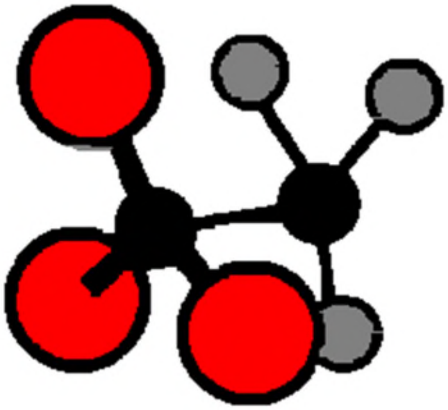

Alternative Compliance Strategies for Open Top Vapor Degreasers under a Prohibition of Trichloroethylene

Draft

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1. Background

EPA is considering restricting the use of trichloroethylene (TCE) as a vapor degreasing solvent under the Toxic Substances Control Act (TSCA). As part of that effort, EPA conducted a detailed risk assessment to evaluate TCE exposure in workers and community members.

This report presents IRTA's estimates for the percentage shares for conversion from open top vapor degreasing to each of the most likely alternatives, presents hypothetical case studies that describe the costs of converting to each suitable alternative, and presents an analysis of the important characteristics that determine the substitution choices.

2. Available Alternatives for Vapor Degreasing with TCE

IRTA's suggests the following classification scheme to categorize alternatives to operating a vapor degreaser with TCE:

- Drop-in Alternatives
    - Perchloroethylene (PERC)
    - Methylene Chloride (METH)
    - n-Propyl Bromide (nPB)
- Non-drop-in Alternatives
    - Hydrofluorocarbons (HFCs)
        - HFC-4310 and blends
    - Hydrofluoroethers (HFEs)
        - HFE 7100 and HFE 7200 and blends
    - Hydrofluoroolefin (HFO)
        - HFO 1233zd
- Water-based Cleaning Alternatives
- Not-in-kind Non-water alternatives
    - Oxygenated solvents
    - Hydrocarbon solvents
    - Terpene based cleaners
    - Parachlorobenzotrifluoride (PCBTF)
    - Volatile methyl siloxanes (VMSs)
    - Soy based cleaners
    - Non-chemical alternatives
- Cold Cleaning

2.1 Drop-in Alternatives

In the early 1990s, EPA developed the Halogenated Solvents Cleaning NESHAP, one of the first regulations for categories using chemicals on the Hazardous Air Pollutants (HAP) list in the Clean Air Act Amendments of 1990. This NESHAP regulation covered vapor degreasers and cold cleaning units that used TCE, perchloroethylene (PERC), methylene chloride (METH), 1,1,1-trichloroethane (TCA), chloroform and carbon tetrachloride (CT). Users could comply with the regulation by meeting certain equipment standards and operating practices or they could rely on an overall solvent loss rate. CT and TCA production were later banned because the chemicals in question contribute to stratospheric ozone depletion. Chloroform was not really used by anyone for vapor degreasing.

Companies had to make a decision about whether or not they should continue to use NESHAP solvents when the regulation became effective. Many of them had equipment that would not satisfy the requirements and their production requirements were high enough so they could not meet the overall loss rate. Some companies, at that stage, converted to alternatives that were not covered by the NESHAP regulation. Some got rid of their degreasers and purchased other equipment for use with alternatives and some continued to use their vapor degreasers with excluded alternatives. Other companies upgraded their degreasers to comply with the standards. Companies using TCE today were likely those who decided to upgrade their equipment or who had equipment that already complied with the regulation.

For purposes of this analysis, IRTA considers a drop-in alternative to be a chemical that could be used in a NESHAP compliant degreaser. Such degreasers are quite emissive and many of the solvents available for use in vapor degreasing processes would not be used in this equipment because they are too expensive. Thus, in IRTA's view, the drop-in alternatives to TCE in vapor degreasing are limited to two other chlorinated solvents, PERC and METH, and a brominated solvent, n-propyl bromide (nPB).

As a qualification, PERC's boiling point is higher than TCE's boiling point (250 degrees F vs 189 degrees F) and a more powerful heater would be needed to reach the boiling point of the solvent. Most degreasers sold in the past were designed for use with any of the chlorinated solvents, however, so it is likely that the heaters in TCE degreasers would be suitable for using PERC. METH has a much lower boiling point than TCE (103 degrees F) so losses of it from the degreaser would be higher than for TCE. Both solvents are heavily regulated (as is TCE) but, even so, it is likely that some TCE users would convert to these solvents.

When the NESHAP was adopted, many companies using TCE did not want to upgrade their equipment and they converted to alternatives that were not covered in the NESHAP. Some converted to nPB which they continued to use in quite emissive equipment. Some companies using TCE today would likely convert to nPB and it could be considered a drop-in alternative. nPB has certain technical disadvantages, including an instability to hydrolysis. When it comes in contact with water, the water reacts with the stabilizer added to the solvent. If the stabilizer concentration is not monitored carefully, it will be depleted and the solvent will "go acid." This means that hydrobromic acid could be formed which could corrode the equipment and expose the workers to high acid concentrations. nPB would need to be monitored more closely than TCE by users who use it as a replacement.

Whether or not companies could convert to PERC, METH or nPB as drop-ins is heavily dependent on their specific application. TCE is an aggressive solvent and it cannot be used with certain materials. METH is even more aggressive than TCE and, depending on the materials of construction of the parts being degreased, it might be incompatible. nPB also has certain compatibility limitations. Users would obviously have to investigate this carefully for their specific applications to see whether they could use the drop-in alternatives.

2.2 Non-drop-in Alternatives

This category would include several different types of cleaners of the following solvent types:

- HFC blends
- HFE blends
- HFO

These alternatives could, in principle, be used in the equipment currently used for TCE. It would not be economic to do so, however. The existing equipment would need to be substantially upgraded or companies would need to purchase new vapor degreasers to use the solvents properly and cost effectively. Airless/airtight degreasers could be used with these vapor degreasing solvents with the exception of the HFO.

2.3 Water-Based and Not-In-Kind Non-Water Alternatives

The third and fourth categories, water-based and not-in-kind non-water alternatives, would include many different types of alternatives. Some examples of classes of alternatives that might be used include but are not limited to:

- Oxygenated solvents
- Hydrocarbon solvents
- Terpene based cleaners
- Parachlorobenzotrifluoride (PCBTF)
- Volatile methyl siloxanes (VMSs)
- Soy based cleaners
- Water-based cleaners
- Non-chemical methods

The chemical alternatives could, in principle, be used in the existing equipment but modifications, in some cases significant modifications, could be necessary. The first five solvent types have flash points so they should not be heated except perhaps in vacuum equipment which is very expensive. Soy based cleaners have very high flash points but generally, they would not be heated. Water-based cleaners could, in principle, be used in the existing equipment but, in most cases, new equipment would be a better option. These cleaners are virtually always heated and agitation of some kind is generally required for good performance. The last option, non-chemical alternatives, could be exercised by some facilities. This would involve adopting methods like abrasive blasting to remove contaminants, changing the oils that are used so cleaning is not necessary, using other methods of eliminating the need for cleaning, using ovens to burn off the contaminants or off-loading the operations to other companies.

Many of the alternatives in the list would not be used in the same way as the TCE is currently. When the parts are placed in the vapor degreaser, the TCE removes the contaminants and the part exits from the vapor degreaser clean and dry. Since vapor degreasers are generally not used with the not-in-kind alternatives, the equipment necessary to achieve the same cleaning capability could include water rinse systems and dryers. Several solvents of the types listed above would leave a residue on the part and they would need to be rinsed with water and dried if the parts need to be residue free. Soy based cleaners have very low vapor pressure and they would need to be rinsed and dried if a residue free part is needed for the next process step. In addition, TCE is quite an aggressive solvent and some of the other classes of solvents, like the VMSs for instance, would not be aggressive enough in many cases to achieve the same cleaning result. Water-based cleaners, in contrast, can clean very aggressively and with the proper heat, agitation, rinsing and drying equipment are probably the best of the not-in-kind alternatives. Water-based cleaners would be suitable for all operations except those that are water intolerant, like degreasing of beryllium parts, for example. The non-chemical options would have to be adopted on a case-by-case basis and would be acceptable in certain types of operation and not others. They would involve different processing of the parts.

2.4 Cold Cleaning

Depending on their specific operation, users could convert to a cold cleaning bath operation where the TCE would be in a container or a handwipe operation where TCE would be used in a tabletop can or a spray bottle. Most users would be unlikely to convert to cold cleaning operations because they would be more difficult and labor intensive than using the vapor degreaser and they would be less effective. Even so, some users might be able to adopt these cold cleaning approaches.

3. Compliance Strategies for Facilities Operating Vapor Degreasers with TCE

In the vapor degreasing application, IRTA considers two regulatory strategies. The first strategy would be a ban on TCE altogether in all vapor degreasing operations. The second strategy would be a ban on TCE in open top vapor degreasing.

For the first and second strategies, users currently using open top vapor degreasers would have to adopt one or more of the alternatives described above, the drop-in alternatives, the non-drop-in alternatives, water-based cleaning alternatives, the not-in-kind non-water alternatives, or cold cleaning. For the second strategy, users would have another option. They could stop using TCE in their open top vapor degreaser and, instead, use it in an airless/airtight degreaser. In both cases, users could actually continue using TCE, but not in an open top vapor degreaser.

3.1 Prohibiting Use of TCE as a Vapor Degreasing Solvent

If EPA banned TCE use in all vapor degreasers, a large fraction of users would convert to the drop-in alternatives, PERC, METH or nPB. This follows from the fact that all users hate change. Many users would want to continue using their current vapor degreaser and would want to use a solvent that is similar to TCE. More users would convert to PERC and nPB than to METH for a few reasons. First, OSHA tightened up their standard on METH several years ago and it requires users to do medical surveillance and monitoring if the exposures exceed certain worker exposure levels. Companies will not be willing to do that. On the other hand, many companies using METH today are not complying with the OSHA standard and there is little enforcement. Second, properties and cleaning capabilities of nPB and PERC are more similar to those of TCE. In most of the country except California, the VOC regulations are not very stringent or they are virtually nonexistent so there would be few barriers to converting to nPB which is a VOC. Because of the strong tendency to avoid change, IRTA estimates that 50% of the users would convert to one of the three drop-in replacement solvents.

PERC has been under regulatory scrutiny for many years but it is not one of the TSCA work plan chemicals. Recent data on toxicity in IRIS show that it is a neurotoxin as well as a carcinogen. Companies may not know that, however, or they may not care. If companies are currently using TCE which is a carcinogen, they would probably not have any compunction about converting to PERC. The suppliers of nPB are strongly marketing the chemical as a green and non-toxic alternative to TCE, PERC and METH, presumably because nPB is not on the HAP list or regulated by OSHA and the other three solvents are. This might result in a slight market advantage for nPB over PERC. Taking these factors into consideration, IRTA estimates that of the 50% of companies which convert to the drop-in replacements, 35% would convert to PERC, 60% would convert to nPB and 5% would convert to METH.

