvent. The second product, a blend of acetone and naphtha, is called Compliant Surface Cleaner. The third product, composed of plain acetone, is called Bondo Acetone.

IRTA is currently working on two projects sponsored by DTSC that focus on alternative cleanup solvents for autobody coatings. IRTA has conducted testing of acetone at five of the facilities participating in the projects and has found plain acetone to be an effective cleanup solvent in all five cases.

REPAIR AND MAINTENANCE CLEANING

This type of cleaning was discussed in the section on D5. Repair and maintenance cleaning is performed by auto repair shops and industrial firms that repair equipment from the field or that are or have machine shops. In the South Coast Basin, the VOC content of cleaners used in repair and maintenance cleaning is set at 25 grams per liter. Water-based cleaners are widely and commonly used for repair and maintenance cleaning.

Some suppliers offer PCBTF for repair and maintenance cleaning in Southern California. PCBTF complies with the SCAQMD VOC limit for this type of cleaning because it is not classified as a VOC. The companies that use PCBTF believe that they need to use solvents for their cleaning activities and that water-based cleaners will not work for them. An MSDS for a typical PCBTF repair and maintenance cleaner, called QSOL 220 Cleaning Solvent, is shown in Appendix B.

The PCBTF is used in equipment designed with a sink and drum setup. The PCBTF is pumped into a sink from a reservoir below. The parts are cleaned in the sink and the spent cleaner flows from the sink drain back to the reservoir below. When the unit is not being used, the solvent is distilled and the sludge is sent off-site as waste. The units using PCBTF generally have a ventilation hood because the odor of the solvent is strong.

A picture of a typical repair and maintenance cleaning unit designed for use with PCBTF is shown in Figure 3-7.

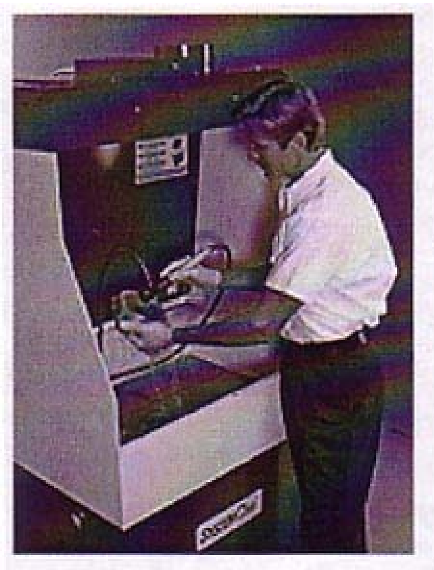

Figure 3-7. PCBTF Cleaning System

Alternatives in Repair and Maintenance Cleaning

As part of this project, IRTA visited two shops that use PCBTF parts cleaners for repair and maintenance cleaning. One of the shops provides engine service to marine vessels and uses the system to clean engine parts. The other facility rebuilds automotive engine and motorcycle parts and uses the system for cleaning the motorcycle parts. There are many facilities that clean and rebuild engine parts and whole engines and they use water-based cleaners. These two facilities could readily convert to systems using water-based cleaners. One company IRTA worked with on low-VOC rust inhibitors remanufactures engines and calipers for a large automotive manufacturer. The company has several cleaning systems that are used as part of the remanufacturing process and they all use water-based cleaners. The standards for remanufacturing are much higher than the standards for rebuilding.

IRTA compared the cost for a typical engine and parts rebuilder for using the PCBTF cleaning system and using a water-based parts cleaning system. The cost of a PCBTF cleaning unit is about $4,000 and the cost of a water-based parts cleaning system is about $1,500. Assuming that both systems have a useful life of 10 years and that the cost of capital is five percent, the annualized cost of the PCBTF system is $420 and the annualized cost of the water-based system is $158.

The PCBTF cleaning system is a 30 gallon system. Because it includes a distillation unit, the company would only need to purchase 15 gallons per year of makeup solvent. The cost of servicing the unit and providing makeup solvent would amount to $35 for an annual cost of $525. The still bottom can be disposed of with waste oil. The company would pay 15 cents per gallon and a stop fee of $50 for disposal once a year. The total annual cost of the disposal, assuming five gallons of sludge was generated, would be $51.

The water-based cleaning system has a 30 gallon tank. It would require change out every twelve weeks. The servicing cost for the system, which includes cleaning and draining the unit, changing out the detergent and disposing of the spent cleaner would be $175 per service. The annual cost of servicing the unit would be $758.

The PCBTF unit has a 6 kW heater which is used when the solvent is distilled. Assuming distillation is performed twice a month and that it requires six hours, the company would use 864 kWh per year. Assuming a cost of 12 cents per kWh, the electricity cost of running the PCBTF unit would be $104 annually. The water-based parts cleaner has a 2 kW heater that cycles on and off. Assuming the parts cleaner is used four hours per day, that it cycles on half the time, that it is used for 260 days per year and that the electricity cost is 12 cents per kWh, the annual electricity cost of the water-based cleaner is $167.

Table 3-3 shows the annualized cost comparison for the typical engine and parts rebuilder for the PCBTF unit and the water-based cleaning system. The cost of using the PCBTF and water cleaning systems is comparable.

**Table 3-3**
**Annualized Cost Comparison for Engine Rebuilder**

| | PCBTF System | Water-BasedCleaning System |
|---|---|---|
| Cleaning Unit Cost | $420 | $158 |
| Servicing/Disposal Cost | $576 | $758 |
| Electricity Cost | $104 | $167 |
| Total Cost | $1,100 | $1,083 |

COSMETIC STAIN REMOVER

PCBTF is used in cosmetic stain removers for removing lipstick, mascara, foundation, suntan lotion, hair preparation, eye makeup and other cosmetics from clothing and other items like shoes or handbags made of fabric. One consumer product called EverBlum Cosmetic Stain Remover, has an applicator for applying the formulation and it is not an aerosol. A product sheet and an MSDS for this product is shown in Appendix B. PERC and TCE are also used extensively as spot removers in the dry cleaning industry. One aerosol consumer product containing both chemicals is called Sprayway 830--Spot Remover. A product sheet and MSDS for this product is shown in Appendix B. PERC and TCE stain removers would obviously not be safer alternatives for PCBTF cosmetic stain removers. Alternatives for PERC and TCE spotting agents would also be potential alternatives for products containing PCBTF.

The textile cleaning industry uses so-called Paint, Oil and Grease (POG) removers to pre- and post-spot garments before and after dry cleaning or wet processing. POG stain removers are designed to remove cosmetics. The industry has historically relied on PERC and TCE POG spotting agents. Consumers also use spotting agents before laundering garments and for general purpose cleaning. The EverBlum and Sprayway products described above would be marketed for dry cleaner or consumer use.

Alternatives in Cosmetic Stain Removal

IRTA identified several products that are advertised as cosmetic stain removers that do not contain PCBTF. Product sheets and MSDSs for four of these products, called Citrus Carpet Spotter--Citrus Gel, Kleerwite Nature--L, Kleerwite Super P.O.G. and Aqua Clean Laundry Pre-Spot, are shown in Appendix B. The Citrus product contains terpenes and a hydrocarbon. The next two products made by Kleerwite are designed to remove oil and grease and a range of cosmetics. The ingredients for Super P.O.G. include mineral spirits, amyl acetate and a glycol ether. The last product, Aqua Clean Laundry Pre-Spot, is apparently an alkaline water-based material containing isopropyl alcohol. These products would likely all be safer than the PERC/TCE and the PCBTF products discussed above.

IRTA is currently conducting a project sponsored by DTSC and EPA to identify, develop, test and demonstrate alternative low-VOC, low toxicity alternatives to PERC and TCE POG spotting agents in the dry cleaning industry. IRTA has tested two water-based cleaners that are effective, one soy based product that is effective, a blend of soy and acetone and a glycol ether product. Only one of these materials is currently a commercial spotting agent. An MSDS for this material which is called Cold Plus, is shown in Appendix G. All of these materials would be safer than the PERC/TCE or PCBTF products.

AEROSOL RUST PREVENTION

Aerosol rust inhibitors could be used by consumers or industrial facilities to lubricate and/or rust inhibit ferrous metal parts. An MSDS for one product that contains PCBTF, called Zero Rust Aerosols, is shown in Appendix B. This product contains a small amount of PCBTF, according to the MSDS, three percent. The MSDS indicates the product also contains PERC (called tetrachloroethylene).

Alternative Rust Inhibitors

MSDSs for several alternative rust inhibitors are shown in Appendix B. The first product, called Crown 3090 Tool & Die Saver/6007 Rust Inhibitor--Aerosol, contains aliphatic hydrocarbons, heptane and a glycol ether. The second product, called LPS 3 Heavy-Duty Rust Inhibitor, is based on mineral spirits. The third product, called 6545: Rust Inhibitor, contains a variety of materials including n-hexane which causes peripheral neuropathy. This particular product would not be a safer alternative. The last product, called WD-40, is based on petroleum distillates.

IRTA is currently conducting a project focusing on alternative low-VOC, low toxicity alternative rust inhibitors for industrial applications. IRTA has found soy based products and water-based products that are very effective alternatives for a variety of industrial applications. These products are not currently in aerosol form but they could be marketed in aerosol packaging for the consumer market.

# IV. n-PROPYL BROMIDE

## BACKGROUND

1-Bromopropane or n-propyl bromide (NPB) is a reproductive, developmental and nerve toxin. It causes sterility in both male and female test animals and harms the developing fetus when tested in pregnant animals. NPB can damage the nerves, causing weakness, pain, numbness and paralysis. It is undergoing chronic toxicity testing to determine if it is a carcinogen; many similar chemicals do cause cancer. The American Conference of Governmental Industrial Hygienists (ACGIH) recently evaluated NPB and recommends a worker exposure level of 10 ppm. HESIS developed a Health Hazard Alert for the chemical in July 2003 and recommends that the workplace exposure be limited to about 1 ppm to protect against the reproductive and nerve toxicity. The recommendation is still being evaluated by Cal/OSHA.

NPB is fairly new to the market so it is not listed on EPA's HAP list. It does appear on the Proposition 65 list in California as a male and female reproductive toxin and a developmental toxin. NPB is classified as a VOC that contributes to the formation of photochemical smog.

Over the last several years, NPB has been marketed aggressively in certain solvent applications as replacements for ozone depleting and chlorinated solvents, primarily in cleaning. IRTA and HESIS decided to focus the analysis of NPB alternatives in three major applications. These include:

- industrial and precision cleaning
- adhesives
- aerosol cleaning

The balance of this section includes a discussion of NPB use in these applications. In each case, it begins with a description of the application. Then it presents and discusses safer alternatives that are available to replace NPB. For cleaning and adhesives, case studies of companies that analyze the cost of using alternatives are presented. NPB use in industrial and precision cleaning and aerosol cleaning is intimately linked to the use of DCE use in these applications. DCE is another chemical of focus in this project. DCE containing formulations are potential alternatives to NPB and the alternatives to DCE are examined later in this document.

## INDUSTRIAL AND PRECISION CLEANING

Most industrial and precision solvent cleaning is performed using vapor degreasers. The most common type of vapor degreaser is an open top metal tank with a heater that contains solvent. A picture of a typical open top vapor degreaser is shown in Figure 4-1. It has cooling coils that encircle the tank. The solvent is heated to its boiling point which creates a vapor zone of solvent above the liquid in the tank. The cooling coils condense the solvent in the vapor zone and prevent all of the solvent from escaping the tank. When parts are cleaned, they are lowered in a basket into the vapor zone. The solvent condenses on the colder part and carries the contaminants into the liquid bath. The vapor zone always contains clean solvent. At times, the parts are cleaned in the liquid solvent as well as in the vapor zone, depending on the cleaning application. When the solvent is too contaminated for further use, the solvent is changed out.

Figure 4-1. Typical Open Top Vapor Degreaser

Many vapor degreasers have other features that enhance the cleaning capability of the solvent. There are conveyorized vapor degreasers where the parts are moved through the vapor and/or liquid solvent on a conveyor system. Some open top vapor degreasers include ultrasonics which helps remove contaminants from crevices and blind holes in some parts.

Because vapor degreasers heat the solvent to the boiling point, only solvents with no flash point can be used for this purpose. Solvents with flash points can be use in vapor degreasers that are airless or airtight. These devices are generally operated in a vacuum and, since no oxygen is present, ignition of the solvent does not occur. These airless/airtight degreasers are much more expensive and more difficult to use than open top vapor degreasers.

Historically, the most widely used solvents in vapor degreasers were the chlorinated solvents CFC-113, TCA, METH, trichloroethylene (TCE) and PERC. Production of CFC-113 and TCA was banned in 1996 because the chemicals contribute to stratospheric ozone depletion. Although TCA in particular was still used for several years, virtually no inventory has remained for many years. METH, TCE and PERC are carcinogens and they have been increasingly regulated over the last several years. All three chemicals are classified as HAPs by EPA and TACs in California; they are also listed on Proposition 65.

EPA developed a National Emission Standard for Hazardous Air Pollutants (NESHAP) regulation as required by the Clean Air Act Amendments of 1990. The Halogenated Solvent Cleaning NESHAP regulated the use of TCA, TCE, METH and PERC in vapor degreasing and cold cleaning applications. The regulation required improvements in the equipment used with the solvents and established a rigorous recordkeeping and reporting regime. In California, the SCAQMD banned chlorinated solvent use in vapor degreasers under Rule 1122 several years ago so chlorinated solvents cannot be used in about half the state. Because the solvents are TACs, many other air districts in California also restrict but do not forbid their use in cleaning.