Water-based cleaning processes are institutionalized today, largely because the ban on TCA and CFC-113 in the 1990s caused many water-based cleaner and water-based cleaning equipment suppliers to work diligently on determining the best ways to use these materials. Companies in the country previously using TCE or TCA in vapor degreasers for virtually every different type of process have successfully converted to a water-based process. It is probably safe to say that well over 90 percent of the operations could be converted to water-based cleaning economically. Even so, users hate change and many users who are unfamiliar with water-based cleaning would reject it out of hand. There is a general feeling on the part of users, ignorant about how water cleaning processes work, that water rusts the parts and that it would not clean well enough. Although these things are not true, many solvent users still believe they are. Furthermore, they hear negative things about water cleaning from their solvent suppliers and other chemical suppliers and also, in many cases, from technical assistance providers who are similarly ignorant about water cleaning. At the TCE workshop held by EPA, some attendees and even presenters stated these incorrect refrains. The alternative chemical suppliers are also much more aggressive than water cleaning suppliers in marketing their products because there is more profit in selling solvents and water cleaning systems already have a much larger share of the cleaning market. Taking into account these factors, IRTA estimates that 25% of the users would convert from TCE to water cleaning processes.

Some TCE degreaser users would convert to non-drop-in vapor degreasing alternatives, the HFCs, HFEs or HFO. Some users might try out these alternatives in their existing equipment. Because the solvents and blends are much more expensive, however, companies would be deterred strongly from adopting them in their current equipment where solvent losses would be high. Those users who end up converting to these solvents would be forced to upgrade their equipment or buy a new vapor degreaser to minimize the solvent losses. This would also be expensive and therefore an unattractive option. On this basis, IRTA estimates that only about 5% of users would exercise this option.

If EPA simultaneously banned TCE use in cold cleaning operations, the remaining 20% of users would convert to the non-water not-in-kind alternatives. No one alternative would probably dominate. Selection of an appropriate alternative in the non-water not-in-kind category is process dependent. Users would have to test the alternatives and determine which would work for their particular operation. If EPA did not ban the use of TCE in cold cleaning operations, perhaps some 5% would convert to cold cleaning and only 15% would convert to non-water not-in-kind alternatives.

3.2 Prohibiting Use of TCE as an Open Top Vapor Degreasing Solvent

The results of this strategy would not be that different from the results of the strategy of banning TCE use altogether in degreasers. There would be some users, however, who would elect to purchase and use airless/airtight degreasers and continue to use TCE. Many TCE operations involve degreasing of large metal parts. Airless/airtight degreasers are very expensive and most TCE users would be shocked at the prices. For a system with a small 12 inch diameter chamber, the cost would be more than $100,000. The cost of a system for cleaning larger parts would be much higher. IRTA estimates that no more than about 5% of users of TCE in open top vapor degreasers would opt to continue to use TCE in an airless/airtight degreaser.

Under this option, where users can still use TCE in airless/airtight degreasers, it would not make sense for a user to purchase an airless/airtight degreaser and use one of the non-drop-in degreaser alternatives. TCE is a much more effective cleaner than the HFCs, HFEs and HFO and it is also much less costly. Thus, some of the users who might otherwise purchase better equipment for use with the more expensive solvents would probably instead purchase an airless/airtight degreaser and simply continue using TCE. Better equipment that could be used with the non-drop-in alternatives would be less costly than an airless/airtight degreaser, however, and some users could still opt for this option. Under this strategy, IRTA estimates that no more than 5% of users would convert to non-drop-in degreaser alternatives.

Because the option of using TCE in an airless/airtight degreaser is available under this strategy, fewer users would convert to the drop-in alternatives. In this case, the users who continue using TCE in an airless/airtight degreaser would come from the pool of users who would otherwise convert to a drop-in alternative. Thus, about 45% of users under this strategy would convert to drop-in alternatives and the solvent choice partitioning among nPB, PERC and METH would remain the same.

The fraction of users converting to water-based cleaners and other not-in-kind alternatives would remain the same under this strategy.

3.3 Summary of Compliance Strategies

Table 1 below summarizes the estimates of the conversion choices for facilities operating vapor degreasers with TCE.

Table 1: IRTA Estimates of Conversion Choices for Vapor Degreasers (Percentages)

Conversion Choice	Option 1: Ban TCE Use in all Vapor Degreasers	Option 2: Ban TCE Use in Open Top Vapor Degreasers
TCE Vapor Degreaser	0%	5%
Drop-In Alternatives	50%	45%
PERC	35%	35%
METH	5%	5%
nPB	60%	60%
Non-Drop-In Alternatives	5%	5%
Water-Based Cleaning	25%	25%
Other Not-In-Kind Alternatives	15%	15%
TCE Cold Cleaning	5%	5%
Total	**100%**	**100%**

4. Case Studies: Existing Open Top Vapor Degreasers Operated with TCE

This section presents three case study-type cost estimates to demonstrate the costs of the different alternatives to TCE vapor degreasing applications. The case studies focus on generating and comparing the cost of using different types of alternatives in place of TCE vapor degreasing. The case study alternatives for evaluation include:

- TCE Vapor Degreasing
- Drop-In Alternatives
    - PERC
    - METH
    - nPB
- Non-Drop In Alternatives
- Water-Based Cleaning
- Other Not-In-Kind Alternatives
- TCE Cold Cleaning

The first case study is a precision cleaning application which requires the use of an ultrasonic water-based system. The second and third case studies represent grosser cleaning tasks which are more commonly done with TCE vapor degreasers. The second and third case studies involve the use of a spray cabinet and a conveyorized spray system for the water-based cleaning example. All alternatives listed above are not appropriate for certain of these applications so only those that would be reasonably selected were considered.

4.1 Case Study #1

The first case study that was selected for the vapor degreasing application is a facility that makes contacts and specialty connectors for military and civilian applications. This case study is meant to represent a precision cleaning application for TCE. As part of the assembly process, the connectors, which are small but vary in size and have a very small internal diameter, are currently cleaned in an open top vapor degreaser with TCE. The contaminants on the parts are oils of various types. The vapor degreaser has ultrasonic capability and the capacity of the two sump machine is 15 gallons. The company cleans about 1,000 contacts and runs an average of 10 loads through the degreaser per day. The degreaser is used for cleaning parts for about four hours per day. The contacts are made of a variety of metals including brass, copper and stainless steel.

4.1.1 Baseline-Using an Open Top Vapor Degreaser With TCE

The company purchases 250 gallons of TCE per year. The current price of TCE when purchased in drum quantities is $24 per gallon. On this basis, the annual cost of the solvent is $6,000. The company already has an open top vapor degreaser and, for purposes of analysis, it was assumed that it is paid off.

The vapor degreaser is used for four hours per day. It has a nine kW heater, a one kW ultrasonic generator and a one horsepower refrigeration unit for a total electric load of 10.75 kW. Assuming a cost of 12 cents per kWh, the electricity cost is \$5.16 per day. The degreaser operates five days a week for 52 weeks a year. On this basis, the total annual electricity cost is \$1,342 per year.

The worker who operates the vapor degreaser spends part of the time the degreaser is operating doing other tasks. The total labor time spent for loading and unloading the parts and starting the degreasing cycle is two hours per day or 520 hours per year. At a burdened labor rate of \$20 per hour, the annual labor cost is \$10,400.

The company must dispose of the waste solvent. About 75 percent of the solvent is lost through emissions and 25 percent goes out as waste. This implies that there is 62.5 gallons of hazardous waste generated annually (25% · 250gal = 62.5gal). The cost of disposing of a drum of liquid solvent is \$350 to \$375 and the cost of disposing of the solid contaminants is about \$1.10 per pound. Assuming the midpoint of the range, the liquid disposal cost would be \$412 per year (see Equation (1)).

$$\begin{matrix}\text{Disposal}\\\text{Costs}\\\text{Liquids}\end{matrix}\ \$ = \left(\frac{\begin{matrix}\text{Hazardous}\\\text{Waste}\end{matrix}\,\text{gal}}{\begin{matrix}\text{Drum}\\\text{Volume}\end{matrix}\,\frac{\text{gal}}{\text{drum}}}\right)\cdot\left(\begin{matrix}\text{Liquids}\\\text{Disposal}\\\text{Cost}\end{matrix}\,\frac{\$}{\text{drum}}\right) \rightarrow \left(\frac{62.5\text{ gal}}{55\,\frac{\text{gal}}{\text{drum}}}\right)\cdot\left(362.5\,\frac{\$}{\text{drum}}\right) = \$412 \qquad (1)$$

The baths in the degreaser are changed out when the contamination level from oil reaches about 30%. Assuming a cost for disposal of the solids of \$1.10 and a density of oil and solids of about eight pounds per gallon, the disposal cost of the solids is equal to \$236 (see Equation (2)). The total disposal cost is \$648 annually (\$412 + \$236 = \$648).

$$\begin{matrix}\text{Disposal}\\\text{Costs}\\\text{Solids}\end{matrix}\ \$ = \left(\frac{\begin{matrix}\text{Hazardous}\\\text{Waste}\end{matrix}\,\text{gal}}{\left(100\% - \begin{matrix}\text{Oil}\\\text{Contamination}\\\text{Level}\end{matrix}\,\%\right)} - \begin{matrix}\text{Hazardous}\\\text{Waste}\end{matrix}\,\text{gal}\right)\cdot\left(\begin{matrix}\text{Oil and Solids}\\\text{Density}\end{matrix}\,\frac{\text{lb}}{\text{gal}}\right)\cdot\left(\begin{matrix}\text{Solids}\\\text{Disposal}\\\text{Cost}\end{matrix}\,\frac{\$}{\text{lb}}\right) \rightarrow$$

$$\left(\frac{62.5\text{ gal}}{(100\% - 30\%)} - 62.5\text{ gal}\right)\cdot\left(8\,\frac{\text{lb}}{\text{gal}}\right)\cdot\left(\frac{\$1.10}{\text{lb}}\right) = \$236 \qquad (2)$$

The total cost to the company of using the open top vapor degreaser includes the cost of purchasing the solvent, paying for the electricity, paying the worker and the cost of disposal. The total cost amounts to \$18,390 per year.

There will be additional costs to the company for using the TCE degreaser which is regulated under the Halogenated Solvents Degreasing NESHAP. That regulation requires record keeping and reporting. In addition, air agencies in various states and localities charge emissions fees because TCE is a toxic and it is also a VOC. In general, most air agencies require a permit for a vapor degreaser and there is generally an annual fee associated with it. Most air agencies also require record keeping and reporting of toxics and VOCs. Because there is such great variation in what the requirements are likely to be across the country, IRTA did not quantify these costs but they do need to be recognized qualitatively.

4.1.2 Substituting Drop-In Alternatives

The so-called drop-in alternatives to TCE in the vapor degreaser are PERC, METH and nPB. PERC and METH are covered by the NESHAP regulation so they can obviously be used in the NESHAP-compliant TCE degreaser. nPB is not covered by the NESHAP regulation but there is no reason it could not be used in a NESHAP-compliant degreaser. Depending on how old the vapor degreaser is, slight modifications might be necessary but they are likely to be very low in cost.

The evaporation rate of a solvent, to some extent, is related to the vapor pressure and boiling point. The higher the vapor pressure and the lower the boiling point, the greater the tendency to evaporate. Table 2 below shows the boiling points and vapor pressures for the solvents for reference purposes.

Table 2: Vapor Pressure and Boiling Point of TCE and Drop-In Alternatives

Solvent	Vapor Pressure (mm Hg)	Boiling Point (degrees F)
TCE	74	189
PERC	18	250
METH	350	104
nPB	111	159

There is no way to know with accuracy how much the emissions from the vapor degreaser would change with substitution of the alternatives, so IRTA estimated what the changes could be. PERC has a low vapor pressure and high boiling point so solvent usage and emissions are likely to be less than for TCE. IRTA assumed a 20% lower emission rate for PERC. METH has a very high vapor pressure and a very low boiling point so losses from the degreaser are likely to be much higher. IRTA assumed the emissions would increase by 40% in this case. nPB has a higher vapor pressure and lower boiling point than TCE so emissions are likely to be higher. IRTA assumed they would be 20% higher than for TCE.

Some of the costs for operating the degreaser would remain the same with substitution of the drop-in alternatives and some would be different. The electricity cost, the labor requirement and the disposal cost would remain the same. The price given above covers disposal of halogenated solvents which is significantly higher than for non-halogenated solvents. The use and emissions of solvents would change with substitution of the alternatives. The differences are discussed for each of the solvents below.

<u>PERC.</u> IRTA estimates that the emissions of PERC would be about 20% lower than the emissions of TCE. Emissions of TCE in the baseline case are 187.5 gallons per year (75% · 250gal = 187.5gal). Emissions of PERC from the same vapor degreaser would be 150 gallons per year (see Equation (3)).

$$\underset{\text{Emissions}}{\text{Drop-in}}\,\text{gal} = \left(\underset{\text{Emissions}}{\text{Baseline TCE}}\,\text{gal}\right) \cdot \left(100\% + \underset{\text{Emissions}}{\text{Change in}}\,\%\right) \rightarrow$$

$$\underset{\text{Emissions}}{\text{PERC}}\,\text{gal} = (187.5\ \text{gal}) \cdot (100\% + {}^{-}20\%) = 150\ \text{gal} \tag{3}$$

The amount of waste generated would not change but the cost of purchasing the solvent would. Instead of purchasing 250 gallons of TCE, the company would purchase 212.5 gallons of PERC (62.5gal + 150gal = 212.5gal). The price of PERC currently, if purchased in drum quantities, is $29 per gallon. The cost to the company for purchasing PERC is $6,163 annually. The other costs, including the electricity cost, the labor cost and the disposal cost, would be the same as for TCE. The total annual cost of using PERC would be $18,553.

PERC, like TCE, is covered by the Halogenated Solvents NESHAP regulation so additional costs of complying with the record keeping and reporting requirements would be incurred with this option. PERC is also considered a toxic by virtually all state and local air agencies so there could be fees associated with the emissions. Unlike TCE, PERC is exempt from VOC regulations so it would not be regulated as a VOC and there would be no fees for VOC emissions.

<u>METH.</u> IRTA estimates that the emissions of METH would be 40% higher than emissions of TCE. Emissions of TCE are currently 187.5 gallons per year so emissions of METH would increase to 262.5 gallons per year (see Equation (3) for drop-in emissions estimation details). Purchases would be higher, at 325 gallons per year. The price of METH, purchased in drum quantities, is between about $10 and $14 per gallon. On this basis, assuming a cost for METH of $12 per gallon, the cost of purchasing METH would be $3,900 per year. Again, the other costs of using METH in the existing degreaser would be the same with one exception which is discussed below. The total annual cost of using METH would amount to $16,290.

OSHA developed a regulation in 1997 that restricts the allowed worker exposure limit for METH. The regulation specifies a Permissible Exposure Limit (PEL) of 25 ppm and an action level of 12.5 ppm. Companies using the chemical must conduct medical surveillance and monitoring if the action level is above 12.5 ppm. If the exposure level is above 25 ppm, engineering controls must be used to reach 25 ppm. If companies were to comply with the additional OSHA requirements, the labor costs would be higher. Furthermore, the existing vapor degreaser almost certainly would not be capable of meeting an exposure limit of 25 ppm so it would likely require a costly upgrade or the company would have to purchase much tighter cleaning equipment. The costs in complying with the OSHA regulation are difficult to quantify but they could be very high.

METH, like TCE, is covered by the Halogenated Solvents NESHAP regulation so additional costs of complying with the record keeping and reporting requirements would be incurred with this option. METH is also considered a toxic by virtually all state and local air agencies so there could be fees associated with the emissions. Unlike TCE and like PERC, METH is exempt from VOC regulations so it would not be regulated as a VOC.

<u>nPB.</u> IRTA estimates that nPB emissions would be 20% greater than TCE emissions. On this basis, nPB emissions from the existing degreaser would amount to 225 gallons per year year (see Equation (3) for drop-in emissions estimation details). Purchases would be 287.5 gallons per year. The cost of nPB is estimated at $44 to $50 per gallon when purchased in drum quantities. Assuming a price of $47 per gallon, the cost of purchasing the nPB would be $13,513 per year. The other costs of using nPB would be the same as the costs of using TCE. Taking this into account, the total annual cost of using nPB is $25,903.

nPB is not covered by the Halogenated Solvent Degreasing NESHAP so there would be no related record keeping and reporting cost. nPB is a VOC, however, and some air agencies consider it to be a toxic so there could be costs associated with emissions.

4.1.3 Using an Airless/Airtight Degreaser With TCE

One of the options EPA could adopt is to ban the use of TCE in open top vapor degreasers. In that event, there could be a few companies who might consider purchasing an airless/airtight degreaser and continuing to use TCE. IRTA obtained a price for a small airless/airtight degreaser. The price of a small system with ultrasonics and a chamber that is 12 inches in diameter and a working depth of seven inches is $125,000.

Use of the airless/airtight degreaser would reduce TCE emissions by an estimated 90 percent to 18.75 gallons (see Equation (4)).

$$\begin{array}{c}\text{Airless/airtight}\\ \text{Degreaser}\\ \text{TCE Emissions}\end{array}\text{gal} = \left(\begin{array}{c}\text{Baseline TCE}\\ \text{Emissions}\end{array}\text{gal}\right)\cdot\left(100\% + \begin{array}{c}\text{Change in}\\ \text{Emissions}\end{array}\%\right)\rightarrow$$

$$(187.5\ \text{gal})\cdot(100\% + {}^{-}90\%) = 18.75\ \text{gal} \tag{4}$$

The amount of waste generated would remain the same. Solvent use would be 81.3 gallons per year (18.75gal + 62.5gal = 81.3gal). Using the price for TCE of $24 per gallon, the purchase cost would be $1,951 per year.

The system uses a small vacuum pump for the cleaning cycle but this is offset by the fact that the solvent does not need to be heated; the electricity cost is likely to remain roughly the same and is a very small fraction of the total cost in any case. The labor and disposal costs would not change. Thus, the total cost of using TCE in an airless/airtight degreaser would be $139,341 the first year and would be $14,341 in subsequent years.

4.1.4 Non-Drop-In Alternatives

IRTA evaluated the cost of using two non-drop-in alternatives, an HFC Vertrel blend of HFC-4310 and 1,2-trans dichloroethylene and the new Solstice solvent, an HFO. HFC is generally combined with another solvent such as 1,2-transdichloroethylene (DCE), because HFC is not an aggressive cleaner. DCE is more aggressive. It has a flash point but, when it is added to the HFC, the blend does not have a flash point so it can be used in a vapor degreaser. The costs for each of these are discussed below.

<u>HFC Blend.</u> The Vertrel material has a very high vapor pressure of 226 mm Hg and a very low boiling point of 102 degrees F. It would not be practical to use this solvent in the existing vapor degreaser because of cost concerns. The solvent losses would be extremely high and the solvent is very expensive. It would be necessary to purchase an extremely tight open top vapor degreaser or use the solvent in an airless/airtight degreaser.

The cost of purchasing an airless/airtight degreaser is $125,000, the same system and cost as given above for TCE. Alternatively, the company could purchase a much tighter open top degreaser. One such degreaser, the F-100 made by Crest Ultrasonics, would be suitable for cleaning the parts. The cost of this system for Vertrel is $35,000.

The F-100 is a smaller machine than the baseline TCE degreaser with a solvent capacity of nine gallons instead of 15 gallons. The smaller machine capacity means that about 60% of the solvent used in the baseline degreaser would be used annually in this machine. It is also a tighter machine so losses would be much lower. IRTA made the assumption that the tighter machine and the higher emissions of Vertrel would net out. Making this assumption, the annual use of Vertrel in the machine would be 150 gallons (250gal · 60% = 150gal) and 75% of the losses or 112.5 gallons would be emitted and 37.5 gallons would be hazardous waste. The cost of one 55 gallon drum of Vertrel is about $12,000 or $218 per gallon. The cost of purchasing 150 gallons of solvent would be $32,700 per year.

Less waste would be generated in this machine because it is smaller than the baseline degreaser. As before, the cost of disposing of a drum of liquid solvent is $362.5 and the cost of disposing of the solid contaminants is about $1.10 per pound. The cost of disposal for the 37.5 gallons of liquid solvent would be $247 and the cost of the solids disposal would be $141 for a total disposal cost of $388.

IRTA assumed the electricity cost and the labor cost for the F-100 machine would be the same as for the baseline case. Thus, the total cost of using the F-100 equipment would be $79,830 the first year and would be $44,830 in subsequent years.