Several companies started marketing NPB as an alternative to TCA in vapor degreasing when TCA production was banned. Because NPB had not been used when the HAP list was developed in 1989, it was not covered by the NESHAP. NPB could therefore be used in old vapor degreasing equipment that did not need to be upgraded to comply with the NESHAP standards. Many companies that had been using METH, TCE or PERC converted to NPB to avoid the NESHAP equipment standards, recordkeeping and reporting. In California, the SCAQMD regulated VOC solvents used in vapor degreasing in 2006 so NPB, which is classified as a VOC, could no longer be used in half the state.

<u>Industrial Cleaning Alternatives</u>

A typical MSDS for an NPB formulation, called EnSolv GCS, suitable for use in industrial metal cleaning is shown in Appendix C. It contains NPB and stabilizers. In this application, the NPB is used in vapor degreasers to clean fairly heavily contaminated metal parts. The most widely applicable alternatives for NPB used in industrial cleaning are water-based cleaners. Water-based cleaners are used extensively, particularly in California, as alternatives to the chlorinated solvents and NPB.

Water-based cleaners are not used in vapor degreasers. There is a variety of equipment available for use with water-based cleaners. The most suitable equipment and water-based cleaning formulation depends on the types of parts that need to be cleaned and the contaminants that need to be removed. Water-based cleaners generally contain rust inhibitors so they can be used to clean virtually any kind of metal part. In some applications, a dryer in addition to a cleaning system will be required.

Another alternative method involves the use of an airless/airtight degreaser. The units clean the parts and distill the solvent for reuse. These degreasers generally perform cleaning in a vacuum and can use solvents with or without flash points if they are designed properly. The systems are expensive and more difficult to use than open top degreasers. They must be depressurized prior to the cleaning cycle and cleaning cycles can be relatively long. Although NPB could be used in an airless/airtight degreaser, most users of the technology use PERC or TCE in the systems because they are lower cost. Using NPB, PERC or TCE in these systems is better than using the materials in open top vapor degreasers because emissions and worker exposure are reduced. Even so, conversion to a safer alternative is preferable so the solvents do not have to be handled at all.

Two case studies of companies that converted from solvent vapor degreasing to water-based cleaners are presented below. Both companies used chlorinated solvents and not NPB but they are typical of companies that use NPB for cleaning. In both case studies, the cost of the water-based cleaning system is compared with the cost of using the chlorinated solvent and NPB. One of the companies used the vapor degreaser to clean oil from metal parts and the other used the vapor degreaser to clean buffing compound from metal parts. The alternatives the two companies adopted are suitable for similar facilities using NPB.

<u>Case Study--Nameplate Manufacturer.</u> The nameplate manufacturer is a small firm with more than 200 employees in Los Angeles. The company manufactures nameplates and membrane switches. Aluminum, stainless steel and brass stock for the nameplates are shipped to the facility with a protective film of oil. Historically, the company used a TCA degreaser to remove the oil from the metal. About 1,000 sheets were cleaned in the vapor degreaser each day.

TCA production was banned on January 1, 1996 and the company needed an alternative that would not increase their VOC emissions. In 1995 and 1996, IRTA worked with the company to identify, test and implement a water-based cleaning alternative. After substantial testing, the company purchased a conveyorized cleaning system and began using a water-based cleaner. Since then, the company identified a different water-based cleaner that is more effective for cleaning the parts.

A picture of the water-based cleaning system is shown in Figure 4-2. The capital cost of the system was $128,000. Assuming a five percent cost of capital and a 10 year equipment life, the annualized cost was $13,440.

Figure 4-2. Cleaning System at Nameplate Manufacturer

Before the conversion, the company was using about 400 gallons per month or 4,800 gallons per year of TCA. The cost of TCA at the time was $16.15 per gallon because of a congressional tax on the material. The annual cost of purchasing TCA amounted to $77,520. The cost for disposal was very low, perhaps $200 per year because the TCA was recycled. If the company was using NPB, the cost of a drum of NPB would be $1,912 or an annual cost of $166,865. The cost of disposal of the NPB would be $200 per year, the same as the disposal cost for the TCA.

The nameplate manufacturer is using the new water-based cleaner at a concentration of about 10 percent. Approximately 40 gallons of cleaner per month or 480 gallons per year are used by the company. At a cost of $8.24 per gallon, the annual cost of cleaner is $3,955. The wash and rinse baths are changed out about every two months. The company has a wastewater treatment system for their anodizing operation and the company has permission to discharge the water from the cleaning system. The company estimates that the disposal cost is about $100 per month or $1,200 per year.

The nameplate manufacturer operated the vapor degreaser for two shifts or 16 hours per day. A worker was needed to process the parts during operation. At a labor rate of $10 per hour, the labor cost for operating the vapor degreaser amounted to $41,600 annually. The water-based cleaning system reduced the labor hours to 10 per day because it is an automated machine and the workers have only loading labor. The annual labor cost with the water-based cleaning system is $26,000.

The electricity cost has increased since purchase of the new water-based cleaning system. The company estimates the increase at $100 per month or $1,200 per year.

The costs are summarized and compared in Table 4-1 below for TCA, NPB and the water-based cleaner. The cost of using the water-based cleaner is less than half the cost of using TCA and less than one-fourth the cost of using NPB.

**Table 4-1**
**Annualized Cost Comparison for Nameplate Manufacturer**

| | TCA | NPB | Water-Based Cleaner |
|---|---|---|---|
| Annualized Capital Cost | - | - | $13,440 |
| Cleaner Cost | $77,520 | $166,865 | $3,955 |
| Labor Cost | $41,600 | $41,600 | $26,000 |
| Electricity Cost | - | - | $1,200 |
| Disposal Cost | $200 | $200 | $1,200 |
| Total Cost | $119,320 | $208,665 | $45,795 |

Case Study--Plater. The plater IRTA worked with in 1998 was a small company with 19 employees located in Los Angeles. The company provides high volume chromium and nickel plating for zinc die cast, steel and brass parts. The facility has two plating lines. In the automated line, which is used for high volume jobs, the parts, which do not contain polishing compound, are cleaned in-line. In the hand line, which is used for plating custom smaller volume jobs, the parts are contaminated with polishing or buffing compound.

The plating company used a PERC vapor degreaser to clean all of the parts. IRTA began working with the company to identify, test and implement a water-based cleaning system as an alternative to the PERC degreaser. After testing parts containing a buffing compound, a water-based cleaning agent that is effective in removing the compound was selected. The company purchased an ultrasonic water-based cleaning system to clean the parts. A picture of the new ultrasonic system is shown in figure 4-3. The company converted to a water-based process for the parts on the custom line which are cleaned on plating fixtures. The vapor degreaser was still used for the parts on the automated line until the company installed a hoist so the parts from the automated line could be cleaned in baskets in the ultrasonic cleaning system.

Figure 4-3. Cleaning System at Plating Company

The cost analysis was conducted before the hoist was installed so the company was still using PERC for the parts on the automated line. The plating company used about 100 gallons of PERC per month before the purchase of the water-based system; the use was reduced to about 100 gallons every three months. At a cost of PERC at the time of $6.75 per gallon, the PERC purchases amounted to $8,100 annually before the water system was installed and $2,700 after the installation. Waste generation was about two drums every three months; this was reduced to about two drums every nine months. At a cost for disposal of $100 per drum, the cost before the water system installation for the hazardous waste disposal was $800 ; the cost after the water system was $267.

If the plater used NPB instead of PERC, the cost of purchasing a drum of NPB is $1,912. The cost of purchasing 100 gallons of NPB before the conversion is $41,716 annually and the cost of purchasing the NPB after the conversion is $13,905. Waste disposal costs for NPB would be less than waste disposal costs for PERC because the NPB can be recycled. Before the conversion, the waste disposal cost is estimated at $100 per year.

The cost of the ultrasonic cleaning unit was $21,670. Assuming a 10 year life for the equipment and a five percent cost of capital, the annualized cost of the water cleaning unit is $2,275. The cost of the water-based cleaner is $500 per drum or about $9 per gallon. The 150 gallon cleaning unit requires an eight percent charge of the cleaning concentrate. Thus, 12 gallons are required to charge the system. The bath is changed out every two months. The annual cost of the cleaning agent for charging the system is $648. Make-up cleaner is also required to replace evaporation and drag-out; this amounts to 10 percent of the charge. The total cost of the cleaner amounts to $713 per year. The cleaning agent does not require disposal; the plating facility treats thousands of gallons of wastewater each day and the bath is discharged to the treatment system every two months.

One of the owners of the company estimates that before the water cleaning system was installed, the labor used to clean in the vapor degreaser was three hours per day. The labor now, after the installation of the water cleaning system, is only about three hours per week. The owner also estimates that the labor used in the water-based cleaning is only 50 percent of the labor used in vapor degreasing. This follows from the fact that the ultrasonic capability automates the cleaning. At a labor rate of $8 per hour, the labor cost for vapor degreasing before the conversion was $6,240 annually. The annual labor cost for vapor degreasing after the conversion is $2,496 and the labor cost for cleaning with the water-based system is $1,248 per year.

The ultrasonic cleaning unit contains 4,800 watts of power. Assuming that the ultrasonics are operating about four hours each day or 1,040 hours per year and that the cost of electrical power is 12 cents per kWh, the electricity cost for running the ultrasonics is $599 per year. The unit is heated with a boiler. The owner estimates that the gas cost for the ultrasonic system amounts to $50 per month or $600 per year. Although the degreaser uses gas for heating as well, this cost is assumed to be negligible.

Table 4-2 compares the costs of using the PERC and NPB in the degreaser and the water-based cleaning system. Conversion from PERC to the water-based system reduced the costs by 28 percent. If the company had used NPB, conversion to the water-based cleaning system would cut costs by about half. Although the company had to purchase a new water-based cleaning unit and there was an increase in utility costs, this is offset by the lower cost of the cleaning agent and a reduction in cleaning labor.

**Table 4-2**
**Annualized Cost Comparison for Plating Firm**

| | PERC | NPB | Water-Based Cleaning |
|---|---|---|---|
| Annualized Capital Cost | - | - | $2,275 |
| Cleaner Cost | $8,100 | $14,618 | $3,413 |
| Labor Cost | $6,240 | $6,240 | $3,744 |
| Electricity Cost | - | - | $599 |
| Gas Cost | - | - | $600 |
| Disposal Cost | $800 | $100 | $267 |
| Total Cost | $15,140 | $20,958 | $10,898 |

Printed Circuit Board Cleaning Alternatives

Much of electronics cleaning is the cleaning of printed circuit boards (PCBs) or printed wiring assemblies 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 TCA or CFC-113 in formulations with alcohol. CFC-113 and TCA production were banned in 1996 because the chemicals cause ozone depletion. After the production ban went into effect, NPB began being marketed as an alternative to TCA and CFC-113 for electronics cleaning. An MSDS for a typical NPB formulation used for flux removal, called Hypersolve, is shown in Appendix C. Note that the formulation contains NPB, stabilizers and t-butanol, an alcohol.

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 to using NPB for flux removal. 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 4-4.

Figure 4-4. Conveyorized Printed Circuit Board Cleaning System

Other solvents are also used for flux removal but they are less desirable from an overall health and environmental standpoint. These alternatives include HCFC-225, HFEs and HFC-4310. These formulations are discussed in more detail below under precision cleaning and later in the section on DCE. Briefly, HCFC-225 contributes to stratospheric ozone depletion and, for this reason, production of the chemical will be banned in 2015. The HFEs and HFC-4310 contribute to global warming. As discussed later, nearly all formulations composed of HCFC-225, the HFEs or HFC-4310 also contain DCE. All of these materials, although they have limitations, would be safer alternatives than NPB in this application. Better alternatives, however, are the no-clean flux option or the water-based cleaning options.

As for industrial cleaning, users could purchase an airless/airtight degreaser to use NPB/alcohol or an HCFC, HFC or HFE alternative described above. In some cases, particularly for the HCFC, HFC or HFE alternatives, the cost of the airless/airtight degreaser could be justified. The price of these solvents is extremely high and the emission reductions (and savings in solvent purchases) could be high. Again, better alternatives are the no-clean flux or water-based cleaning options.

Two case studies of companies that converted from solvents to alternative processes are discussed below. Although the companies described in the case studies used TCA and CFC-113, the alternatives they adopted would be suitable for companies using NPB formulations for flux removal.

Case Study--Aerospace Subcontractor. This company is an aerospace subcontractor with more than 500 employees located in Burbank, California. The company manufactures braking systems, pumps and airlocking devices and also does repair work on the pumps used in military and commercial aircraft like the C-130 transport and the C-17.

The company was using TCA for removing the flux from PCBs after soldering components to them. This operation had a military specification that required the use of rosin flux. A vapor degreaser was used to remove the flux from the boards after soldering. The company had another commercial PCB operation that used water soluble flux. In this operation, the company used plain D.I. water to clean the flux from the boards in a small dishwasher cleaning system.

In 1998, the company purchased a large batch dishwasher and adopted a water-based cleaner. This cleaner, unlike many others used for removing rosin flux, contains no solvent additives. A picture of the cleaning system is shown in Figure 4-5. The cost of the new cleaning system, including racks and tax was $24,950. This cleaning system is now used for cleaning both the commercial and the military printed circuit boards. The company also purchased an evaporator at a cost of $6,950 that is used for disposal of the water-based cleaners. The total cost of the cleaning unit and evaporator including associated equipment and taxes was $37,378. Assuming a five percent cost of capital and a 10 year life for the equipment, the annualized capital cost is $3,925.