The F1 Tiyoda airless/airtight degreaser would reduce the emissions from the currently used degreaser by 90%. If Vertrel were used in an airless/airtight degreaser instead of TCE, the emissions would be 40% higher than those of TCE, or 262.50 gallons per year. The airless/airtight degreaser would reduce these emissions by 90% to 26.25 gallons per year (see Equation (5)).

$$\begin{array}{c}\text{Airless/airtight}\\ \text{Degreaser Vertrel gal}\\ \text{Emissions}\end{array} = \left(\begin{array}{c}\text{Baseline TCE}\\ \text{Emissions}\end{array}\text{gal}\right)\cdot\left(100\% + \begin{array}{c}\text{Change in}\\ \text{Emissions}\\ \text{(Due to Degreaser)}\end{array}\%\right)\cdot\left(100\% + \begin{array}{c}\text{Change in}\\ \text{Emissions}\\ \text{(Due to Solvent)}\end{array}\%\right)$$

$$\rightarrow (187.5\text{ gal})\cdot(100\% + {}^{-}90\%)\cdot(100\% + 40\%) = 26.25\text{ gal} \tag{5}$$

The waste solvent generated would be the same at 62.5 gallons per year. This leads to a total use of about 88.75 gallons per year (26.25gal + 62.5gal = 88.75gal). Assuming the price of $218 per gallon, the cost of purchasing the solvent would amount to $19,348 annually.

The electricity costs and the labor costs for using the airless/airtight system with Vertrel are likely to be similar to the electricity costs for the TCE baseline. For the airless/airtight case, IRTA also assumed that the waste disposal costs were the same as before. On this basis, the total cost of using the Vertrel with the airless/airtight degreaser is $156,738 the first year and is $31,738 in subsequent years.

Solstice. The Solstice HFO solvent has an extremely high vapor pressure of 945 mm Hg and it cannot be contained within an airless/airtight degreaser. It also has a very low boiling point of 66 degrees F. The solvent must be used in controlled non-vacuum equipment. The Solstice can be used in the F-100 Crest Ultrasonic system described above. The standard F-100 can be used with Vertrel but modifications are required to use the HFO. The cost of the machine modified for use with the HFO is higher, at $45,000.

This solvent has not been used for a sustained period of time since it is so new to the market and there is little information on what the losses might be. Making the same assumption about solvent usage as for Vertrel, 150 gallons of the solvent would be used yearly. The cost of this solvent is somewhat less than the cost of the Vertrel, at between $160 and $180 per gallon. Assuming a cost of $170 per gallon, the cost of purchasing the Solstice would amount to $25,500 annually.

Again, the electricity and labor costs of using the HFO are likely to be the same as for the TCE baseline. The cost of disposal for the HFO would be the same as for the Vertrel used in the F-100. Taking this into account, the total cost of using the HFO is $82,630 the first year and is $37,630 in subsequent years.

4.1.5 Water-Based Cleaning

A water-based cleaning system suitable for cleaning contacts is offered by a company called Omega Sonics. It has a wash, rinse and dry section. The wash is ultrasonic and the dryer consists of a blower with air knives. The rinse bath would have to have recirculating capability with capacity of two to three gallons per minute. The base cost of the machine is $28,000 and the cost of the recirculating rinse is about $15,000. The total cost of the system would be $43,000.

An alkaline water-based cleaner made by Brulin, called Brulin 3887, is designed to clean multiple metals and would be suitable for cleaning the contacts. The cost of the cleaner is $20 per gallon and a 10 percent concentration would be required. The wash bath has a 20 gallon capacity. In addition to the water-based cleaner, one-tenth of one percent of a copper brightener, at a cost of $20 per pint, would be added to the bath. The wash bath would need to be emptied and replenished every month. On this basis, two gallons of cleaner would be required each month. The annual cleaner use would amount to 24 gallons and the cost would be $480 per year. Including a pint of copper brightener each year, the total cost for cleaning materials would be $500 annually.

To clean 1,000 contacts per day, the machine would need to operate about four hours per day and the cleaner would be heated to about 135 degrees F. The machine is rated at about 10 kW and the total energy use would be 40 kWh per day. Using a cost of 12 cents per kWh, the electricity cost per day would be $4.80 and the annual cost would be $1,248 ($4.80 · 260day = $1,248).

In the case of the water cleaning system, the labor requirement would not increase so the annual labor cost would amount to $10,400.

The water cleaning bath needs to be changed out every month. The bath has a 20 gallon capacity. On this basis there would be 240 gallons of waste each year. The cost for disposal of water waste amounts to about $2 per gallon. The cost of waste disposal would be $480 annually.

The equipment for the recirculating rinse water would have to be maintained. This feature includes beds that produce deionized water (D.I.) for rinsing. The D.I. beds, which consist of carbon, a cationic and anionic bed, would have to be changed out approximately three times per year at a cost of $750 each time for an annual cost of $2,250. The rinsewater would not need to be changed out.

The total cost of using the water-based cleaner includes the equipment purchase cost, the cleaner cost, the rinsewater bed changeouts, the electricity cost, the labor cost and the disposal cost. This amounts to $57,878 the first and to $14,878 subsequent years.

4.1.6 Other Not-In-Kind Alternatives

This case study is an example of a precision cleaning operation that companies using TCE might have. It is highly unlikely that any of the not-in-kind alternatives, which generally have flash points, would be used for cleaning these parts. In addition, many of the not-in-kind alternatives would leave a residue on the parts and this would not be acceptable for the connectors in this case study. One way these alternatives might be used is in an airless/airtight degreaser. If companies decided to purchase an airless/airtight degreaser however, they would likely just continue to use TCE and not convert to an alternative. Thus, for this precision cleaning case study, IRTA did not include analysis of converting to a not-in-kind alternative.

4.1.7 TCE Cold Cleaning

It is also unlikely that users cleaning the connectors would convert to TCE cold cleaning. Higher technology applications are simply not performed with cold cleaning solvents. If EPA were to ban TCE in open top degreasers, however, companies might consider continuing to use TCE in cold cleaning.

To exercise this option, the company might modify the degreaser to remove the cooling or refrigerated coils and the heater. This would leave a tank with ultrasonic cleaning capability. IRTA ignored the costs of modification because they are likely to be small. In principle, the parts could be cleaned with cold TCE. The company would have to conduct tests to insure that adequate cleaning was achieved, however.

With cold cleaning, the cooling coils do not contain the solvent in the degreaser but the solvent is not heated so the losses are likely to be comparable. The solvent would probably get contaminated more quickly because none of the cleaning could be done in the vapor zone. Waste with conversion to a cold process could be 40% of solvent use. This leads to a total use of 312.5 gallons per year (see Equation (6)). On this basis, the cost of purchasing 312.5 gallons of solvent annually would amount to $7,500 per year.

$$\begin{matrix}\text{Cold Cleaning}\\ \text{Solvent Use}\end{matrix}_{\text{gal}} = \frac{\left(\begin{matrix}\text{Baseline TCE}\\ \text{Emissions}\end{matrix}_{\text{gal}}\right)}{\left(100\% - \begin{matrix}\text{Hazardous}\\ \text{Waste}\end{matrix}_{\%}\right)} \rightarrow \frac{(187.5\text{gal})}{(100\% - \ 40\%)} = 312.5 \tag{6}$$

The cost of disposal of the solvent would also increase. With waste equal to 40% of solvent use, there would be 125 gallons of liquid waste per year ($312.5\text{gal} \cdot 40\% = 125\text{gal}$). Liquid disposal costs would be $824 (see Equation (1)) for details on estimating liquid disposal costs). The total disposal cost of solids is $471 (see Equation (2) for details on estimating the disposal cost of solids). The total cost of disposal for the waste would be $1,295 ($824 + $471 = $1,295).

The electricity cost would change since only the electricity associated with use of the ultrasonics would still be used. This amounts to 1 kW. Assuming the unit is used for four hours per day, five days per week and 52 weeks per year and that the price of electricity is 12 cents per kW, the annual electricity cost would be $125. The labor cost and hazardous waste disposal cost would not change so the total cost of using the solvent would be $19,320 per year.

4.1.8 Summary of Baseline and Alternatives

Table 3 summarizes the results of the alternatives evaluation for this case study. In Table 3, costs are presented as first year, recurring, and annualized using a discount rate of 3 percent over a period of 10 and 20 years. When annualized over a period of 10 years, the lowest cost option is converting to METH in the existing vapor degreaser. Again, this option does not include the cost of compliance with the OSHA regulation and that is the reason it is so low. Continuing to use TCE and converting to PERC in the existing degreaser or modifying the degreaser and using TCE cold cleaning are the next lowest cost options. Converting to water-based cleaning is the next lowest cost option even though new equipment is required. Converting to nPB in the existing equipment is a more costly option because of the higher cost of nPB. Using TCE in an airless/airtight degreaser is slightly higher in cost than using nPB in the existing degreaser. Using the HFC or HFO are the most costly options, primarily because of the high cost of the solvents. When annualized over a period of 20 years, alternatives that require new equipment become less costly relative to the other alternatives. The lowest cost option remains converting to METH in the existing vapor degreaser. Converting to water-based cleaning becomes the next lowest cost option even though new equipment is required. Continuing to use TCE and converting to PERC in the existing degreaser or modifying the degreaser and using TCE cold cleaning are the next lowest cost options. Using TCE in an airless/airtight degreaser becomes slightly less costly than using nPB in the existing degreaser. Using the HFC or HFO remain the most costly options, primarily because of the high cost of the solvents.

Table 3: Annual Cost Comparison for TCE Baseline and Alternatives for Case Study #1										
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**	**D.I. Water**	**Costs**			
							1st Yr.	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline	-	$6,000	$1,342	$10,400	$648	-	$18,390	$18,390	$16,460	$17,232
PERC	-	$6,163	$1,342	$10,400	$648	-	$18,553	$18,553	$16,606	$17,385
METH	-	$3,900	$1,342	$10,400	$648	-	$16,290	$16,290	$14,581	$15,264
nPB	-	$13,513	$1,342	$10,400	$648	-	$25,903	$25,903	$23,185	$24,272
TCE-airless/airtight	$125,000	$1,951	$1,342	$10,400	$648	-	$139,341	$14,341	$25,952	$21,311
HFC-airless/airtight	$125,000	$19,348	$1,342	$10,400	$648	-	$156,738	$31,738	$41,524	$37,612
HFC-good equipment	$35,000	$32,700	$1,342	$10,400	$388	-	$79,830	$44,830	$43,799	$44,211
HFO-good equipment	$45,000	$25,500	$1,342	$10,400	$388	-	$82,630	$37,630	$38,403	$38,094
Water-Based	$43,000	$500	$1,248	$10,400	$480	$2,250	$57,878	$14,878	$17,829	$16,649
TCE Cold Cleaning	-	$7,500	$125	$10,400	$1,295	-	$19,320	$19,320	$17,293	$18,103

4.2 Case Study #2

The second case study is a firm that manufactures and rebuilds valves of all kinds using a TCE vapor degreaser. The valve bodies and component parts processed by the company are made of brass, bronze, cast iron, stainless steel, monel and carbon steel. They are contaminated with various types of cutting, drawing and tapping fluids. Some of the valves from the field that are being reworked are contaminated with unusual materials like caked-on bakery flour residue. The parts are processed through the degreaser prior to brazing and/or coating. They are cleaned in the vapor zone and the degreaser has a spray wand for flushing. The liquid capacity of the degreaser is 35 gallons. This case study is meant to represent the need to clean heavily contaminated metal parts and would be considered more of a gross cleaning operation.