Figure 4-5. Aerospace Subcontractor Cleaning System

In the year prior to the conversion, the cost of the TCA purchased for the printed circuit board operation was $25,000. If NPB were used instead of TCA, the cost of purchasing the NPB would be the same as the cost of purchasing TCA or higher. The cost of the D.I. water used in the second commercial machine was $4.

The water-based cleaning system is operated for an average of five cycles per day. The length of a cycle is about 50 minutes. The machine takes about 10 minutes to heat the five gallon tank of formulation. It requires five minutes for the wash step; it goes through four five minute rinse steps and a 15 minute drying step. The water-based cleaner is used in a 10 percent concentration in the five gallon wash bath and each time the unit is operated, a new cleaning bath is required. Assuming 260 days per year of operation, the amount of cleaner required is 650 gallons per year. At a cost of about $12 per gallon, the annual cost for the water-based cleaning agent is $7,800. D.I. water is required for rinsing the boards; the company estimates this cost of this water at about $20 per year.

Disposal costs for the spent TCA from the cleaning operation are estimated at $400 annually. If the company used NPB, the cost of disposal could be assumed to be the same. The sludge from the water-based cleaning formulation that remains after evaporation requires disposal. Assuming a five percent contamination level and the evaporation of 25 gallons per day, the amount of contaminants that require disposal are 325 gallons annually. This sludge contains lead from the solder and is classified as hazardous waste. At a cost for disposal of about $200 per drum, the total annual cost of the sludge disposal is $1,200.

About half the 14,000 boards were cleaned in the TCA system and half in the D.I. water system before the conversion. Both the new and old equipment was automated. The workers required four minutes labor time to clean each board in the TCA degreaser. They required one minute labor time to clean each board in the D.I. water system. With the change to the new system, the labor required was one minute for all boards. At a labor rate of $19.50 per hour, the total annual labor cost before the conversion was $11,375. The total annual labor cost after the conversion was $4,550.

The electricity cost for the vapor degreaser and the D.I. water unit are not known and will be assumed to be negligible for purposes of analysis. On the new system, the pump power is 600 watts. The pump runs during the wash and rinse steps for 25 minutes per cycle. The total annual electricity use for the pump is 325 kW. The power for the blower in the dryer is 10.4 kW. The dryer operates for 15 minutes each cycle. The annual electricity use from the dryer is 3,380 kW. The evaporator is assumed to operate eight hours per day. The heater power in the evaporator is 11 kW. The annual electricity use from the evaporator amounts to 22,880 kW. Assuming a cost of 12 cents per kWh, the total annual electricity cost for operating the new system is $3,190.

Table 4-3 shows the cost comparison for the company for the TCA and D.I. water system and the new water-based cleaning system. The cost of using the new water-based cleaning system is 44 percent lower than the cost of using the TCA and D.I. water system. Note that if the company had used NPB, the savings from using the water-cleaning system would be the same or greater because of the high cost of NPB.

**Table 4-3**
**Annualized Cost Comparison for Braking System Manufacturer**

| | TCA/D.I. Water | Water-Based Cleaning |
|---|---|---|
| Annualized Equipment Cost | - | $3,925 |
| Cleaner Cost | $25,000 | $7,800 |
| D.I. Water Cost | $4 | $20 |
| Labor Cost | $11,375 | $4,550 |
| Electricity Cost | $3,190 | |
| Disposal Cost | $400 | $1,200 |
| Total Cost | $37,046 | $20,685 |

Case Study--Aerospace Electronics Company. This company is located in Azusa, California. The aerospace firm designs and manufactures space surveillance, meteorological sensor and smart weapon systems. As part of the operation, the company assembles PCBs that are used in the equipment.

In the mid 1990s, the aerospace company completed their evaluation of alternatives to TCA and CFC-113; production of the chemicals was banned because they contribute to stratospheric ozone depletion. The company had been using various CFC-113 blends in a vapor degreasing process for removing flux from PCBs. The company conducted an extensive set of tests to determine which technology they should adopt.

The aerospace manufacturer determined early on that the research focus would be on water-based cleaning alternatives. The company tested water soluble flux and found it could be effectively removed with D.I. water. The company also identified a rosin flux saponifier that did not contain solvent additives.

Since the company had a number of military contracts, they were required to continue using rosin flux and the decision was to adopt the saponifier. The personnel thoroughly investigated cleaning and wastewater treatment equipment that would be flexible enough so the process could one day be converted to water soluble flux when the contracts had expired. The water soluble flux process is attractive because the boards can be cleaned with plain D.I. water and the entire system can be close looped.

After evaluating a range of equipment options, the company purchased a conveyorized custom designed system that could be adapted to water soluble flux removal. Although the equipment has other stages, the stages that are being used today for cleaning include a wash that contains the saponifier, a rinse that contains D.I. water and a final rinse that contains D.I. water. The final rinse recirculates to the first rinse so the boards see the purest water at the end of the cycle.

The company was committed to zero discharge and investigated methods of recycling and disposal. In the end, the company purchased a closed loop recycling system that utilizes a mixed ion bed filtration technology; this system is used to process the rinse water. It cleans the water and recirculates it back to the rinse chamber. The company also purchased an evaporator that treats the spent wash water when it can no longer be used.

Precision Cleaning Alternatives

NPB or NPB blends with alcohol are used for various types of precision cleaning performed for parts that are manufactured by the aerospace, defense, commercial and medical industries. The types of applications that are covered by precision cleaning include electrical components, relays, electromagnetic components, hybrid circuits, fuel injectors, optical components and space components.

The SCAQMD implemented a regulation in the South Coast Basin that required solvents used in open top vapor degreasers to have a VOC content of 25 grams per liter or less by January 1, 2006. Companies that wish to use higher VOC content solvents must use airless/airtight degreasers. The SCAQMD conducted a technology assessment for this category prior to the January 1, 2006 deadline. All companies either converted to very low VOC alternatives or purchased airless/airtight degreasers to comply with the regulation.

Many of the companies that use solvents for precision cleaning believe that they must use solvents and cannot use water-based cleaners. Companies that need to clean flux and other contaminants from hybrid circuits, electronics and other electrical components fall into this category. The first option is to convert to a solvent alternative. SCAQMD found that several of these companies converted to plain HCFC-225 or HCFC-225 with a small amount of alcohol before the regulation deadline. One supplier offers a compliant HCFC-225 product called Rho-Tron 225 AES-VL (for very low VOC) that has performed acceptably for most users. An MSDS for this material is shown in Appendix C. The second option is to purchase an airless/airtight degreaser and use the degreaser with NPB or one of the high VOC solvent blends. The third option is to use water-based cleaners which can be used for cleaning many of these types of components. In some cases, using water-based cleaners to clean the components, like hybrid circuits or relays, for example, would require very good drying systems. Although vacuum dryers are expensive, they could be effective for drying precision components.

Case studies for several facilities that exercised one of these options are presented below. The case studies include three facilities that converted to low-VOC alternative solvents, one company that purchased an airless/airtight degreaser and one company that converted to a water-based cleaner.

Case Study--Defense Electronics Manufacturer. This company designs and manufactures high quality navigation systems, altimetry systems and test equipment for the Department of Defense. The company uses a water-based cleaning system for cleaning most of their electronic components. The company does have one vapor degreaser which uses HCFC-225 VL for removing baked-on flux from hybrid assemblies which are harder to clean. The company has conducted testing to verify the cleaning capability of the HCFC-225 VL for the hybrids. The findings indicate that the cleaner cleans the assemblies but requires more degreasing time.

Case Study--Filter Manufacturer. This facility manufactures electromagnetic interference filters for reducing noise interference. When the SCAQMD staff visited the facility, the company was using an HCFC-225/alcohol blend with a VOC content higher than 25 grams per liter. This cleaner was being used to remove solder flux and excess putty (asphalt-silica) compound from filter casings. The putty compound is used as a heat sink to dissipate heat away from the electronic components inside the filter casing. The company had tested HCFC-225 VL and a representative indicated that the lower VOC cleaner worked as well as the higher VOC cleaner for flux removal. The change to the lower VOC cleaner would require additional hand cleaning with a non-VOC cleaner to remove the excess putty compound.

Case Study--Fuel Injection System Manufacturer. Another facility that manufactures fuel injectors used NPB for cleaning fuel injector parts. The company purchased a new open top vapor degreaser and now uses pure HCFC-225. The cost of the new vapor degreaser was $48,000 and it is designed to minimize emissions. The vapor degreaser, which now uses HCFC-225, is used only to process the fuel injector nozzles. They are first cleaned in a water-based cleaner and are essentially dried in the vapor degreaser.

Case Study--Relay Manufacturer. This company routinely cleans relays that are used in various military and space applications. The relays range in size from one-fourth inch by one-half inch to one inch by one inch. The company wanted to find an alternative to ozone depleting substances and tested a variety of alternative cleaners. The testing indicated that a water-based cleaning system was suitable for cleaning many of the relays. Some of the relays, however, were not cleaned effectively with the water-based system. Drying was also a problem for some of the relays. The company purchased two airless/airtight cleaning systems and is using a blend of HCFC-43-10, DCE and methanol for cleaning these relays in the equipment.

Case Study--Contract Cleaning Company. This company is located in Downy, California. It is one of the nation's leading precision cleaning contractors specializing in the cleaning of high purity gas and fluid systems. The company provides precision cleaning services and cleanliness certification for pipes, valves, tubing, components, tanks, hoses and fittings for almost every industry, including aerospace, military, pharmaceutical, microelectronics and semiconductor.

There is a perception that solvent cleaning agents are required for precision cleaning operations. The reasoning is that water-based cleaners are appropriate for general metal cleaning but cannot clean as effectively as solvents for precision applications. This particular case study demonstrates that water-based cleaners perform as well as or better than solvents in the company's precision cleaning applications.

The company used TCA for many years in a vapor degreasing process. The firm converted to NPB in late 1997 and used it for about one year. The company planned to stop using solvents but did not want to upgrade the degreaser to use any of the NESHAP solvents including TCA, TCE and PERC.

IRTA conducted extensive testing with the company and the company purchased an ultrasonic water-based cleaning system that consists of an ultrasonic wash bath and two immersion rinse baths. Each of the baths holds about 700 gallons. The cost of the system, including installation, was $171,788. The company amortized the cost over a four year period. Assuming a cost of capital of 7.75 percent, the annualized cost for the equipment is $50,085.

The company's cost of purchasing NPB is $66,240 for the year NPB was used. The company is now using a water-based cleaner in the ultrasonic cleaning system; the cleaner has aerospace approval. The cost of purchasing the water-based cleaner is $2,160 annually.

The cost of gas that was used with the NPB vapor degreaser was $3,297 per year. The increase in the cost of electricity after the water-based cleaning system was installed was $684 per month or $8,208 per year. The cost of supplying D.I. water for the water-based system is $225 per month or $2,700 per year.

Table 4-4 shows the annualized cost comparison for the NPB vapor degreaser and the water-based cleaning system. Conversion to the water-based cleaner reduced the cost of cleaning by about nine percent. The savings would be even greater if a 10 year or longer lifetime for the water cleaning equipment was assumed.

**Table 4-4**
**Annualized Cost Comparison for Precision Contract Cleaner**

| | NPB Vapor Degreasing | Water-Based Cleaning |
|---|---|---|
| Annualized Equipment Cost | - | $50,085 |
| Cleaner Cost | $66,240 | $2,160 |
| Gas Cost | $3,297 | - |
| Electricity Cost | - | $8,208 |
| Water Cost | - | $2,700 |
| Total Cost | $69,537 | $63,153 |

After the new water system was installed, the contract cleaning company measured the non-volatile residue (NVR) on 25 different pieces of hardware cleaned with the NPB and the water system. NVR is a measure of the contamination level left on the parts after cleaning. Lower NVR means that cleaning is better. Of the 25 pieces tested, 21 had a lower NVR when they were cleaned with the water-based system. Three of the pieces had the same NVR. Only one piece had a lower NVR when it was cleaned with NPB. The average NVR level achieved when the hardware was cleaned with NPB was 0.756 milligrams per square foot. The average NVR level achieved with the water-based cleaning system was 0.616 milligrams per square foot. The company concluded that the water-based cleaning system is as effective or more effective than the NPB vapor degreasing system.

Optics Cleaning Alternatives

Prior to the 2006 deadline for SCAQMD Rule 1122, several facilities used NPB for removing pitch from optical components. Nearly all companies converted to alternatives before the deadline became effective.

The SCAQMD reports that companies are using water-based cleaners in conjunction with acetone and soy based cleaners as alternatives. One facility decided to continue using NPB and purchased an airless/airtight degreaser. A case study for another facility that avoided the use of NPB after the production bans on TCA and CFC-113 is presented below.

Case Study--Guidance System Manufacture. This company manufactures laser guidance systems for commercial and military aerospace applications including spacecraft and aircraft missiles. The high precision parts are lapped and polished and blocking materials are used to hold the parts in place during these operations. The parts are cleaned in several steps of the process to remove the lapping, polishing and blocking compounds.

In the past, the company relied heavily on CFC-113 and TCA for cleaning the parts. Several years ago, the firm initiated an effort to find alternatives. The company converted to alternative solvents and water-based cleaners. Many other companies converted to NPB at that time. In the 1999 time frame, the company converted away from the alternatives to water-based cleaners, acetone and not cleaning at all by making several process changes.

In the frame manufacturing operation, the company used N-methyl pyrrolidone (NMP) to clean wax which was used to plug the frame bores to prevent lapping compound from intruding. The company eliminated this cleaning step by using plugs with O-rings to block the frame bores acting as a physical barrier to the lapping compound. In another step, epoxy was used to bond the frames to holding fixtures during lapping and polishing. NMP was used to remove the epoxy. Hot air at a temperature of 200 degrees F is now used to separate the frame from the fixture. The thermal expansion differences between the glass frame, metal fixture and epoxy causes the debonding.

In another operation, the substrate operation, pitch was used to hold the mirror substrates to mounting blocks during lapping and polishing. NMP, a terpene based cleaner and small amounts of methanol and methylene chloride were used for deblocking and cleaning. The company substituted a thermoplastic for the pitch in the bonding operation. Acetone is currently used to dissolve most of the thermoplastic; this cleaning step is followed by a soak in a water-based cleaner.

In the prism operation, wax is used to bond the prisms to mounting blocks for lapping and polishing. A terpene product was used to dissolve the wax and clean the parts. This product has been replaced with a water-based cleaner.

The company used 10 drums of NMP per year in their process in the past. The cost of the NMP was $450 per drum. The total annual cost of purchasing the NMP was $4,500. Fourteen drums of the terpene cleaner were used each year at a cost of $550 per drum. The total cost of using the terpene was $7,700 per year. Fourteen drums of a second terpene product were also used each year at a cost of $1,695 per drum. The total cost of using the product was $23,730 annually. The cost of the methanol and methylene chloride amounted to about $200 per year. The total yearly cost for purchasing all of these solvents was $36,130.

The new operations involve the use of two water-based cleaners. The company estimates that three drums of one of the cleaners at a cost of $850 per drum will be required. Two drums of the other water-based cleaner at $105 per drum will also be required. The total cost of purchasing the two water-based cleaners amounts to $2,760 annually.

The company substituted thermoplastic for pitch in the bonding operation. The thermoplastic, at a cost of $12,000 annually, is much more expensive than the pitch which carried a cost of about $2,000 per year.

Disposal costs for the two terpene cleaners amounted to $3,780 per year. The disposal cost for the spent NMP was $1,350 per year. The total disposal cost for the solvents was $5,130 annually. The disposal cost for one of the water-based cleaners is $405 per year.

Table 4-5 shows the cost comparison for the solvents and the water-based cleaners. By making the conversions to not cleaning and to water-based cleaning, the company reduced their costs by about 65 percent.

**Table 4-5**
**Annualized Cost Comparison for Guidance System Manufacturer**

| | Solvent Cleaning | Water-Based Cleaning |
|---|---|---|
| Cleaner Cost | $36,130 | $2,760 |
| Materials Cost (Thermoplastic and Pitch) | $2,000 | $12,000 |
| Disposal Cost | $5,130 | $405 |
| Total Cost | $43,260 | $15,165 |

ADHESIVES

There are 23 companies with about 75 pouring plants in the U.S. that manufacture flexible polyurethane foam. This slabstock foam is a low value, low density products and foamers are generally located near their markets because of the high cost of transporting the foam. The major markets for the foam are predominantly carpet underlay, furniture and bedding. There are large concentrations of furniture manufacturers in the Southeastern U.S. and in Southern California. All of the foam that is manufactured is fabricated, a term that refers to cutting up the foam into pieces that are an important component in products like furniture and bedding. About half the foam is fabricated in foam manufacturing facilities owned by foam manufacturers and the remainder is fabricated by independent fabricators. Some of the foam is purchased directly by furniture and bedding manufacturers and fabricated at their sites.

Part of the foam is fabricated using adhesives and part is not. Foam fabrication adhesives are used by foam fabricators, upholstered furniture manufacturers and mattress manufacturers to bond polyurethane flexible foam to other substrates like foam, fabric and wood. It is estimated that about one-third of the foam used in furniture manufacture and five percent of the foam used in bedding manufacture requires adhesive in the fabrication operation. In the South Coast Basin in California, there are about 120 foam fabricators which accounts for about one-third of the nation’s fabricators; there are 38 home upholstered furniture manufacturers and 84 mattress manufacturers. Figure 4-6 shows a picture of a foam fabrication operation.

Figure 4-6. Foam Fabrication Operation

Adhesive Alternatives

Historically, TCA was used as the carrier in the adhesives used for foam fabrication, furniture and mattress manufacturing. When the production ban on TCA became effective, most of the foam fabrication industry adopted METH as the alternative carrier in the adhesives. OSHA adopted a much more stringent regulation on METH that went into effect in 2000 and the industry began investigating other alternatives so they would not have to implement measures to comply with the new workplace standards. Most companies would have to make a substantial investment in ventilation equipment and implement medical surveillance and monitoring programs to comply with the new OSHA standards. One of the alternatives that was marketed extensively by adhesive suppliers was NPB.

Upholstered furniture manufacturers and mattress manufacturers did not adopt NPB as an alternative when TCA and METH were more stringently regulated. Most of the companies in those industries either used hot melt adhesives which are 100 percent solids or water-based adhesives. In a few niche applications, acetone based adhesives were used.

In southern California, when the TCA production ban went into effect, the SCAQMD regulations on Toxic Air Contaminants would not allow foam fabricators to use METH based adhesives. The suppliers began marketing water-based adhesives and, although it took several years for the water-based adhesives to be optimized, many foam fabricators in southern California adopted them. Other fabricators in Southern California adopted acetone based adhesives; acetone is not classified as a VOC. The Southern California companies could not use NPB based adhesives because of stringent VOC regulations. In other parts of the country, however, many foam fabricators converted to NPB based adhesives.

IRTA investigated alternative adhesives in a project sponsored by EPA that was completed in 2003. The major alternatives to METH, TCA and NPB for foam fabricators are water-based adhesives which use latex and synthetic adhesive components and acetone based adhesives where acetone is used as the carrier. An MSDS for a typical water-based and a typical acetone based adhesive are shown in Appendix C. Companies that adopted these alternative adhesives needed to install ventilation systems; they generally didn't use ventilation systems with TCA or METH. The NPB based adhesives require ventilation systems to prevent worker exposure to high concentrations of NPB. An MSDS for a typical NPB adhesive is shown in Appendix C. The acetone based adhesives require ventilation systems as part of fire department regulations to keep the concentration below the lower explosion limit. Water-based adhesives that are sprayed form aerosols that can be annoying to workers so ventilation systems are generally used to reduce exposure to the web material.

In the earlier EPA project, IRTA developed case studies of several foam fabrication facilities that converted to a range of different alternatives when OSHA more heavily regulated METH. Case studies for four companies that made conversions are shown below. The first case study is a company located in North Carolina that tested a variety of different types of adhesives including a one-part water-based, a two-part water-based, an acetone based and an NPB based adhesive. The cost comparison shows that the cost of using the one-part water-based and the NPB based adhesives is comparable. The cost of using the acetone based adhesive is lower than the cost of using the NPB based adhesive. The second case study shows the cost to a company for converting from a METH to an acetone based adhesive. Note that using acetone is somewhat more costly than using METH. The third case study shows the cost comparison to a company for converting from a METH to an NPB based adhesive. Note that this company did not install a ventilation system for the conversion to NPB. The cost of using NPB is somewhat higher than the cost of using METH. The fourth case study shows a cost comparison for a company in California that used acetone based adhesives and converted to a water-based adhesive. The cost of using the water-based adhesive is slightly lower than the cost of using the acetone based adhesive. The case studies illustrate that water-based and acetone adhesives are viable alternatives to NPB adhesives.

Case Study--Foam Fabricator #1. This company, located in North Carolina, used TCA until 1991 when the company switched to a water-based adhesive. They used a water-based one-part adhesive for a time and switched to a water-based two-part adhesive. They were not satisfied with either of the water-based adhesives and they have been testing several different technologies including acetone and NPB. Currently one line uses a water-based one-part adhesive and the other line uses an NPB based adhesive. The analysis below compares the cost of using the one-part water-based, the two-part water based, the acetone and the NPB adhesives.

Equipment purchases were necessary for the conversion to water-based adhesives. The company has two glue lines, each of which has 14 stations. They also have two additional stations. The company purchased 30 spray booths at a cost of $1,400 each. The total cost of the spray booths was $42,000. The company also purchased 30 HVLP spray guns at a cost of $700 each for a total cost of $21,000. Two pumps at $2,800 each were also necessary for a total cost of $5,600. The total capital cost amounted to $68,000. These purchases would have been necessary for the acetone and the NPB as well. The acetone technology had an additional cost for spark arresters which carried a price of $6,000. The total cost for the acetone system amount to $74,600. Assuming a cost of capital of five percent and a 10 year life for the equipment, the annualized capital cost for all the technologies except acetone is $11,182. For acetone, the annualized capital cost is $12,160.

The firm used 93,750 gallons per year of the one-part water-based adhesive at a price of $7 per gallon. The annual cost of purchasing this adhesive is $656,250. The company used 67,800 gallons of the two-part water-based glue at a cost of $20 per gallon. The annual cost of purchasing this adhesive is $1,356,000. The company estimates that it would use 36,450 gallons of acetone adhesive at a price of $6 per gallon. The annual cost of purchasing this glue is $218,700. The company also indicates it would use the same amount of NPB based adhesive at a cost of $18 per gallon. The annual cost of purchasing the NPB adhesive is $656,100.

In all four cases, the same amount of labor is required to apply the adhesive. Forty workers spray the glue full time. Assuming a 40 hour work week and 50 weeks per year, each worker sprays for 2,000 hours per year. The total annual number of gluing hours is 80,000. At a labor rate of $9 per hour, the labor cost amounts to $720,000 annually.

The maintenance cost for all of the technologies is the same with the exception of the two-part water-based adhesive. In the other cases, 420 maintenance hours are required per year. At a labor rate of $9 per hour, the maintenance cost is $3,780 annually. For the two-part water-based adhesive, 800 hours of maintenance per year are required. The maintenance cost for the two-part adhesive is $7,200 annually.

The electricity cost is the same for all four technologies. The plant uses 1,500 kWh per month. At a cost of 12 cents per kWh, the total annual electricity cost amounts to $2,160.

Training of the workers was necessary when the plant converted to water-based glues. In the case of the one-part and the two-part water-based adhesives, 30 employees had to be trained for about 40 hours each. Assuming a labor rate of $9 per hour, the training cost amounted to $10,800. That training cost should be spread over the useful life of the technology. In this case, it was spread over 10 years. This leads to an annual training cost of $1,080. The workers did not require training to use acetone or NPB.

Table 4-6 shows the cost comparison for the four technologies. According to the company's estimates, the lowest cost option is acetone adhesives. The highest cost is for the two-part water-based and the NPB adhesive.

**Table 4-6**
**Annualized Cost Comparison for Foam Fabricator #1**

| | One-Part Water-Based | Two-Part Water-Based | Acetone Adhesive | NPB Adhesive |
|---|---|---|---|---|
| Annualized Capital Cost | $11,182 | $11,182 | $12,160 | $11,182 |
| Adhesive Cost | $656,250 | $1,356,000 | $218,700 | $656,100 |
| Labor Cost | $720,000 | $720,000 | $720,000 | $720,000 |
| Maintenance Cost | $3,780 | $7,200 | $3,780 | $3,780 |
| Electricity Cost | $2,160 | $2,160 | $2,160 | $2,160 |
| Training Cost | $1,080 | $1,080 | $1,080 | $1,080 |
| Total Cost | $1,394,452 | $2,097,622 | $957,880 | $1,394,302 |

Case Study--Foam Fabricator #2. This company, also located in North Carolina, used METH based adhesives until the OSHA regulation became effective and then converted to acetone adhesives. The facility has 16 stations where adhesive is applied. When the METH adhesives were used, the plant had fans but no ventilation system as such. For the conversion to acetone, the company installed ventilation systems that collect from the floor at 11 of the stations and, at five of the stations, a fan pulls the air outside.

The capital cost of the ventilation system equipment for use with the acetone adhesives was $11,000. Using a cost of capital of five percent and a 10 year life for the equipment, the annualized cost for the capital purchase is $1,793.

The plant used 11,000 gallons of METH based adhesives and still uses the same amount of acetone based adhesive. The cost of the METH adhesive was $5 per gallon for a total annual cost of $55,000. The cost of the acetone adhesive is $6 per gallon for a total annual cost of $66,000.

Sixteen employees apply the acetone adhesives, the same number that applied the METH adhesive. Assuming a 50 week year and 40 hours a week, the employees devote 32,000 hours to applying adhesives. At an average labor rate of $9 per hour, the labor cost amounts to $288,000 for both the METH and acetone adhesives.

The company indicates that 267 hours per year were devoted to maintenance for the METH based adhesives; the same amount of maintenance is required for the acetone adhesives. At labor rate of $9 per hour, the maintenance labor in both cases is $2,403.

The electricity cost increased when the company converted from METH to acetone based adhesives because of the new ventilation equipment. The company now uses 875 kWh per month for the adhesive operation. At a cost of 12 cents per kWh, the annual electricity cost is $1,260.

There was no training cost because applying the acetone and METH adhesives is similar.

The conversion to acetone based adhesives did not change the company's insurance premiums because of the low flash point of acetone. There were no premium adjustments as long as the company met the insurance company recommendations.