4.2.1 Baseline-Using an Open Top Vapor Degreaser With TCE

The company purchases 500 gallons of TCE per year. The current price of TCE when purchased in drum quantities is $24 per gallon. On this basis, the annual cost of the solvent is $12,000. IRTA again assumed that that the degreaser is paid off for the baseline case.

The vapor degreaser is used for six hours per day. It has two 4 kW heaters and a 3 HP refrigeration unit for a total electric load of 10.75 kW. Assuming a cost of 12 cents per kWh and that the degreaser operates five days a week for 52 weeks a year, the total annual electricity cost is $2,012 per year.

The worker who operates the vapor degreaser spends his eight hour shift in cleaning or loading and unloading parts for the degreaser. The total labor time is 2,080 hours per year. At a burdened labor rate of $20 per hour, the annual labor cost is $41,600.

The company must dispose of the waste solvent. Again, about 75 percent of the solvent is lost through emissions and 25 percent goes out as waste. This implies that there is 125 gallons of hazardous waste generated annually. The cost of disposing of a drum of liquid solvent is $350 to $375 and the cost of disposing of the solid contaminants is about $1.10 per pound. Assuming the midpoint of the range, the liquid disposal cost would be $824 per year (see Equation (1) for baseline liquid waste disposal cost estimation details). The solvent in the degreaser is changed out when the contamination level from oil reaches about 30%. Assuming a cost for disposal of the solids of $1.10 and a density of oil and solids of about eight pounds per gallon, the disposal cost of the solids is $471 (see Equation (2) for baseline solid waste disposal cost estimation details). The total disposal cost is $1,295 annually ($824 + $471 = $1,295).

The total cost to the company of using the open top vapor degreaser includes the cost of purchasing the solvent, paying for the electricity, paying the worker and the cost of disposal. The total cost amounts to $56,907 per year.

Again, there will be additional costs to the company for using the TCE degreaser including the costs associated with complying with the NESHAP and the local air agency regulations.

4.2.2 Substituting Drop-In Alternatives

As before, the drop-in alternatives to TCE in the vapor degreaser are PERC, METH and nPB. The same assumptions about solvent losses made for the first case study are made here. IRTA assumed a 20% lower emission rate for PERC, an evaporation rate 40% higher for METH and a 20% higher evaporation rate for nPB. For purposes of analysis, it was again assumed that 75% of the losses would be to the air and 25% would be waste.

PERC. IRTA estimates that the emissions of PERC would be about 20% lower than the emissions of TCE. Emissions of TCE in the baseline case are 375 gallons per year. Emissions of PERC from the same vapor degreaser would be 300 gallons per year (see Equation (3) for drop-in emissions estimation details). The amount of waste generated would not change but the cost of purchasing the solvent would. The price of PERC currently, if purchased in drum quantities, is $29 per gallon. The cost to the company of purchasing PERC is $12,325 annually. The other costs, including the electricity cost, the labor cost and the disposal cost, would be the same as for TCE. The total annual cost of using PERC would be $57,232.

METH. IRTA estimates that the emissions of METH would be 40% higher than emissions of TCE. Emissions of TCE are currently 375 gallons per year so emissions of METH would increase to 525 gallons per year (see Equation (3) for drop-in emissions estimation details). Purchases would be higher, at 650 gallons per year. Assuming the price of METH is $12 per gallon if purchased in drum quantities, the cost of purchasing METH would be $7,800 per year. Again, the other costs of using METH in the existing degreaser would be the same. The total annual cost of using METH would amount to $52,707. As before, the cost of using METH excludes the cost of complying with the OSHA regulation and that cost could be significant.

nPB. IRTA estimates that nPB emissions would be 20% greater than TCE emissions. On this basis, nPB emissions from the existing degreaser would amount to 450 gallons per year (see Equation (3) for drop-in emissions estimation details). Purchases would be 575 gallons per year. The cost of nPB is estimated at $44 to $50 per gallon when purchased in drum quantities. Assuming a price of $47 per gallon, the cost of purchasing the nPB would be $27,025 per year. The other costs of using nPB would be the same as the costs of using TCE. Taking this into account, the total annual cost of using nPB is $71,932.

4.2.3 Airless/Airtight Degreaser and Non-Drop-In Alternatives

It is highly unlikely that companies with larger gross cleaning operations like this one would purchase an airless/airtight degreaser. The cost of an airless/airtight system large enough to process the parts would be very high. It is also highly unlikely such companies would ever consider using the HFC and HFO formulations. These formulations are probably not aggressive enough to remove the heavy contamination from the valves and would be very costly for this application. These options were not evaluated or considered further for this case study.

4.2.4 Water-Based Cleaning

A water-based cleaning system suitable for cleaning the valve bodies is a spray cabinet made by Almco with a 50 gallon cleaning tank. The parts are placed on a platform in the cabinet and a water-based cleaner is sprayed onto the parts. There is no rinse or dry because, in this case, the task is gross cleaning. The base cost of the machine is $8,000 for a stainless steel system.

An alkaline water-based cleaner called Brulin 1990 is designed for spray cleaning applications. The cost of the cleaner is $19 per gallon and a 10% concentration would be required because some of the parts may be heavily contaminated. The wash bath, which holds 50 gallons, would need to be emptied and replenished every month and a half. On this basis, 40 gallons of cleaner would be required each year assuming the 10% concentration. The annual cleaner cost would amount to $760.

The machine would need to operate about eight hours per day, the same as for the vapor degreaser baseline and the cleaner would be heated to about 160 degrees F. The machine is rated at 40 amps and the voltage requirement is 240 for a total energy use of 9.6 kW. Using a cost of 12 cents per kWh and assuming the machine is used eight hours per day five days a week for 52 weeks per year, the electricity cost would be $2,396 annually.

The labor cost for this process should be the same as for the TCE baseline. Thus, the annual labor cost would amount to $41,600.

The water cleaning bath needs to be changed out every month and a half. The bath has a 50 gallon capacity. On this basis there would be 400 gallons of waste each year. The cost for disposal of water waste amounts to about $2 per gallon. The cost of waste disposal would be $800 annually.

The total cost of using the water-based cleaner includes the equipment purchase cost, the cleaner cost, the electricity cost, the labor cost and the disposal cost. The total cost of using the solvent amounts to $53,556 in the first year and $45,556 in subsequent years.

4.2.5 Not-In-Kind Alternatives

IRTA evaluated this case for cold cleaning with a mineral spirits formulation called ShellSol D-38. This solvent has a reasonably high vapor pressure so it would evaporate from the valves so the subsequent operations could be performed. A mineral spirits formulation was selected because it is likely to be one of the lowest cost options for the not-in-kind alternatives.

The company would use the mineral spirits in a Fountain three foot square carbon steel agilift system with a neumatic pump that holds 80 gallons of solvent. In an agilift system, the parts are placed on a platform and moved up and down in the liquid for agitation to remove the contaminants. The cost of the carbon steel system would be $5,656.

In cold cleaning, in contrast to vapor degreasing, the solvent becomes contaminated more quickly because the contaminants are loaded into the liquid. In vapor degreasing, the vapor is used to do the cleaning and the contaminants condense into the liquid bath. Thus, with vapor degreasing, the cleaning is largely done with clean solvent so the bath lasts longer. In this case, the bath would be changed out at least every month. The solvent required to replace the waste material would be 960 gallons per year. Emissions for this cold cleaning operation are likely to be quite high and makeup solvent is estimated at one gallon per day or 260 gallons per year. The total solvent use is therefore 1,220 gallons per year. The cost of the solvent is about $10 per gallon for drum purchases. Thus, the cost of solvent purchases would amount to $12,200 per year.

The cost of disposal for the solvent would be between $125 and $150 per drum. Assuming the cost is $137.50, the annual disposal cost would amount to $2,400. The cost of disposing of non-halogenated solvents is less than the cost of disposing of halogenated solvents. Halogens are fire suppressants and non-halogenated solvents have much higher BTU value and can be burned much more economically.

Because the solvent cleaning system is pneumatic, there is no electricity cost for using it. The labor cost for using the system is likely to be about the same as for the TCE vapor degreaser or $41,600 per year. The total cost of using the solvent amounts to $61,856 in the first year and $56,200 in subsequent years.

4.2.6 TCE Cold Cleaning

For this case, TCE cold cleaning would also be an option. The same equipment used for the mineral spirits described above could be used. TCE is a much more expensive solvent than the mineral spirits, however, and emissions might even be higher than for mineral spirits. Because the cost of using TCE in this application in cold cleaning would be so high, IRTA did not evaluate it further.

4.2.7 Summary of Baseline and Alternatives

Table 4 summarizes the cost of the different options for this case study. In Table 4, costs are presented as first year, recurring, and annualized using a discount rate of 3 percent over a period of 10 and 20 years. When annualized over a period of 10 or 20 years, the lowest cost option in this case is using the water-based cleaner. This is true even though the company would have to purchase new equipment. The cost of using mineral spirits is comparable to the cost of using the vapor degreasing chlorinated solvents. The cost of using nPB is the highest cost option of those evaluated.

Table 4: Annual Cost Comparison for TCE Baseline and Alternatives for Case Study #2									
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**	**Costs**			
						1st Yr.	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline	-	$12,000	$2,012	$41,600	$1,295	$56,907	$56,907	$50,936	$53,323
PERC	-	$12,325	$2,012	$41,600	$1,295	$57,232	$57,232	$51,227	$53,627
METH	-	$7,800	$2,012	$41,600	$1,295	$52,707	$52,707	$47,176	$49,387
nPB	-	$27,025	$2,012	$41,600	$1,295	$71,932	$71,932	$64,384	$67,402
Water-Based	$8,000	$760	$2,396	$41,600	$800	$53,556	$45,556	$41,615	$43,191
Mineral Spirits	$5,656	$12,200	-	$41,600	$2,400	$61,856	$56,200	$50,896	$53,017

4.3 Case Study #3

The third case study is a firm that manufactures metal nameplates using a TCE vapor degreaser. The metal sheets arrive at the facility with a light coating of oil. Most of the sheets are 18 by 24 inches but some sheets are 12 by 40 inches. Much of the stock, perhaps 90%, is aluminum and the remainder is stainless steel and brass. About 1,000 nameplates are processed through the degreaser per day. The vapor degreaser holds 50 gallons of TCE.

4.3.1 Baseline-Using an Open Top Vapor Degreaser With TCE

The company purchases 1,500 gallons of TCE per year. The current price of TCE when purchased in drum quantities is $24 per gallon. On this basis, the annual cost of the solvent is $36,000. IRTA again assumed that that the degreaser is paid off for the baseline case.

The vapor degreaser is used for the full eight hours per day. It has two 6 kW heaters and a 3 HP refrigeration unit for a total electric load of 12.75 kW. Assuming a cost of 12 cents per kWh and that the degreaser operates five days a week for 52 weeks a year, the total annual electricity cost is $3,182 per year.

In this case, a significant amount of parts must be processed through the degreaser so two workers would spend a total of 10 hours per day in cleaning or loading and unloading parts for the degreaser. The total labor time is 2,600 hours per year. At a burdened labor rate of $20 per hour, the annual labor cost is $52,000.

The company must dispose of the waste solvent. Again, about 75 percent of the solvent is lost through emissions and 25 percent goes out as waste. The company uses 1,500 gallons of TCE per year. This indicates that 1,125 gallons are emitted and 375 gallons are hazardous waste. Again, the cost of disposing of a drum of liquid solvent is $350 to $375 and the cost of disposing of the solid contaminants is about $1.10 per pound. Assuming the midpoint of the range, the liquid disposal cost would be $2,472 per year (see Equation (1) for baseline liquid waste disposal cost estimation details). The solvent in the degreaser will be changed out when the contamination level from oil reaches about 30%. Assuming a cost for disposal of the solids of $1.10 and a density of oil and solids of about eight pounds per gallon, the disposal cost of the solids is $1,414 (see Equation (2) for baseline solid waste disposal cost estimation details). The total disposal cost is $3,886 annually ($2,472 + $1,414 = $3,886).

The total cost to the company of using the open top vapor degreaser includes the cost of purchasing the solvent, paying for the electricity, paying the worker and the cost of disposal. The total cost amounts to $95,068 per year.

Again, there will be additional costs to the company for using the TCE degreaser including the costs associated with complying with the NESHAP and the local air agency regulations.

4.3.2 Substituting Drop-In Alternatives

As before, the drop-in alternatives to TCE in the vapor degreaser are PERC, METH and nPB. The same assumptions about solvent losses made for the first case study are made here. IRTA assumed a 20% lower emission rate for PERC, an evaporation rate 40% higher for METH and a 20% higher evaporation rate for nPB. For purposes of analysis, it was again assumed that 75% of the losses would be to the air and 25% would be waste.

PERC. IRTA estimates that the emissions of PERC would be about 20% lower than the emissions of TCE. Emissions of TCE in the baseline case are 1,125 gallons per year. Emissions of PERC from the same vapor degreaser would be 900 gallons per year (see Equation (3) for drop-in emissions estimation details). The amount of waste generated would not change so the total purchases would amount to 1,275 gallons per year. The price of PERC currently, if purchased in drum quantities, is $29 per gallon. The cost to the company for purchasing PERC is $36,975 annually. The other costs, including the electricity cost, the labor cost and the disposal cost, would be the same as for TCE. The total annual cost of using PERC would be $96,043.

METH. IRTA estimates that the emissions of METH would be 40% higher than emissions of TCE. Emissions of TCE are currently 1,125 gallons per year so emissions of METH would increase to 1,575 gallons per year (see Equation (3) for drop-in emissions estimation details). Total purchases would be 1,950 gallons per year. Assuming the price of METH is $12 per gallon if purchased in drum quantities, the cost of purchasing METH would be $23,400 per year. Again, the other costs of using METH in the existing degreaser would be the same. The total annual cost of using METH would amount to $82,468. As before, the cost of using METH excludes the cost of complying with the OSHA regulation and that cost could be significant.

nPB. IRTA estimates that nPB emissions would be 20% greater than TCE emissions. On this basis, nPB emissions from the existing degreaser would amount to 1,350 gallons per year (see Equation (3) for drop-in emissions estimation details). Purchases would be 1,725 gallons per year. The cost of nPB is estimated at $44 to $50 per gallon when purchased in drum quantities Assuming a price of $47 per gallon, the cost of purchasing the nPB would be $81,075 per year. The other costs of using nPB would be the same as the costs of using TCE. Taking this into account, the total annual cost of using nPB is $140,143.

4.3.3 Airless/Airtight Degreaser and Non-Drop-In Alternatives

It is highly unlikely that companies with larger operations like this one would purchase an airless/airtight degreaser. The cost of an airless/airtight system large enough to process the parts would be very high. It is also highly unlikely such companies would ever consider using the HFC and HFO formulations because of the solvent cost. These options were not evaluated or considered further for this case study.

4.3.4 Water-Based Cleaning

A water-based cleaning system for cleaning the nameplates is a conveyorized system with wash, rinse and drying chambers. The rinse has a recirculating feature. The wash tank holds 150 gallons. The parts are placed on a conveyor and a water-based cleaner is sprayed in the wash section, deionized water is used in a spray for rinsing and then the parts pass through a dryer. The cost of the machine is $120,000 to $150,000 and the cost of the recirculating rinse feature is $15,000. Assuming the midpoint for the machine cost and adding in the cost of the recirculating rinse, the total system cost is $150,000.

An alkaline water-based cleaner called Brulin 1990 is designed for spray cleaning applications. The cost of the cleaner is $19 per gallon and a 10 percent concentration would be required in the wash bath. The wash bath, which holds 150 gallons, would need to be emptied and replenished every month and a half. On this basis, 120 gallons of cleaner would be required each year to achieve a 10% dilution rate. The annual cleaner cost would amount to $2,280.

The machine would be operated for eight hours per day, the same as for the vapor degreaser baseline and the cleaner would be heated to about 130 degrees F. The machine is rated at 60 amps and the voltage requirement is 480 for a total energy use of 28.8 kW. Using a cost of 12 cents per kWh and assuming the machine is used eight hours per day five days a week for 52 weeks per year, the electricity cost would be $7,188 annually.

In the case of the water cleaning system, the labor requirement is likely to be lower than the labor requirement for the vapor degreaser because the water cleaning system is automated. IRTA estimated that one full time equivalent worker would be needed to load and unload the parts and see to the maintenance of the system. This indicates that the labor hours would be 2,080 per year. Assuming a labor rate of $20 per hour, the labor cost would be $41,600 annually.

The water cleaning bath needs to be changed out every month and a half. The bath has a 150 gallon capacity. On this basis there would be 1,200 gallons of waste each year. The cost for disposal of water waste amounts to about $2 per gallon. The cost of waste disposal would be $2,400 annually.

There is also a cost for changing out the recirculating rinse water. Again, this feature includes beds that produce deionized water (D.I.) for rinsing. The D.I. beds, which consist of carbon, a cationic and anionic bed, would have to be changed out approximately every quarter at a cost of $750 each time for an annual cost of $3,000. The rinsewater would not need to be changed out.

The total cost of using the water-based cleaner includes the equipment purchase cost, the cleaner cost, the electricity cost, the labor cost and the disposal cost. This amounts to $206,468 in the first year and $56,468 in subsequent years.

4.3.5 Not-In-Kind Alternatives

IRTA evaluated the same mineral spirits formulation that was discussed in the second case study for this case study as well. The company could use the same 80 gallon agilift system to clean the nameplates. The annualized cost of this system is $588.

Because the company has to process about 1,000 nameplates per day through the equipment, the solvent would have to be changed out more often than for the valve cleaning operation discussed in Case Study #2. IRTA estimates the bath would have to be changed out once every two weeks instead of once a month. Thus 2,080 gallons would be used to replenish the bath. Makeup solvent to replace the emissions would also be higher than for the valve case study. In this case, about 1.5 gallons of makeup solvent would be required per day. On this basis, the makeup solvent would amount to 390 gallons. The total solvent use would be 2,470 gallons annually. Assuming the solvent price is $10 per gallon, the cost of purchasing solvent would amount to $24,700 per year.

The cost of disposal for the solvent would is estimated to be about $137.50 per drum. On this basis, the annual disposal cost would amount to $5,200. Again, this cleaning system is pneumatic so there is no electricity cost for using it. The labor cost for using the system is likely to be about the same as for the TCE vapor degreaser or $52,000 per year. The total cost of using the solvent is $87,556 in the first year and $81,900 in subsequent years.

4.3.6 TCE Cold Cleaning

It is not likely that companies would use TCE cold cleaning for this type of operation. The losses would be very high and the option would be costly.

4.3.7 Summary of Baseline and Alternatives

Table 5 summarizes the cost of the different options for this case study. In Table 5, costs are presented as first year, recurring, and annualized using a discount rate of 3 percent over a period of 10 and 20 years. When annualized over a period of 10 or 20 years, the values indicate that the lowest cost option is the water-based cleaner. Converting to METH and using mineral spirits are the next lowest cost options. The use of nPB is the highest cost option.

Table 5: Annual Cost Comparison for TCE Baseline and Alternatives for Case Study #3										
							Costs			
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**	**D.I. Water**	**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline	-	$36,000	$3,182	$52,000	$3,886	-	$95,068	$95,068	$85,093	$89,080
PERC	-	$36,975	$3,182	$52,000	$3,886	-	$96,043	$96,043	$85,965	$89,994
METH	-	$23,400	$3,182	$52,000	$3,886	-	$82,468	$82,468	$73,815	$77,274
nPB	-	$81,075	$3,182	$52,000	$3,886	-	$140,143	$140,143	$125,438	$131,316
Water-Based	$150,000	$2,280	$7,188	$41,600	$2,400	$3,000	$206,468	$56,468	$66,282	$62,359
Mineral Spirits	$5,656	$24,700	$0	$52,000	$5,200	-	$87,556	$81,900	$73,900	$77,098

4.4 Other Case Studies for Not-In-Kind Alternatives

In some cases, users with a particular type of operation can adopt not-in-kind alternatives that do not involve conventional liquid cleaning. IRTA did not perform a cost comparison for these types of alternatives but they do bear discussion.

The first example is a company that transfers metal stock from one building to another. The company puts a protective oil on the parts so they will not rust after plating. The parts are transferred to another building for painting and a vapor degreaser is used to remove the protective oil. Some companies can change their operation to paint the parts in the same location so the oil does not have to be applied and therefore does not need to be removed. No cleaning process is required at all.

Another example of a company where a cleaning process can be eliminated again involves metal parts. They are processed and stored with a protective oil. Then when a customer places an order involving the part, a vapor degreaser is used to remove the oil prior to additional processing. Instead of storing a range of different parts, the company can adopt just-in-time manufacturing and process the part completely without storing it. This effectively eliminates the cleaning process.

Some companies who need to remove light oil from parts can use a burnoff oven instead of a vapor degreaser for removing the oil. In some cases, parts are heat treated anyway so this would be a good option in those instances. The cost of using more energy would have to be compared with the cost of using the cleaning process to see if this would be cost effective.

Some companies could convert to a lighter vanishing oil which would evaporate from the part so further processing could be done without cleaning at all.