Table 4-7 shows the cost comparison for the company for the METH and the acetone based adhesives. The figures show that the cost of using the acetone adhesives is higher by about four percent. The cost is higher primarily because the acetone based adhesive is slightly more costly than the METH based adhesive for the plant.

**Table 4-7**
**Annualized Cost Comparison for Foam Fabricator #2**

| | METH Adhesive | NPB Adhesive |
|---|---|---|
| Annualized Capital Cost | - | $1,793 |
| Adhesive Cost | $55,000 | $66,000 |
| Labor Cost | $288,000 | $288,000 |
| Maintenance Cost | $2,403 | $2,403 |
| Electricity Cost | - | $1,260 |
| Total Cost | $345,403 | $359,456 |

Case Study--Foam Fabricator #3. This company is located in High Point, North Carolina and has 35 employees. Much of the foam fabricated by the company is used in seat backs for buses. The company used METH based adhesives for many years and, about a year and a half ago, converted to an NPB adhesive that also contains TCE.

The company had a ventilation system when METH was used and the same ventilation system was used with NPB.

The company used about 5.5 drums per month of the METH adhesive. This amounts to 3,630 gallons per year. At a cost of $8 per gallon, the annual adhesive cost was $29,040. After the conversion to the NPB adhesive, the company reduced their adhesive use to about 3.5 drums per month or 2,310 gallons per year. The cost of the NPB adhesive is $16 per gallon. The total annual adhesive cost for the company is now $36,960.

The company has 13 adhesive application stations and seven of them are used every day. Nine workers apply the adhesive during one shift per day and their labor rate is $8 per hour. Assuming the workers work a 40 hour week 50 weeks per year, the total annual labor cost is $144,000. The labor cost has not changed since the conversion to the NPB adhesive.

The workers spend about 25 hours a year maintaining the spray equipment. At a labor rate of $8 per hour, the labor maintenance cost is $200 annually. The workers used 100 gallons of METH for cleanup. At $6 per gallon, the cleanup solvent cost was $600 annually. The total maintenance cost is $800 per year and the plant manager indicates that this cost has not changed with the conversion.

The company uses about 500 kWh per month to run the ventilation system. At a cost of 12 cents per kWh, the annual electricity cost amounts to $720. This cost has not changed since the conversion to the NPB based adhesive.

Table 4-8 presents the cost comparison for METH and NPB based adhesives for the company. The cost of using the NPB based adhesive is about five percent higher than the cost of using the METH adhesive.

**Table 4-8**
**Annualized Cost Comparison for Foam Fabricator #3**

| | METH Adhesive | NPB Adhesive |
|---|---|---|
| Adhesive Cost | $29,040 | $36,960 |
| Labor Cost | $144,000 | $144,000 |
| Maintenance Cost | $800 | $800 |
| Electricity Cost | $720 | $720 |
| Total Cost | $174,560 | $182,480 |

Case Study--Foam Fabricator #4. This company has several locations and one plant is in California. The company fabricates foam and produces two types of foam bonded mattresses. The first type of mattress is a latex mattress for which the company bonds latex-to-latex. The second type of mattress is a polyurethane and latex mattress for which the company bonds latex-to-polyurethane foam. The company uses a one-part water-based adhesive for the latex bonding and a different one-part water-based latex adhesive for the polyurethane foam bonding.

Early on, the company used a METH based adhesive. The firm converted to acetone based adhesives and then, finally, to the water-based adhesives they use today. When acetone based adhesives were used, the company had to purchase spark arresters at a cost of $800. Assuming the company paid cash for these purchases and that they were used for two years, the annual cost amounted to $400.

The company used 4,884 gallons of acetone adhesive annually. At a cost of $7 per gallon, total annual costs for the acetone adhesive amounted to $34,188. The firm now uses 3,420 gallons per year of a one-part water-based latex adhesive. The cost of the water-based adhesive is $8 per gallon; the total cost of the water-based adhesives is $27,360 annually.

The company has 10 employees that apply adhesives. When the acetone adhesives were used, each employee worked 50 weeks per year and 40 hours per week. At a labor rate of $9.80 per hour, the labor cost was $196,000. The number of workers and labor hours has not changed with the conversion to water-based adhesives.

When the company used acetone adhesives, 50 hours of maintenance were required each year. At a labor rate of $9.80 per hour, the total annual maintenance cost was $490. The water-based systems require less maintenance time, about 38 hours per year. The total maintenance cost of the water-based systems is $372 per year.

The electricity cost remained the same when the company converted from acetone to water-based adhesives. The kWh usage is 1,000 per month or 12,000 per year. At a cost of 12 cents per kWh, the total electricity cost is $1,440 annually.

The company had a training cost for the workers so they could learn to apply the on-part latex adhesive. The synthetic water-based adhesive was easier to apply and there was no training required. Four workers were trained for 120 hours each. At a labor rate of $9.80 per hour, the training cost amounted to $4,704. Assuming this training cost is spread over 10 years, the annual cost was $470.

Table 4-9 shows the annualized cost comparison for the company for acetone and the water-based adhesives. The cost of using the water-based adhesives is about three percent lower than the cost of using the acetone adhesives.

**Table 4-9**
**Annualized Cost Comparison for Foam Fabricator #4**

| | Acetone Adhesive | Water-Based Adhesive |
|---|---|---|
| Annualized Capital Cost | $400 | - |
| Adhesive Cost | $34,188 | $27,360 |
| Labor Cost | $196,000 | $196,000 |
| Maintenance Cost | $490 | $372 |
| Electricity Cost | $1,440 | $1,440 |
| Training Cost | - | $470 |
| Total Cost | $232,518 | $225,642 |

AEROSOL CLEANING

Aerosol contact cleaners are used to remove particles, flux, oil and grease from energized and non-energized electrical equipment. Energized electrical equipment is equipment through which a current is passing during the cleaning. Devices cleaned with contact cleaners included printed circuit boards, motors, generators, transformers and other types of electronic and electrical equipment. Historically, TCA and CFC-113 were used for aerosol contact cleaning. In 1996, the production ban on ozone depleting substances, including TCA and CFC-113, became effective. These materials were used for several more years until the inventory was depleted.

At that stage, the packagers began using an alternative cleaner, HCFC-141b, for contact cleaning. An MSDS for a typical HCFC-141b aerosol formulation, called ECOLINK 2005 (A), is shown in Appendix C. HCFC-141b, like TCA and CFC-113, has no flash point and is not appreciably conductive so it could be used successfully for cleaning energized electrical equipment. Although it is not necessary to use a cleaner with no flash point for cleaning non-energized electrical equipment, it was a selling point that the same material could be used for both energized and non-energized equipment. Production of HCFC-141b was banned in 2003 because the chemical contributes to ozone depletion. It is still available in the inventory, however, so some packagers are still using it in contact cleaning formulations. Several other halogenated solvents, including NPB, are now being used for contact cleaning.

Alternative Contact Cleaners

Some packagers have begun marketing alternatives to HCFC-141b and the others still using it will market alternatives when the inventory is exhausted. Alternatives to HCFC-141b aerosol cleaners include TCE, PERC, NPB, HCFC-225, HFC-4310 and the HFEs. Cleaners formulated with these materials have no flash point so they can be used for cleaning both energized and non-energized electrical and electronic devices. MSDSs for these alternative products are shown in Appendix C. The first product, called Phase II (A) Aerosol, contains TCE and isopropyl alcohol. The second product, called Ramco UN 2000, contains PERC. The third product, called TECHSPRAY No-Clean Flux Remover, contains HCFC-225, DCE and methanol. The fourth product, called MG Super Cleaner Degreaser, contains the HFEs, DCE and ethyl alcohol. The fifth product, called ECO-SPRAY (A), contains both the HFEs and HFC-4310.

PERC, TCE and NPB are all relatively aggressive cleaners. In contrast, HCFC-225, HFC-4310 and the HFEs are less aggressive cleaners. These materials are often combined with DCE which, like PERC, TCE and NPB, is an aggressive solvent. DCE has a flash point, however, so the HCFC-225, HFC-4310 and HFEs are combined with it to ensure the mixture has no flash point. Other solvents, like small amounts of alcohols, are used in some of the products designed for flux removal. Acetone is also sometimes combined with these materials but in small quantities so the mixture will not have a flash point.

All of the solvents used as contact cleaners are halogenated and they have problems of various kinds. PERC and TCE are carcinogens, they are on EPA's HAP list and they are on the California TAC list and Proposition 65. NPB is a reproductive and developmental toxin and it is listed on Proposition 65. HCFC-225 causes ozone depletion and its production is scheduled to be phased out in 2015. HFC-4310 and the HFEs contribute to global warming. DCE is one of the chemicals of focus in this project and is discussed later.

Halogenated solvents have the advantage of not having a flash point but they do have environmental and toxicity problems. For contact cleaning where the item being cleaned is not energized, there is no requirement to use a cleaner without a flash point. There are a variety of alternatives on the market that can be used for non-energized contact cleaning. An MSDS for one cleaner, called Hercules Electrical Contact Cleaner, that has a flash point is shown in Appendix C. This product contains petroleum distillates. An MSDS for a second cleaner, called Betco Contact and Circuit Board Cleaner, also with a flash point, is shown in Appendix C. Water-based cleaners can also be used for non-energized electrical contact cleaning. An MSDS for one water-based cleaner tested by

IRTA for cleaning non-energized electrical cleaning, is shown in Appendix C; it is called Power Kleen: Spray Clean 12.

Non-Energized Electrical Equipment Cleaning

IRTA worked with one company to find an alternative to TCE for non-energized electrical equipment cleaning. The company was not using NPB but might adopt it in place of TCE in the future. The alternative tested by IRTA for TCE would also be a viable alternative for NPB. The case study is presented below.

Case Study--Electricity Generator. This company has an electricity generating facility in Sun Valley, California. The company provides electrical power to Southern California Edison. The company maintains their generators in the field on a regular basis. The generators are not energized when the cleaning occurs.

The company historically used mineral spirits to clean the generators but now uses TCE both in liquid form and aerosol cans. The company offered a discarded generator so IRTA and the company could test alternatives. A high pressure spray system that was used for spraying the mineral spirits was used for testing alternatives. IRTA and the company tested a soy based cleaner that contained a rust inhibitor in various dilutions with water. A blend of 70 percent water, 25 percent soy and five percent rust inhibitor performed well in cleaning the generator and did not rust the parts.

The company uses 32 gallons of TCE at their two locations including the Sun Valley plant. About 80 percent of the TCE volume or 25.6 gallons is used in aerosol cans. Assuming there are 13 cans in a gallon, the company uses 333 cans per year. The price of the TCE is $6.94 per can. The annual cost for purchasing the aerosol cans is $2,311. The remaining 6.4 gallons of TCE is used in a blend of 80 percent TCE and another component. The price of the blend is $47 per gallon so the cost of purchasing the 6.4 gallons is $301 per year. The total annual cost of purchasing the TCE products is $2,612.

IRTA estimates that if the company converted to the soy material, they would have to use about 10 percent more product to obtain equivalent cleaning. The company uses 32 gallons of TCE based products currently so 35.2 gallons of the soy blend would be required annually. The blend is made up of about nine gallons of soy, about two gallons of rust inhibitor and the remainder is water. The cost of soy and the rust inhibitor are about $6 and $10 per gallon respectively. The annual cost of purchasing the blend would be $74.

Table 4-10 summarizes the cost comparison for the generator cleaning. The cost of using the soy based cleaner is 37 times lower than the cost of using TCE. If NPB were used in place of TCE, the cost savings for converting to the soy cleaner would be even greater since NPB is more expensive than TCE.

**Table 4-10**
**Annualized Cost Comparison for Energy Generator**

| | TCE Cleaning | Soy Cleaning |
|---|---|---|
| Cleaner Cost | $2,612 | $74 |
| Total Cost | $2,612 | $74 |

Energized Electrical Equipment Cleaning

For energized electrical equipment cleaning, the cleaner must not have a flash point or be conductive. From an overall health and environmental standpoint, the preferred alternatives to NPB are HCFC-141b, HCFC-225, HFC-4310 and the HFEs. The three latter cleaners are combined with DCE to make them more effective.

IRTA worked with a small utility that provides water and generates electricity for a city on alternatives for energized and non-energized electrical equipment cleaning. The case study is presented below.

Case Study--Electric Utility. This utility is located in Burbank, California. The company must maintain their equipment in the field and part of that maintenance involves cleaning surfaces of generators and transformers that are not energized and various types of equipment while it is energized.

The company cleans their non-energized field equipment with a water-based cleaner. This water-based cleaner contains less than 10 percent of a glycol ether. The VOC content of the cleaner is about 120 grams per liter. The company uses the cleaner sometimes at full strength and sometimes at 50 percent concentration.

IRTA and the utility tested three alternative water-based cleaners that do not have any solvent additives. One of these lower VOC cleaners was judged to be about as good as the current cleaner. IRTA provided five gallons of the cleaner to the facility and it was judged to clean well.

The utility uses 85 gallons per year of their water-based cleaner to maintain their non-energized electrical equipment. The cost of the water-based cleaner is $9.09 per gallon. The total annual cost of purchasing the cleaner is $773. The cost of the alternative cleaner is about $10 per gallon. Assuming the same level of use, the annual cost of purchasing the alternative water-based cleaner would be $850.

Table 4-11 shows the cost comparison for the water-based cleaners for cleaning the non-energized electrical equipment.

**Table 4-11**
**Annualized Cost Comparison for Electric Utility for Non-Energized Electrical Equipment Cleaning**

| | Current Water-Based Cleaner | Alternative Water-Based Cleaner |
|---|---|---|

| | | |
|---|---|---|
| Cleaner Cost | $773 | $850 |
| Total Cost | $773 | $850 |

The utility, like many other companies that maintain energized electrical equipment, uses an HCFC-141b aerosol cleaner. IRTA tested three alternatives with the company that could be replacements for the HCFC-141b when it is no longer available. The cleaners that were tested are also alternatives to NPB. The first of these was based on HCFC-225. This HCFC is not as aggressive a cleaner as HCFC-141b and employees at the utility did not think it performed well. IRTA provided two other cleaners to the company. One of these was a combination of HFEs and DCE. The other was a blend of an HFC called HFC-245fa and DCE. Both of these cleaners worked well and the employee judged they worked as well as HCFC-141b. The HFEs and HFC do not contribute to the cleaning capability but DCE is a strong cleaner.

The utility currently uses 247 16-ounce cans per year of the HCFC-141b aerosol cleaner at a cost of $14 per can. The total annual cost of using this cleaner is $3,458. The cost of the HFE/DCE cleaner is $25.98 for a 12-ounce can. This translates to $34.64 for 16 ounces. Assuming the same usage, the annual cost of purchasing the HFE/DCE blend is $8,556. The cost of the HFC/DCE blend is $16.16 per 16-ounce can. Again, assuming the same usage, the annual cost of purchasing the HFC/DCE blend amounts to $3,992.

The employee who supervises and performs the cleaning indicated that the alternative cleaners worked well but he was concerned that the workers that do the cleaning might have to spend more time cleaning if the cleaners failed to work as well in some instances. For this scenario, IRTA assumed the cleaning labor would increase by 30 percent. Currently, six people spend two hours per week performing this type of cleaning. Assuming a labor rate of $30 per hour, the labor cost for energized electrical equipment cleaning is $18,720. If the labor cost increased by 30 percent through adoption of one of the alternatives, the labor hours would amount to 811 per year and the labor cost would total $24,336.

Table 4-12 shows the cost comparison for energized electrical equipment cleaning. The cost of using the HFE/DCE blend if labor remains the same is 23 percent higher than the cost of cleaning with HCFC-141b. The cost of using the HFC/DCE blend if labor remains the same is comparable to the current cost of using HCFC-141b. If the labor cost increases, the cost of using both of the alternatives is much higher than using HCFC-141b.

**Table 4-12**
**Annualized Cost Comparison for Electric Utility for Energized Electrical Equipment Cleaning**

| | Current Cleaner | HFE/DCE (same labor) | HFC/DCE (same labor) | HFE/DCE (more labor) | HFC/DCE (more labor) |
|---|---|---|---|---|---|
| Cleaner Cost | $3,458 | $8,556 | $3,992 | $8,556 | $3,992 |
| Labor Cost | $18,720 | $18,720 | $18,720 | $24,336 | $24,336 |
| Total Cost | $22,178 | $27,276 | $22,712 | $32,892 | $28,327 |

Future Work on Energized Electrical Equipment Cleaning Alternatives

IRTA has just initiated a project sponsored by EPA to find, test and demonstrate safer suitable and effective alternative energized electrical equipment cleaners. IRTA plans to investigate several alternatives including deionized water, carbon dioxide snow or pellets and a laser cleaning device. Water-based cleaners do not have flash points but they are conductive. Deionized water, however, is not conductive and might be a suitable cleaner. If one or more technologies is found to be suitable for this application, no halogenated solvent cleaners would be required.

# V. 1,2-TRANS-DICHLOROETHYLENE

## BACKGROUND

1,2-trans-Dichloroethylene or DCE is structurally similar to PERC, TCE and vinyl chloride, a human carcinogen. DCE has not been tested for chronic toxicity so it is unknown whether it is a carcinogen.

DCE is classified as a VOC. It is not listed as a HAP, a TAC or on Proposition 65. It is found as a biodegradation product at many contaminated sites where PERC and TCE have been used for cleaning or dry cleaning. It is regulated as a hazardous waste under RCRA.

DCE has been used for more than 10 years as a component in formulations designed for vapor degreasing and aerosol cleaning. DCE, in spite of the fact that it is a halogenated material, does have a flash point. As a result, it cannot be used alone in a vapor degreaser where the solvents are heated to their boiling points. In vapor degreasing formulations, it is always combined with other halogenated solvents that do not have flash points so the mixture will not have a flash point. In aerosol cleaning applications, it is similarly combined with other materials with no flash points. The reason for its use in these applications is that the other halogenated solvents it is combined with are poor cleaners and DCE, an aggressive cleaner, enhances the cleaning capability.

IRTA and HESIS decided to focus on the two dispersive major applications of DCE. These include:

- vapor degreasing
- aerosol cleaning

These applications of DCE are discussed in this section and alternatives to DCE are identified and discussed.

## VAPOR DEGREASING

As discussed above, DCE is combined with other less effective solvents in vapor degreasing to enhance their cleaning capability. The other solvents it is often combined with are HCFC-4310, HFEs and HCFC-225. These other materials suppress the flash point of the mixture so the blends can be used in open top vapor degreasers. Product sheets for DuPont's blends of HFC-4310 and DCE and 3M's HFE/DCE blends are shown in Appendix D.

The materials with which DCE is combined are much more expensive than other solvents. For this reason, virtually all the DCE formulations are used in high value applications for PCB cleaning and other precision cleaning operations. In the sections on PCB and precision cleaning for NPB, some of these formulations were discussed. The vapor degreasing equipment for use with DCE blends is generally less emissive than equipment for use with other vapor degreasing solvents because the blends are very expensive.

Printed Circuit Board Cleaning Alternatives

In the section on NPB, alternatives to NPB for cleaning PCBs were discussed. These same alternatives are also alternatives to DCE blends. To summarize, the first alternative is to use low solids flux which does not require cleaning. The second alternative is to use water soluble flux for the PCBs which can be cleaned with plain D.I. water. The third alternative is to use water-based cleaning saponifiers to clean rosin flux from the boards.

Some board assemblers do not accept these alternatives and believe they need to use solvent to clean the flux from the boards. Airless/airtight degreasers can be used with the DCE blends in such cases and the higher cost of the equipment is likely to be justified because of the high cost of the solvents.

Precision Cleaning Alternatives

Again, the alternatives for these types of cleaning applications are the same as the alternatives for NPB precision cleaning. The DCE blends are used to clean hybric circuits, relays, space components and electronic and electrical components. Alternatives include water-based cleaners which can be used in combination with vacuum dryers to ensure all the moisture is removed and airless/airtight degreasers used with the DCE blends. Although converting away from the DCE blends would be the best option, airless/airtight degreasers would minimize emissions of the solvent and worker exposure. The case studies presented earlier in the NPB section on precision cleaning alternatives demonstrate that companies can convert to water-based cleaners or airless/airtight degreasers.

AEROSOL CLEANING

As discussed earlier in the section on aerosol cleaning for NPB, several contact cleaners containing DCE are marketed. An MSDS for one of these blends containing HCFC-225, made by Techspray and called No-Clean Flux Remover was shown in appendix C. Another product made by MG Chemicals and called 412-Aerosol contains HFEs and DCE; an MSDS was shown in Appendix C. These cleaners are used for cleaning energized and non-energized electrical equipment.

Alternatives in Contact Cleaning

The same alternatives that were discussed in the NPB section are also appropriate as alternatives for cleaning non-energized electrical parts. These alternatives include water-based cleaners, soy based cleaners and cleaners containing solvents that have flash points. For energized electrical equipment cleaning, the best alternatives in terms of health and the environment are HCFC-141b which should be available for this type of cleaning for some time and DCE combined with HCFC-225, HFC-4310 or the HFEs. An MSDS for one of the HCFC-141b products, made by CRC Industries and called Contact Cleaner 2000, was shown in Appendix C. As mentioned in the section on NPB, IRTA has just initiated a project sponsored by EPA to identify, test and demonstrate alternatives for energized electrical equipment cleaning that do not include halogenated solvents.

# VI. N-METHYL PYRROLIDONE

## BACKGROUND

N-Methyl pyrrolidone or NMP is a developmental toxicant. The chemical is listed on Proposition 65 and is classified as a VOC. It is not a listed HAP or TAC because those lists were developed before NMP was more widely used. NMP is not regulated by OSHA or Cal/OSHA.

Over the last decade or so, NMP has been marketed in a variety of applications. One of its primary uses is as a paint stripper; the suppliers claim it is a safer alternative to METH in these applications. It is also used in various types of cleaning applications and in some consumer products. IRTA and HESIS decided to focus on the following uses during this project:

- consumer product paint stripping
- furniture stripping
- other stripping activities
- precision cleaning
- pharmaceutical penetration enhancer
- children's shampoo and bath concentrate

The balance of this section summarizes these uses and discusses the alternatives that are available.

## CONSUMER PRODUCT PAINT STRIPPING

Consumer product paint strippers are sold in hardware and home improvement stores. CARB estimates that emissions of VOC solvents, including NMP, from these paint strippers amount to about seven tons per day. METH is not classified as a VOC but it is a carcinogen, a HAP, a TAC and is listed on Proposition 65. METH based strippers are more widely used and CARB estimates emissions of METH from paint strippers at about 10 tons per day. NMP is being marketed by the suppliers as a safe alternative to METH strippers.

The items that are commonly stripped using consumer product paint strippers are made of wood and, less often, metal. A variety of coating types must be stripped using these stripping formulations. Stripping effectiveness is determined by the ability of a stripping formulation to strip the coating and the wood or metal type is comparatively unimportant.

There are three uses of consumer product paint strippers. First, there are companies that provide on-site services to consumers for stripping kitchen cabinets or to offices for stripping wood cabinets; these contractors use the stripper which is purchased from hardware stores to strip in place. Second, more than 400 small facilities in California perform stripping as part of their business; typical facilities would include antique shops that restore antiques. These shops also purchase paint strippers from hardware stores. Third, consumers purchase paint strippers from hardware stores to strip wood furniture, wood molding or patio furniture at home as part of a refinishing operation.

IRTA recently completed a project sponsored by DTSC that focused on identifying, developing, testing and demonstrating consumer product strippers that could serve as alternatives to METH based strippers. The best alternative strippers are also alternatives to NMP strippers. During the project, IRTA worked with Benco Sales, a stripping formulation supplier, who developed alternatives for testing. IRTA tested alternatives with contractors who strip on-site, small furniture stripping facilities and on panels designed to represent substrates stripped by consumers.

Alternatives for Contractor Stripping On-Site

A picture of a contractor preparing a kitchen for stripping is shown in Figure 6-1. The stripping formulations used for this type of stripping activity are fairly viscous since they must strip vertical services. The baseline stripper, in this case, was a METH stripper called Lifteeze Paint & Varnish Remover. An MSDS for this stripper is shown in Appendix E. The stripper contains METH, methanol, acetone and toluene. Other strippers containing NMP might also be used for this purpose.

Figure 6-1. Preparing Kitchen for Stripping

The on-site stripping was conducted at a house with kitchen cabinets made of pine with a varnish coating. The kitchen is first broken down; the drawers and doors are removed from the cabinetry. The procedure is to apply the stripper, remove the coating residue and sand and stain the cabinetry with the new finish.

Two non-METH strippers that contain benzyl alcohol were tested as alternative strippers. These strippers did not contain NMP. MSDSs for the two strippers, called #B95 and #B74, are shown in Appendix E. Benzyl alcohol, the major ingredient of the strippers, is lower in toxicity than both METH and NMP.

The first test involved applying the three strippers to a panel divided with tape into three sections. #B74 was applied to the left hand side of the panel, #B95 was applied to the middle of the panel and Lifteeze, the baseline stripper, was applied to the right hand side of the panel.  Figure 6-2 shows the three strippers being applied to the panel.  In a second test, the strippers were applied to a second panel.  In a third test, the strippers were applied to a third panel that had coating on top and an adhesive residue on the bottom. The results of the testing indicated that the METH based stripper, Lifteeze, performed better than the two alternative strippers.  The contractor judged that the #B95 worked almost as well as the Lifteeze stripper, however, and he said he would be willing to use it. The #B74 alternative stripper did not work as well as the #B95 and the contractor did not like the odor.

Figure 6-2.  Brushing Stripper on Panel

<u>Alternatives for Hand Stripping at Small Furniture Stripping Firms</u>

The second set of tests was conducted at two furniture stripping facilities to mimic hand stripping by small furniture stripping firms.  At one stripping facility, Sunset Strip, the items that were stripped included a bed rail with a shellac coating, a chair with two coats of enamel and a bookcase shelf with a lacquer coating.  Figure 6-3 shows a picture of the bed rail with five strippers applied.  The baseline stripper was a METH based stripper called #B4.  An MSDS for this stripping formulation is shown in Appendix E.  Two of the alternative strippers contained benzyl alcohol and acetone and two contained benzyl alcohol.  The best performing stripper was #B95, the same stripper that performed well in the kitchen stripping.  The hand stripping of several items at the second furniture stripping facility, Strip Joint, revealed that #B95 was also the best alternative stripper for the items tested at that location.