IRTA worked with a company that made silicone dispersions for medical devices. They made the dispersions in metal pots that were cleaned with great difficulty in a vapor degreaser. IRTA found a manufacturer that made high density polyethylene pots for the dispersions. High density polyethylene is non-stick for silicone. After the parts were made in the pots, the dispersion material hardened and it could be pulled off in a solid sheet and disposed of as solid waste. The company eliminated the need for cleaning altogether.

In certain cases, dry ice blasting systems can be used to remove light films from metal parts, like mold protectant material, for example. This eliminates the need for a liquid cleaner.

4.5 Discussion of Case Study Results

IRTA selected the three case studies for analysis because they represent different types of users who rely on TCE vapor degreasing. The first case study is an example of a higher technology application where companies generally use more expensive equipment and can also consider using higher cost solvents. The second case study represents companies that clean oil or grease from parts and assemblies that do not really require stringent cleanliness. The third case study illustrates a high throughput application that requires oil removal.

Most companies using TCE would not consider using the higher cost solvents as alternatives. They are not really aggressive cleaners and they are too expensive to use in nearly all operations currently using TCE. Mineral spirits and other not-in-kind alternatives can be used but they are not as versatile as water-based cleaning. Water-based cleaning is aggressive and it can be used for higher technology parts and gross cleaning applications. Water cleaning relies on heat and mechanical action and a range of cleaning equipment is available and cost effective for virtually any cleaning application where TCE is currently used. Using water-based cleaners generally “gets companies off the hook” and stops the shell game of converting from one thing to the next. It offers a permanent solution. With water-based cleaning, however, companies need to select the best system for their operation. The cost analysis also indicates that using water-based cleaning is the lowest cost option in Case Study #2 and #3 and it is only slightly more costly in Case Study #1 than continuing to use TCE.

In Southern California, the regulations are very stringent and there are very few vapor degreasing operations left. The VOC regulations prevent the use of most non-drop-in alternatives and the other not-in-kind alternatives because they are VOCs or contain VOC components. The California toxic and VOC regulations prevent the use of the drop-in alternatives for the most part. As a result, almost all companies in Southern California have used water-based cleaners for years. Water-based cleaning has become institutionalized there and most companies, once they have converted, appreciate the benefits of opting out of the shell game.

4.6 Issues Affecting the Case Study Results

There are several issues that influence the cost numbers in tables 2, 3 and 4. There is one issue that could reduce the cost of disposal of the solvents and therefore reduce the overall cost of using solvents. There are several regulatory or health and environmental issues that indicate the costs presented for the solvents in the tables are actually underestimated. Finally, there are several operation and company characteristics that can influence the choice of alternative. These are discussed below.

<u>On-and Off-Site Recycling</u>

Some users have distillation units or stills on-site for processing the contaminated solvent. With distillation, the solvent is heated to its boiling point and is then condensed to a liquid. The contaminants, which are generally oils and solids of various kinds are separated from the solvent because they boil at a much higher temperature. They are left in the bottom of the still and called still bottoms. The still bottom is sent off-site as hazardous waste for disposal. The clean reclaimed solvent is put back in the process and can substitute for virgin solvent.

With off-site recycling, the user sends the contaminated solvent off-site to a facility licensed to treat hazardous waste. The recycler also has a still and performs the separation. The reclaimed solvent can be sent back to the original user (called tolling) or it can be pooled with reclaimed solvent from other solvent users and sold back into the market as a replacement for virgin solvent.

In both cases, the cost of the reclaimed solvent is less than the cost of virgin solvent. Thus, some of the purchase cost for the solvents can be offset by recycling. If recycling is done on-site, the user must purchase a separate still or use vapor degreasers with an attached still which are more costly than simple vapor degreasers. Thus there is an additional capital cost and additional operating costs which include labor and the electricity cost for recycling. If the solvent purchase costs are not that high, it might not be cost effective for users to exercise this option. In addition, many companies refuse to use recycled solvent because they do not trust the quality. In fact, however, recycled solvent, if reclaimed properly, should be able to substitute for virgin solvent easily. Even so, for high technology applications, users would be less likely to use an off-site recycler for purchasing solvent unless they did it through tolling. They would be more willing, in many instances, to perform on-site recycling because the contaminants in their solvent are their contaminants and they would be less likely to cause a problem with the parts.

For the higher cost solvents, since the solvent purchase costs dominate, it may be more cost effective to recycle the solvent on- or off-site. A few companies are equipped to recycle the Vertrel blends and at least one company is planning to obtain the necessary permits to process the HFO in the future.

Regulatory or Health and Environmental Issues

There are several regulations currently in place that would act to increase the costs of using the solvents considered in the case studies. IRTA did not quantify the costs of complying with the NESHAP, paying permit, toxic and VOC emissions fees to state or local air agencies or keeping records of the hazardous materials stored on-site for fire departments or local hazardous waste authorities. Additional costs of complying with the OSHA regulations, particularly for METH, would also have to be included.

Other regulations that are likely to be or may be adopted in the future could also influence the cost of using the solvents. There are two petitions to add nPB to the HAP list and they are likely to be successful. If nPB were added to the HAP list, it could be covered under the NESHAP regulation in the future. In California, Cal/OSHA has established a very low worker exposure limit for nPB that, if followed, would preclude its use. Other states or federal OSHA could follow suit. nPB is one of the chemicals EPA is focusing on for risk assessments. METH is also a chemical EPA is considering for further regulation.

The HFCs in the Vertrel blends and the HFEs to a smaller extent have global warming potential. They are far stronger greenhouse gases (GHGs) than carbon dioxide on a pound for pound basis. There could be future regulations at the state, federal or international level. This could and should affect the choice of alternative for users.

Mineral spirits are VOCs and in most parts of California, they would not be allowed in the cleaning applications discussed here. EPA is proposing more stringent ozone standards and many other states and local air agencies may develop more stringent regulations that would affect cleaning operations. Mineral spirits formulations also often contain aromatic components which can be toxic.

Other Technical Issues

nPB is very unstable to hydrolysis. This means that if there is water in the system where the solvent is used, it can deplete the stabilizers that have been added in to the formulation. The nPB, if the stabilizer is depleted, will “go acid” or form hydrobromic acid which is very acutely toxic. It can also degrade equipment and component materials in the plant. When companies use nPB, they need to be very vigilant about ensuring the stabilizer is adequate and watching for conditions that would reduce its concentration.

IRTA Assumptions

For all three case studies, IRTA assumed that users could continue using their existing vapor degreasers if they used TCE or any of the drop-in alternatives. Most companies using TCE for vapor degreasing have very old vapor degreasers and it is likely that they would have to purchase new equipment soon in any case. IRTA ignored the costs for purchasing new equipment that would act to raise the cost of the numbers for the drop-in alternatives in the summary tables. If these costs amounted to as little as $1,500 per year, the cost of using these solvents in the existing equipment would be higher than the cost of purchasing and using a water-based cleaning system in Table 3. In the other case studies, it is already more cost effective for companies to use water-based cleaners and including costs for new solvent equipment for TCE and the drop-in alternatives would raise the costs of these options further.

IRTA made estimates of equipment costs based on discussions with equipment suppliers. In general, there can be a large variation in cost even for the same type of system, depending on the options a user selects. Thus the equipment costs could be much higher than those estimated here for all of the alternatives. This would apply to the cost of purchasing a new vapor degreaser for the drop-in alternatives as well. Most vapor degreaser manufacturers are making very low emission, and therefore more costly, equipment at this stage.

IRTA also made certain assumptions about the choice of alternative users would make based on what seems sensible. This may not be the case and users might actually decide to use alternatives that are not really feasible more generally. For example, at EPA's TCE meeting, one of the presentations involved the alternatives to TCE in vapor degreasing that were under consideration at army depots. The operations were generally gross cleaning applications for removing oil and grease contaminants from metal parts. The people involved conducted various types of coupon testing with a range of alternatives. The focus did not seem to be on equipment at all. The HFC blends were apparently under consideration as potential alternatives. It is IRTA's belief that these formulations are completely inappropriate for gross cleaning applications. It is easy to discern that they would require the use of extremely expensive equipment to minimize the losses of the very high cost cleaning agents. As discussed in the case studies, IRTA did not even evaluate the cost of the HFCs or the HFO, which is slightly less costly than the HFC blends, for the two gross cleaning case studies.

IRTA designed the case studies to illustrate the range of different types of operations that are done with TCE vapor degreasing. IRTA based these case studies on some actual case studies IRTA worked on with users and they have been modified as appropriate. Many of the estimates used in the analysis are not hard and fast numbers. Emissions from any type of solvent equipment can vary depending on a range of circumstances. Examples are that users may not maintain their equipment properly, they may not operate it properly, they may use improper practices in cleaning the parts and they may let the solvent go acid. In some cases, companies may not dispose of the waste properly. In effect, there can be a large variation in practices and that can lead to results that either underestimate or overestimate the costs. IRTA tried to fairly estimate what the numbers are likely to be based on experience.

For all three case studies, IRTA assumed that the labor costs for all the alternatives were the same with the exception of the water-based cleaner used in the conveyorized system in Case Study #3. There were two reasons IRTA wanted to include the labor costs. First, it is important to understand that the labor cost is a very large fraction of the total costs, regardless of the process selected. Second, solvent suppliers often argue that water-based cleaning processes require more labor. There is a learning curve when users convert to a non-solvent process but it is generally very short. Water-based cleaning is not more labor intensive than solvent cleaning when the workers are familiar with what they are doing. The third case study lends itself to using a conveyor because thousands of uniform parts are being cleaned day after day in the same way. With any of the alternatives, the user could purchase a conveyorized system and reduce the labor cost. If the TCE user did decide to purchase a conveyorized system, however, there would be a high capital cost that likely would outweigh the reduction in labor costs; using the water cleaning system would still be lower in cost.

Many solvent suppliers argue that water-based cleaning requires more floor space. This may be true for TCE and the drop-in alternatives for the existing equipment. If new equipment is required for solvents, however, it will take up more space too. Compressors must be used for refrigeration on the tighter vapor degreasers. Even so, space is a consideration for all companies in converting their operations.

Variation Across Small and Large Users

Obviously, most smaller companies have less capital to draw on to purchase a new system than do larger companies. Smaller users would probably be more likely to want to convert to one of the drop-in alternatives than to explore using an alternative that would require a different system.

Some companies have very stringent policies on capital costs regardless of whether they are large or small and this can drive the selection of alternatives. IRTA worked with one fairly small company using HCFC-225, a solvent priced similarly to the HFO, in a very emissive vapor degreaser. They had converted to the solvent in their existing degreaser after the chlorinated solvent they were using was more heavily regulated. IRTA suggested the company convert to a water-based cleaning operation that would have required a capital outlay. There would have been a payback in less than a year because of the savings in solvent purchases. The company continued using HCFC-225, with unbelievably high operating costs (something like $95,000 per year) and did not switch because there was no capital budget.