Figure 6-3. Bed Rail After Applying Five Strippers

Alternatives for Consumer Hand Stripping

For the consumer home stripping, IRTA purchased several METH and non-METH strippers at hardware and home improvement stores. Two of the strippers contain METH and two contain NMP. MSDSs for these strippers are shown in Appendix E. The stripping formulations included:

- KS Brushable Stripper made by W.M. Barr & Company which contains 80 to 85 percent METH and methanol;
- BIX Stripper made by BIX Mfg. Co. which contains 15 to 25 percent METH and methanol;
- CS Stripping Gel made by W.M. Barr & Company which contains 40 to 50 percent NMP and a methyl ester;
- Ready-Strip Pro made by Back to Nature Products Co. which contains 25 to 30 percent benzyl alcohol, NMP and formic acid; and
- Ben's Nu-Tech Stripper made by Benco Sales which contains 50 to 60 percent benzyl alcohol and formic acid.

The vast majority of coatings that are encountered by consumers that want to strip wood pieces are nitrocellulose lacquers. Benco Sales provided a wood panel containing a nitrocellulose lacquer for conducting comparative hand stripping tests of the stripping formulations. Other items that are commonly stripped by consumers are metal patio furniture pieces. Benco Sales provided a green metal panel containing an epoxy primer and a cross-linked polyurethane topcoat. Benco sales also provided a silver metal panel containing an epoxy primer and a UV cured topcoat that was meant to represent future coatings that may require stripping by consumers.

The panels were masked off with tape as shown in Figure 6-4. From right to left are the wood panel, the green metal panel and the gray metal panel. The stripping formulations were applied to the masked off sections of the panel and allowed to sit.

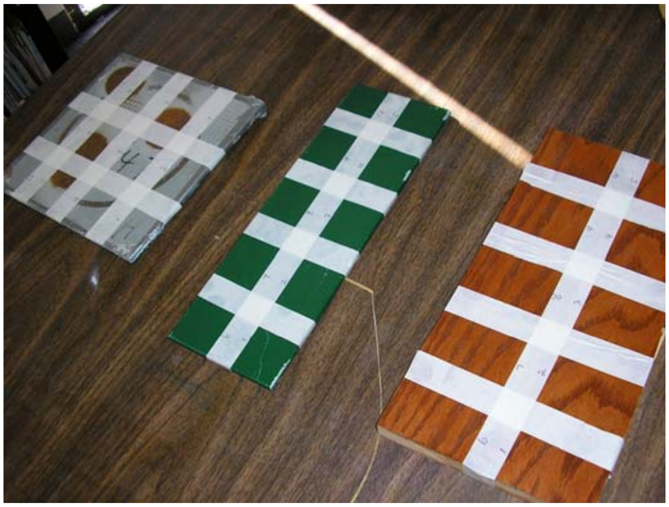

Figure 6-4. Three Masked Panels

Table 6-1 summarizes the results for the stripping tests of the wood panel. An S in the table indicates the coating was fully stripped in the time specified. After 20 minutes, the only stripper that did not strip the coating was Ready-Strip Pro.

**Table 6-1**
**Results of Hand Stripping Tests for Wood Panel With Lacquer Coating**

| Stripper | Description | 10 Minutes | 20 Minutes | One Hour |
|---|---|---|---|---|
| CS Stripping Gel | NMP | S | - | - |
| KS Brushable Stripper | High METH | S | - | - |
| BIX Stripper | Low METH | - | S | - |
| Ben's NuTech Stripper | Benzyl alcohol | S | - | - |
| Ready Strip Pro | Benzyl alcohol, NMP | - | - | S |

The coatings on the green metal panel were more difficult to strip. Table 6-2 summarizes the results of the stripping tests for this panel. B indicates the stripper was beginning to work on the coatings. T indicates the topcoat was removed and P indicates the primer was removed. The results indicate that the high NMP stripper worked more slowly than the benzyl alcohol and the benzyl alcohol/NMP stripper. The benzyl alcohol stripper worked as effectively as the low METH content stripper and worked better than the high METH content stripper.

The coating on the gray metal panel was extremely difficult to remove. After 20 hours, with intense scraping, the two benzyl alcohol strippers were starting to remove the coating. None of the other strippers started to remove the coatings.

**Table 6-2**
**Results of Hand Stripping Tests for Green Metal Panel With Epoxy Primer and Polyurethane Topcoat**

| Stripper | Description | 30 Minutes | 5.5 Hours | 20 Hours |
|---|---|---|---|---|
| CS Stripping Gel | NMP | - | T | T, P |
| KS Brushable Stripper | High METH | B | T | T, P |
| BIX Stripper | Low METH | - | T, P | - |
| Ben's NuTech Stripper | Benzyl alcohol | - | T, P | - |
| Ready Strip Pro | Benzyl alcohol, NMP | - | T, P | - |

A cost analysis was conducted for the consumer product strippers. The costs were developed based on four assumptions. First, it was assumed that about twice as much of a METH based stripper would be required for a stripping task. This follows from the fact that the vapor pressure of METH is very high so the stripper evaporates and needs to be reapplied. During the testing, the METH strippers did dry out much more quickly than the alternative strippers with lower vapor pressure components. Second, the cost analysis was performed assuming a consumer would use two quarts of a METH containing stripper and one quart of a non-METH stripper for a particular stripping job. Third, it was assumed that the consumer would dispose of the waste from the stripping operation in the garbage. Fourth, the price of the strippers was the price paid at a hardware or home improvement store.

Table 6-3 shows the cost comparison for the consumer product strippers. The lowest cost stripper to use is the benzyl alcohol. The highest cost stripper is the stripper containing both benzyl alcohol and NMP.

**Table 6-3**
**Cost Comparison of Consumer Hand Strippers**

| Stripper | Description | Stripper Cost Per Quart | Amount Used | Total Cost |
|---|---|---|---|---|
| CS Stripping Gel | NMP | $10.99 | 1 quart | $10.99 |
| KS Brushable Stripper | High METH | $7.47 | 2 quarts | $14.94 |
| BIX Stripper | Low METH | $5.97 | 2 quarts | $11.94 |
| Ben's NuTech Stripper | Benzyl alcohol | $7.95 | 1 quart | $7.95 |
| Ready Strip Pro | Benzyl alcohol, NMP | $17.69 | 1 quart | $17.69 |

The consumer product stripping tests described here indicate that benzyl alcohol stripping formulations are effective consumer product strippers. Benzyl alcohol can be used as an alternative to METH and NMP based consumer product strippers. Benzyl alcohol is lower in toxicity than both of the other chemicals.

FURNITURE STRIPPING

IRTA has conducted several projects over the last 10 years on alternatives to METH based strippers for furniture stripping firms and on better ventilation systems for stripping firms using METH based strippers. Most of the projects on alternatives focused on using low METH content stripping alternatives. In an earlier project sponsored by SCAQMD, IRTA tested some alternatives to METH that did not contain NMP. In a recent project sponsored by DTSC, IRTA worked with a formulator, Benco Sales, to test alternatives to METH based strippers with furniture stripping firms. According to the stripping firms that tested one of the alternatives in the DTSC project, it performed almost as well as the METH based stripper used by the industry.

In an earlier project, IRTA surveyed the furniture stripping industry in the South Coast Basin in Southern California to determine the level of their METH based stripper usage. IRTA estimated the number of firms in California that use METH based strippers from the information. Table 6-4 presents this information.

**Table 6-4**
**Estimated Annual Stripper Usage by Furniture Stripping Facilities**

| Annual Stripper Usage (gallons per year) | Number of Firms in South Coast Basin | Number of Firms in California |
|---|---|---|
| 1,200 - 2,000 | 3 | 6 |
| 700 - 1,200 | 15 | 30 |
| 200 - 700 | 20 | 40 |
| 5 - 200 | 86 | 172 |
| < 5 | 124 | 248 |
| Total | 248 | 596 |

The values in Table 6-4 indicate that there are about 38 firms in the South Coast Basin that use more than 200 gallons per year of stripper. There are twice that number in California. These larger furniture stripping firms purchase stripper in drum quantities from suppliers. The remaining 210 firms in the South Coast Basin probably do not use equipment for stripping and they may purchase their stripper from hardware stores and home improvement stores. These latter facilities could use the alternative stripping formulations discussed earlier under consumer product strippers.

Figure 6-5 shows a picture of a typical flow tray, the equipment used by larger furniture strippers to apply the stripper to parts. It is a sloped shallow tank eight feet long and four feet wide with a drain at the lower end. The stripper is pumped through a brush from a five gallon container. The item to be stripped is placed in the tray and the worker moves the brush over the part vigorously. At times, it is necessary to scrape the item to completely remove the coating.

Figure 6-5. Typical Flow Tray

When the worker is finished stripping the item, it is transferred from the flow tray to the water wash booth. A picture of a typical water wash booth is shown in Figure 6-6. High pressure wands containing water and oxalic acid are used to rinse the remaining stripper and coating residue from the item. The oxalic acid is used to brighten the wood surface.

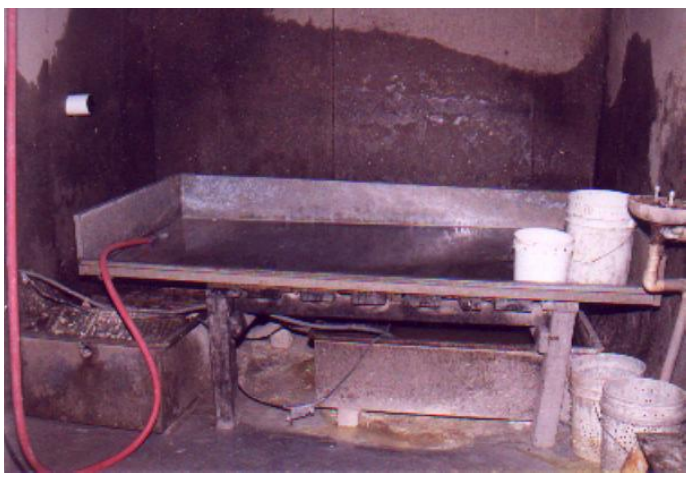

Figure 6-6. Typical Water Wash Booth

An MSDS for a typical METH stripping formulation used by large furniture stripping companies in flow trays is shown in Appendix E. This stripper, called Benco #B7 Industrial Paint Remover, has low viscosity so it can be pumped through the pumps in the flow tray. The stripping formulations used by smaller firms for hand stripping are often more viscous so they will remain on the part long enough to strip the coating. In the last few years, some furniture stripping firms have begun using METH alternatives for stripping. Some of the alternative strippers contain NMP. An MSDS designed for furniture strippers containing NMP is shown in Appendix E; the stripper, called #B23, contains NMP as the major ingredient.

Alternatives for Large Furniture Stripping Firms for Stripping in Equipment

During the DTSC project, IRTA tested the #B7 which contains METH and three alternative non-METH stripping formulations with two large furniture stripping facilities, Strip Joint and Sunset Strip. A number of items containing different types of coatings were stripped at these two facilities. MSDSs for the three alternative stripping formulations that were tested are shown in Appendix E. One of the stripping formulations, #B94, was judged to be too thick for flow tray stripping by the owner of Sunset Strip so it was not tested further. The other two formulations, #B96 and #B73, contain benzyl alcohol (called aromatic alcohol on one MSDS and alpha-hydroxy toluene on the other MSDS).

At Sunset Strip, the items that were stripped with the #B7, the #B96 and the #B73 included:

- chest of three drawers with a lacquer coating;
- mirror frame with a shellac coating;
- door with a shellac coating; and
- chair with a white enamel coating.

A picture of the items in the flow tray at Sunset Strip is shown in Figure 6-7.

Figure 6-7. Items in Flow Tray at Sunset Strip

The results of the stripping tests indicated that the #B7, the METH stripper, stripped the items more quickly than the alternatives. For instance, the #B7 stripped the drawer with the lacquer coating in five minutes whereas the #B96 stripper took about 15 minutes to strip the similar item. The #B96 also required more rinsing. This is to be expected since the stripper components have lower vapor pressure. An advantage of the #B96 was that it did not require rinsing with the oxalic acid which is used with the #B7. The owner, who did the stripping himself, indicated that the #B73 was not as effective as the #B96 and the odor was retained on the furniture items and was difficult to eliminate. The owner indicated that the #B96 performed acceptably and was a viable alternative to #B7.

At Strip Joint, the #B73 was not tested because it was less effective than #B96 and because of the problems with odor at Sunset Strip. The other two stripping formulations, the #B94 and #B96, were tested. As was the case at Sunset Strip, the #B94 was judged to be too thick for flow tray stripping by the worker at Strip Joint.

The items that were stripped at Strip Joint included:

- mahogany drawer with a lacquer coating;
- dental cabinet drawer with multiple layers of a latex coating;
- a mahogany door with several coats of enamel; and
- an oak drawer and door with a varnish coating.

A picture of these items before stripping with #B96 is shown in Figure 6-8.

Figure 6-8. Items Before Applying Strippers at Strip Joint

The #B94 stripper stripped the varnish and lacquer coatings easily. It did not strip the enamel panel completely in the same time allotted for the #B7 baseline METH stripper. It did, however, strip the latex coating from the dental drawer which the #B7 was not able to strip. The #B96 also stripped the varnish and lacquer coatings easily. It stripped the enamel coating as quickly as the #B7 stripper. This stripping formulation stripped the latex coating on the dental drawer more effectively and quickly than the #B94 and much more effectively than the #B7.

The alternative stripping formulation that performed best at the Strip Joint was #B96. It performed better than the #B7 in stripping the latex coating. The owner of the Strip Joint used the #B96 stripper to strip several items in the flow tray at a later date. He indicated that the stripper was acceptable and that it performed effectively as an alternative to #B7.