Companies are not generally concerned with their cleaning operation until something goes wrong. This could be that the parts are no longer clean enough to go on to the next operation or to pass quality control. It happens more often when a regulation is passed that directly affects their use of a cleaning agent. Only then do companies pay attention to their cleaning because it does not represent a very visible component of their operation. The front office does not care about the cleaning until there is a problem with it. This is typical crisis mode management. Even when they begin to deal with the problem, they rarely consider the life cycle costs of the alternatives. Often they will convert from one material, like TCE, to another that will simply have problems in a year, like nPB. They value short term action over longer term planning. This is more of a problem for small users than it is for larger and possibly more sophisticated users. Smaller users have fewer people to consider and evaluate alternatives than do larger companies.

In some cases, cleaning is an integral part of a company's operation. IRTA worked with one company that offers precision cleaning services to the medical and aerospace industry; the company's business is cleaning. The quality control standards they must meet are very stringent. The company had used chlorinated solvents of various types in a vapor degreaser and converted to nPB when the NESHAP was adopted to avoid purchasing new equipment. The company President decided he wanted to examine alternatives and adopt a permanent solution once and for all. IRTA and the company evaluated different water-based cleaning systems and the company purchased an ultrasonic water-based cleaning system several years ago. The company is still remediating their site which was contaminated with chlorinated solvents but, at least, does not have to switch systems yet again. The President and company staff are satisfied they have the best system possible and relieved they do not have to convert down the line to another alternative. This company presented the results of their conversion at EPA's TCE meeting.

This example illustrates the wisdom of finding a permanent solution. Small companies, in particular, may not have the time or expertise to evaluate alternatives for their cleaning every few years. These efforts also carry a cost which can be avoided by adopting a water-based cleaning system. Not only is water-based cleaning a cost effective option, its use also improves the quality of conditions for the workers. They often cite that advantage after converting.

5. Characteristics that Determine Substitution Choices

Vapor degreasing with chlorinated solvents is a very forgiving cleaning process. Parts are placed in the vapor zone of the degreaser and left for a time. They may also be immersed in the liquid solvent or sprayed with a wand while in the degreaser. The parts come out clean and dry. This process was used extensively without consideration of health or environmental effects for decades after World War II. The chlorinated solvents came under increased scrutiny starting in the 1970s because they are toxic and were contaminating sites where they were used. In the 1990s, regulations were adopted at the federal level that started affecting vapor degreasing. This spurred an investigation of alternatives.

It turns out that very few alternatives can be used in the same way as the chlorinated solvents in virtually uncontrolled equipment. A number of alternatives began to be marketed but few, if any, could perform in exactly the same way as the chlorinated solvents. Nearly all of the alternatives on the market today either pose health and environmental problems themselves and/or they require process changes of varying degrees to perform effectively. The alternative cleaning agents are not as forgiving and they require more attention to process details to function well.

As discussed earlier memo, many users have an inherent resistance to using water-based cleaners. The issues that are cited most often are that the water cleaners will rust the parts and that the water cleaners do not clean as well as solvents. Both of these issues are false. Many water-based cleaners are formulated specifically with rust or corrosion inhibitors so the metal parts will not be affected. There is also strong evidence that in most cases, a suitable water-based cleaner will perform better than a solvent in removing contaminants from parts.

Water-based cleaning suppliers are often willing to take potential customers' parts to their lab and define a specific cleaning agent and process for cleaning them. Water cleaning equipment distributors and manufacturers often have demonstration equipment. Users can take their parts to the demonstration site and the manufacturer/distributor will test it in different types of equipment or one type if it is obvious which will be best. The manufacturer/distributor will define the process that can be used and the user can determine whether the process works effectively by cleaning their own parts.

IRTA has worked with many companies over the years who have decided to convert to water-based cleaning processes after testing at demonstration sites. IRTA has also encountered some companies that refuse to even do testing to see if water-based cleaning will work for their process.

5.1 Application/Firm Characteristics That Make Substitution More Difficult: Open Top Vapor Degreaser

The question of whether there are companies that have operations that make substitution impossible or more difficult is very hard to answer. In principle, of course, no chemical is essential. There is strong evidence of this from the experience of the ban on ozone depleting substances. Production of two industrially important solvents, TCA and CFC-113, was banned. Although many companies claimed at the time that they could not process their parts without the solvents, they did convert to alternatives. In many cases, in converting to alternatives, they improved the cleaning results and adopted processes that were less costly to use. Thus, if a chemical is banned, the lesson is that there is always another way of doing it.

To answer the question of whether certain applications or firm characteristics make substitution more difficult, there are two issues to consider. The first issue concerns cost and whether or not a company can convert to an alternative process that is cost effective. As IRTA's estimates indicate for vapor degreasing alternatives, many companies will simply convert to the drop-in alternatives so they do not have to upgrade or purchase equipment. Other companies will convert to other alternatives and they may find that they actually have a more cost effective process even if they have to make an investment and do the work on what alternative would be best for their specific operation.

When EPA adopted the NESHAP regulation, they exempted several different types of facilities from compliance, presumably because it would be too hard and/or expensive for those facilities to investigate and adopt a new process. In some cases, the facilities did not want to convert because they had to meet certain criteria that they believed would be too onerous to change. One company, for instance, was cleaning the outside and inside of tubes with small diameters that are ultimately used in medical devices. The major reason they claimed they could not convert to an alternative was that they would have to demonstrate to the FDA they could achieve similar performance and that this would take several years and likely would not be possible. The company went on to argue that they had to clean tubing that is 40 feet long and that tubing could not be cleaned in airless/airtight equipment. It is very difficult to pull a vacuum on the size of equipment needed for this cleaning process and research would be necessary to figure it out. (Note that the company assumed they would have to adopt an alternative vapor degreasing process and did not consider using a water-based system.)

All of the process details on this operation are not available but it is not obvious why the tubing, which ultimately must be cut into much smaller sections, could not be cut either by this company, by another subcontractor or by the supplier of the tubing before it needs to be cleaned. That way, a huge vacuum system would not be needed.

Why will this company not simply try to find creative or just different solutions for cleaning the tubes? If they did find a process, they could convince the FDA that they could achieve equivalent cleaning effectiveness even if it took years. They would then have a process that they probably would never need to change again. When TCA and CFC-113 were banned, there were literally millions of military specifications requiring the use of the two solvents. All of those had to be changed and many of the military specifications are now performance based rather than individual chemical based. At least the FDA already evaluates alternative methods based on performance.

One other point concerns high technology cleaning applications, applications that involve cleaning parts for implantable medical devices or computer related components like the tube situation above. The medical and computer industries are very wealthy and they can obviously pay a higher price to companies cleaning their parts. In addition, in both industries, there are rapid changes in the technologies and the needs for making and cleaning components will change frequently as a result. When a company making and cleaning parts that are high technology related has a contract change because the parts are different, they can qualify other systems for FDA or their other customers at that time. It is hard to believe that the company making and cleaning the tubes has not had any changes in the parts themselves which would allow a new process to be qualified over the last 20 years since the NESHAP was adopted.

This also raises the issue of unquantifiable costs and/or benefits that are not considered when a company has to change their process. If the company switched to an alternative, they could avoid several costs that are probably involved in using a chemical like TCE. Companies using TCE must comply with the recordkeeping and reporting requirements in the NESHAP. They could avoid these costs by converting to an alternative. They may also have to report their emissions to TRI or to state or local air agencies. They may have to pay emission fees. They have to meet certain OSHA workplace standards for TCE and the controls, ventilation and respiratory protection are costly. They may also have to conduct worker training courses for respirators on a regular basis. They might also have high worker absentee rates because of unpleasant working conditions related to the TCE degreaser. They may incur higher workers compensation costs if workers contract cancer from exposure to TCE. Worker moral could also be increased if they worked with "cleaner" processes. These types of costs are rarely, if ever, considered in the decision to convert. On the other hand, many companies simply do not comply with the regulations that affect them and obviously, in these cases, they do not incur the compliance costs and would not be able to take credit for reducing or eliminating them.

In the case of TCE degreasing, IRTA does not believe there are any operations that could not be converted to alternatives for cost reasons. In some cases, the direct quantifiable costs of the conversion may be higher than the current costs but they are not likely to be prohibitive. There are many different types of alternatives available and users can select the one that is the least costly for them.

The second issue that arises when considering whether companies have applications where conversion to an alternative is more difficult is the mechanics of the cleaning process itself. There are certain cleaning tasks that are more difficult than others. For example, cleaning small diameter tubes is challenging. Cleaning parts with blind holes and crevices is very challenging. Cleaning parts that are energized electrically during the cleaning process is also challenging.

The company cleaning the tubes probably cleans the outside of the tubes in a vapor degreaser. The company likely has a manifold device for their current cleaning operation that attaches to both ends of the tubes for cleaning the inside of the tubes. The solvent is likely flushed through the tubes using the entrance and exit ports. A flushing operation is really the only way to clean the inside of the tubes. It is not clear from the available information whether the company is using TCE or not. If TCE were banned, they would have the option of converting to PERC, METH or nPB in their current operation. If they were willing to investigate alternative processes, they could probably find an alternative that could effectively flush the insides of the tubes. Rocketdyne cleaned tubing for rocket engines that had to be residue free in vapor degreasers and the company adopted water-based cleaning alternatives throughout their facility when production of TCA was banned. They did the work and testing on the alternatives and they found a permanent solution. They will not have to convert to another chemical in the future when it is regulated.

Parts with blind holes and crevices are difficult to clean, even in a vapor degreaser in some cases. It is likely that companies using a vapor degreaser for cleaning these types of parts probably also have ultrasonics in the cleaning equipment. Ultrasonics is the most appropriate method of delivering cleaning agent into small places. Companies cleaning parts like this in vapor degreasers could likely convert to a water-based cleaner with ultrasonics that would be suitable for the operation.

Some companies and utilities need to clean energized electrical equipment like electrical lines, transformers and electrical boxes with energized components. Halogenated solvents have often been used for this purpose because a cleaning process that does not conduct is needed. It turns out that plain deionized water does not conduct and can be used for cleaning electrical lines. Two other approaches, dry ice blasting or carbon dioxide snow cleaning, can be used for cleaning transformers and electrical cabinets. In addition, if water-based cleaners and other solvents are used very carefully, they can be used to clean energized electrical cabinets.

IRTA does not believe there are operations currently that could not be done by using an alternative from a technical standpoint. All of the barriers that companies cite can be resolved if the company is committed to the change. There are strong advantages to finding a permanent solution rather than converting several times from a bad alternative to other regrettable alternatives as they are increasingly regulated.