For the DTSC project, IRTA performed a cost comparison for a hypothetical furniture stripper using 10 drums per year of the METH based stripper, #B7, and a benzyl alcohol stripper, #B96. Benco Sales also supplies an NMP based stripper, called #B23, to a few furniture stripping facilities. During this project, IRTA also compared the cost for the same furniture stripping firm assuming the firm used the NMP based stripper.

If a furniture stripping company converted to the benzyl alcohol stripper, #B96, new polyethylene equipment would be required. One flow tray and one water wash booth tray would be required. The cost of these trays is estimated at $800 each for a total of $1,600. A new pump for the flow tray would also be required; the cost of the pump is $469. The total capital investment a furniture stripping company must make is $2,069. Assuming a 10 year life for the equipment and a cost of capital of five percent, the annualized cost of the capital investment would amount to $217. The same equipment currently used with METH strippers could be used with the NMP formulation, so no capital investment would be required if the stripping company converted to NMP.

The stripping firm currently purchases 10 drums or 550 gallons of the #B7 METH based stripper annually. The cost of the #B7 stripper is $479 per drum. On this basis, the annual cost of purchasing stripper is $4,790. The vapor pressure of the #B7 METH based stripper is very high so it evaporates quickly. During the testing of the alternative benzyl alcohol strippers with the stripping companies, it was estimated that about twice as much of the METH stripper was required as the benzyl alcohol stripper. The vapor pressure of the benzyl alcohol is low and it does not evaporate as readily. The NMP stripper also has a much lower vapor pressure than the METH stripper. Under the assumption that half as much of the #B96 and the #B23 would be required, the stripping company would use only 275 gallons or five drums of the other two strippers annually. At a cost of $850 per drum for the benzyl alcohol stripper, the annual cost of purchasing the alternative stripper would be $4,250. At a cost of $796 per drum for the NMP based stripper, the annual cost of purchasing the alternative stripper would be $3,980.

The #B7 stripper is rinsed in the water wash booth with water and with oxalic acid. The oxalic acid must be used in about a three percent concentration. The cost of the oxalic acid is about $1 per pound. For every 100 gallons of METH based stripper, about 10 pounds of oxalic acid is required. Under this assumption and assuming the facility uses 550 gallons of stripper, the annual cost of the oxalic acid is $55. The NMP based stripper would also be rinsed with water and oxalic acid. Because only half as much stripper is used, however, the cost of the oxalic acid would be less, at $28 annually.

The benzyl alcohol stripper must be rinsed with a dilute 30 percent concentration of hydrogen peroxide in water. The cost of the hydrogen peroxide is $1.50 per gallon. For every 100 gallons of benzyl alcohol stripper, about 30 gallons of hydrogen peroxide is required. On this basis and assuming the stripper use is 275 gallons, the annual cost of purchasing the hydrogen peroxide is $124.

The spent METH, benzyl alcohol and NMP based stripper must be disposed of as hazardous waste. Because the vapor pressure of the METH stripper is higher, more evaporates so there will be less waste generated than when the benzyl alcohol or NMP stripper is used. During the stripping tests, when equal volumes of METH and benzyl alcohol stripper were used, it was estimated that two to three times the waste would be generated with the benzyl alcohol stripper. Currently, for every drum of METH stripper used, five gallons of waste is generated. Since 10 drums of stripper are used by the furniture stripper in this case, 50 gallons of hazardous waste is generated. Assuming the facility must dispose of one drum annually and taking into account that the cost of disposing of one drum of METH stripper is $300, the annual waste disposal cost with the METH stripper is $300. For every drum of benzyl alcohol stripper that is used, between 10 and 15 gallons of waste will be generated. Selecting the higher number to be conservative, the stripper will generate 75 gallons or two drums of waste annually. The disposal cost of one drum of benzyl alcohol stripper waste is estimated at between $150 and $175. Again, assuming the higher figure, the annual waste disposal cost of the benzyl alcohol stripper is $350. It is likely that the same assumptions would apply in the case of the NMP stripper so the disposal cost for that stripper is also $350 annually.

Table 6-5 shows the annualized cost comparison for the furniture stripper using the METH based stripper, the benzyl alcohol stripper and the NMP stripper. The values show the cost of using the NMP based stripper is lower than the cost of using the METH or benzyl alcohol based stripper. The cost of using the safer benzyl alcohol stripper, according to the figures of Table 6-5, is 12 percent higher than the cost of using the NMP stripper.

**Table 6-5**
**Annualized Cost Comparison for Furniture Stripping Company**

| | METH Stripper | NMP Stripper | Benzyl Alcohol Stripper |
|---|---|---|---|
| Annualized Capital Co | - | - | $217 |
| Stripper Cost | $4,790 | $3,980 | $4,250 |
| Rinse Agent Cost | $55 | $28 | $124 |
| Disposal Cost | $300 | $350 | $350 |
| Total Cost | $5,145 | $4,358 | $4,941 |

OTHER STRIPPING ACTIVITIES

NMP strippers are used for stripping in several other applications. These include aircraft parts stripping, boat bottom paint stripping, deck stripping and various other general purpose stripping tasks. NMP began to be used in these applications as a so-called safer alternative to METH. IRTA approached this end use by finding MSDSs for various stripping agents that contain NMP. Other industrial strippers are available that do not contain NMP and these generally contain benzyl alcohol. The availability of the alternative strippers demonstrates that there are alternatives to NMP in these applications.

MSDSs for several general purpose strippers containing NMP are shown in Appendix E. The first stripper, called Safe Strip Paint & Resin Solvent, contains NMP and a glycol ether. The second stripper, called Enviro Klein Enviro Strip NMC, contains NMP, dibasic esters, terpenes and fatty acid methyl esters. The third stripper, called Soy Gel, contains NMP and probably fatty acid methyl esters. The fourth stripper, called 9051 Bio-Blast Bottom Paint Remover, is an antifogging paint remover for boats. The formulation contains NMP a hydrocarbon mixture and an amide. The fifth stripper, called Woman dextrin A&L, is apparently used for stripping the decks of boats. The stripper contains NMP (although the ingredient is not listed on the MSDS) and petroleum naphtha. The sixth stripper, called TURCO 5668, contains NMP, petroleum distillates and various other ingredients. The seventh stripper, called Peel Away 7, contains NMP, dibasic ester and various other ingredients.

Alternative Strippers/Stripping Methods

MSDSs for the alternative industrial general purpose strippers that do not contain NMP are also shown in Appendix E. These strippers include TURCO 6776-LO, TURCO 6813-E, TURCO 6881, TURCO EA Stripper 6930 and CEE-BEE E-2002A. All of these strippers contain benzyl alcohol as the major active ingredient.

There are many alternative methods of stripping that do not involve the use of chemical strippers. Parts, boat or deck bottoms can be blasted with abrasive media. The particular application will determine which type of media stripping is the most applicable. Blasting media include:

- steel shot
- plastic media
- wheat starch
- water

The chemical strippers strip the coatings from the parts and the coating residue and the stripper sludge must be disposed of as hazardous waste if it contains hazardous components. The media, if the coating contains hazardous components, may require disposal as hazardous waste. The disadvantage of media stripping is that, even when the media is recycled, the waste stream that is generated could be large. Another technology that may be commercialized in the next few years is laser stripping. In some applications, for paint stripping metals, a portable hand-held laser stripping device may be the best technology. The laser stripping device, because it relies on light to do the stripping, does not generate a large volume of waste.

## PRECISION CLEANING

NMP is used in a variety of cleaning applications. In one of these applications, NMP is used for deflecting printed circuit boards. In this case, the NMP is used to remove the flux from the boards and it is followed by a water rinse. The so-called semi-aqueous process is not used widely because it is generally more expensive than use of a saponifier or a closed loop water deflecting process. These water-based alternatives are described in the section on NPB for electronics cleaning. It was less costly to use the alternatives and alternative methods than to use the NMP based cleaners.

NMP is also used in other precision cleaning applications. In some applications, it is used to remove polishing or lapping compounds. An example of this is described in the section on NPB in the case study of the company that manufactures laser guidance systems. This company eliminated the use of NMP by changing the process, using acetone and using water-based cleaners.

## PHARMACEUTICAL PENETRATION ENHANCER

NMP is used to improve the water solubility of poorly soluble drugs in pharmaceutical formulations and has a history of use with many different drugs in veterinary medicine. It is used in topical and transdermal pharmaceutical products for humans.

An MSDS for a product called Vitamin AD Injection is shown in Appendix E. The NMP, in this case, is apparently used to improve the solubility of the vitamins.

A technical information sheet for NATROSOL 250 Pharm Hydroxyethylcellulose is shown in Appendix E. The material functions as a thickening agent for preparing gels which are used as pharmaceutical topical formulations. On the second page of this sheet, a typical formulation utilizing the material is shown. Note that it does not contain NMP.

## CHILDREN'S SHAMPOO AND BATH CONCENTRATE

NMP is used in a product called Fruit Enzymes Children's Bath Concentrate. An information sheet describing "a Mild Children's Shampoo and Bath Concentrate" is shown in Appendix E.

There are a variety of alternatives to the product containing NMP. MSDS or product sheets for these products are shown in Appendix E. The first three alternative children's shampoos are called Suave Kids 2-in-1 Shampoo Cherry Blast, Johnson's Baby Shampoo and No More Tears Baby Shampoo. Product sheets for alternative children's bath concentrates including Aveeno Soothing Baby Bath Treatment, Baby Magic, Johnsons Baby Soothing Vapor Bath and Johnsons Soothing Skin Baby Bath are also shown in Appendix E.

# VII. CONCLUSIONS AND RECOMMENDATIONS

In this project, IRTA evaluated alternatives for five so-called emerging solvents. Such solvents enter the market and, over time, are used widely. They often do not have workplace exposure levels and they generally are not on lists of toxic chemicals. Some of these solvents are deemed exempt from VOC regulations which means they will be used more extensively in California where there are stringent VOC regulations. The solvents that were investigated in the project include:

- decamethylcyclopentasiloxane (D5)
- parachlorobenzotrifluoride (PCBTF)
- n-propyl bromide (NPB)
- 1,2-trans dichloroethylene (DCE)
- n-methyl pyrrolidone (NMP)

IRTA evaluated the alternatives to each of these solvents in the major and a few minor applications where they are used. In many cases, IRTA presents results where the alternatives were tested in the applications of interest. In a number of instances, case studies of companies that have converted to safer alternatives are provided. Many of these case studies include a comparative cost analysis.

In some cases, the candidate solvents are substitutes for one another. In particular, both D5 and PCBTF are used in repair and maintenance cleaning. NPB and DCE (combined with other solvents) are used in precision vapor degreasing processes and aerosol contact cleaners.

Table 7-1 summarizes the safer alternatives that are available for the candidate solvents in the applications of interest.

The results of the analysis show that there are safer alternatives for all of the candidate solvents in the applications that were evaluated. In nearly all cases, the alternatives are used today by a variety of companies and consumers. The results of the case study cost comparisons in many categories demonstrate that the cost of using the alternatives is lower in most cases. Even in cases where the cost of using an alternative is higher, it is not significantly higher.

The D5 toxicological studies indicate that the chemical causes cancer in laboratory animals. OEHHA is evaluating the final toxicity study results and expects to present their analysis within the next year. n-Propyl bromide causes reproductive and developmental toxicity in animals; it can damage the nervous system and it is undergoing carcinogenicity testing. NMP is a developmental and reproductive toxin. Additional toxicity testing is needed for PCBTF and DCE. Both chemicals are structurally similar to known carcinogens and they should be tested for carcinogenicity.

| **Table 7-1**<br>**Safer Alternatives for Candidate Solvents in Selected Applications** | | |
|---|---|---|
| Chemical | Application | Alternative(s) |
| D5 | Dry Cleaning | water-based systems, carbon dioxide, hydrocarbons |
| | Repair and Maintenance Cleaning | water-based cleaners |
| | Consumer Products | IDNP, GD, DC, HP, various products |
| PCBTF | Autobody Coatings | various products |
| | Autobody Coating Thinner | various products, acetone and acetone blends |
| | Autobody Coating Cleanup | acetone, acetone/methyl acetate blend |
| | Repair and Maintenance Cleaning | water-based cleaners |
| | Cosmetic Stain Removal | various products, water-based cleaners, soy based cleaners, soy/acetone blends, glycol ether, glycol ether/acetone blend |
| | Aerosol Rust Prevention | various products, water-based products, vegetable based products |
| NPB | Industrial/Precision Cleaning | water-based cleaners, low solids flux, DCE blends, airless/airtight degreasers |
| | Adhesives | water-based products, acetone based products |
| | Aerosol Cleaning | water-based cleaners, cleaners with flash points, soy based cleaners, HCFC-141b, DCE blends |
| DCE | Vapor Degreasing | water-based cleaners, airless/airtight degreasers |
| | Aerosol Cleaning | water-based cleaners, cleaners with flash points, soy based cleaners, HCFC-141b |
| NMP | Consumer Product Paint Stripping | benzyl alcohol formulations |
| | Furniture Stripping | benzyl alcohol formulations |
| | Other stripping activities | various products/benzyl alcohol formulations |
| | Precision Cleaning | water-based cleaners, acetone, process changes |
| | Pharmaceutical Penetration Enhancer | various products |
| | Children's Shampoo and Bath Concentrate | various products |

Note: IDNP is isodecyl neopentanoate; GD is glycol distearate; DC is dicapryly carbonate; HP is hydrogenated polydecen.

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