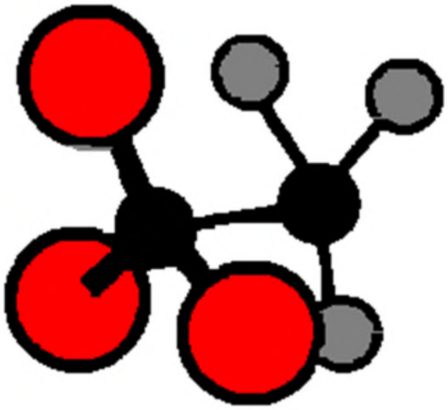

Alternative Compliance Strategies for Enclosed and Conveyorized Vapor Degreasers under a Prohibition of Trichloroethylene

Draft

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1. Background

EPA is considering expanding the scope of their TSCA Section 6 Action on TCE to include all vapor degreasing with TCE. This means that in addition to restricting TCE use in open top vapor degreasing, EPA may also restrict TCE use in enclosed and in-line (conveyorized) systems. This report makes estimates of the alternatives that could be adopted in light of a ban in these two types of machines.

2. TCE Use in Enclosed Systems

IRTA investigated vapor degreasers that are enclosed. The number of enclosed systems, the type of solvent used in these systems and the alternatives that are likely substitutes are discussed below.

2.1 Description of Vacuum Degreasing

IRTA contacted a few manufacturers of enclosed systems as part of this task. These manufacturers generally make vacuum systems which reduce emissions of solvents substantially. Although there are probably several additional European based companies that have sold a few vacuum systems to companies in the U.S., the following companies routinely do or have done business in the U.S:

- Durr
- Tiyoda
- Serec
- Pero

In most of the systems, the work chamber is under vacuum during the entire process. When the parts are loaded and the door is sealed, the air in the system is evacuated and the pressure is reduced to below about 5 torr. The solvent vapor is introduced to the chamber. The vapor condenses on the colder part and the vapors are evacuated with a vacuum pump, which accelerates the drying. The chamber is returned to atmospheric pressure and the remaining solvent in the chamber (perhaps 3 to 5 ppm) is exhausted through a carbon filter. Vacuum degreasers can, if they are constructed appropriately, use any solvent including halogenated solvents and solvents with flash points.

2.2 Number of Vacuum Degreasers Using TCE

Although estimates from the manufacturers vary, there may be as many as 2,000 vacuum degreasers in the U.S. today. In Europe, the chlorinated solvents are heavily restricted so the European based manufacturers (Durr and Pero) recommend that users purchase machines for use with hydrocarbons or modified alcohols. Although they also offer machines for halogenated solvents, they discourage users from using them. Tiyoda and Serec, on the other hand, sell machines largely for use with halogenated solvents.

Taking into account the differing approaches and perspectives of the equipment manufacturers, IRTA estimated the number of vacuum degreasers in the U.S and the percentage of them that use each solvent or solvent type. Of the 2,000 systems, about 80% of the units use hydrocarbons, modified alcohols or lower flash point solvents like certain alcohols or acetone. The remaining 400 degreasers use halogenated solvents of various kinds. Perhaps 60% use TCE (trichloroethylene) or PERC (perchloroethylene), 25%

may use nPB (n-propyl bromide) and the remaining 15% may use the fluorinated solvents. Of the 240 degreasers using TCE or PERC, half or 120 use TCE and 120 use PERC. About 100 vacuum systems use nPB and perhaps 60 use fluorinated solvents based on the HFEs (hydrofluoroethers) or HFCs (hydrofluorocarbons). The new Honeywell HFO (hydrofluoroolefin) cannot be used in an enclosed system. Table 1 summarizes these estimates, which have wide uncertainty ranges.

Table 1: Vacuum Degreasing Systems by Solvent Type

Solvent Type	**Number of Vacuum Degreasers**
TCE	120
PERC	120
nPB	100
Fluorinated solvents	60
Hydrocarbons, modified alcohols and other	1,600
Total	2,000

2.3 Conversion from TCE to Alternatives in Vacuum Degreasers

This section involves determining the alternatives users would move to if TCE were banned in vacuum systems. In light of the fact that the vacuum systems are very expensive, it is likely that users would continue to use their existing systems if possible.

Durr makes two different types of systems, one type for TCE and PERC and another for hydrocarbon or modified alcohols. Pero makes several different types of machines and will custom design systems. Pero has a universal machine that can run with any solvent including TCE, PERC, nPB, fluorinated solvents, hydrocarbons and modified alcohols. Serec has standard systems and also does custom designs. The company can run any solvent in their machines with certain modifications.

Under the NESHAP, there is a standard for emissions for machines without air/vapor interfaces and vacuum systems fall into this category. The emission limit is fairly high and vacuum systems could probably all meet the limit easily. The three vacuum system manufacturers also sell equipment in the South Coast Air Quality Management District (SCAQMD) which has had a regulation for many years that restricts the use of solvents with more than 25 grams per liter VOC content to airless/airtight systems. It also restricts the use of NESHAP listed solvents to airless/airtight systems. NESHAP listed solvents include TCE and PERC; nPB, hydrocarbons, modified alcohols and fluorinated solvents blended with 1,2-trans-dichloroethylene are VOCs so they are therefore also restricted to airless/airtight systems. The SCAQMD restricts emissions from vacuum systems much more stringently than the NESHAP. All of the vacuum system manufacturers design systems that can meet this limit.

In discussions with the system manufacturers, IRTA determined that users with a universal system from Pero can convert from TCE to any solvent without making costly changes to the machine. All Pero equipment users may not have a universal machine, however. Serec also offers a universal machine but makes many custom designed units as well. Durr offers two types of machines. One type is a machine designed to use either TCE or PERC. The other is a machine designed to use either hydrocarbon or modified alcohols. If the user purchased a machine designed to use either TCE or PERC from Durr, the machine could be directly used without modifications to use PERC. Durr is not familiar with nPB since they say it is banned in Europe so they indicate their machines cannot be converted to use this solvent. Durr also indicates that they will not convert a TCE machine to a fluorinated solvent or a hydrocarbon or modified alcohol machine. It is not clear whether one of the other manufacturers would be willing to convert a Durr machine to use another of these solvents. If they did make a modification to another supplier machine, however, the warranty on the machine would be invalid. In any case, if TCE were restricted or banned, Durr machine users could convert to PERC so they would have at least one conversion option.

What this means is that if EPA were to ban TCE in vacuum degreasers, whether users of TCE in vacuum systems have a machine made by Durr, Pero or Serec could matter and whether they have a universal machine or not could also matter. Because the machines are very expensive, users would certainly want to convert them rather than purchase a new system. Durr machine users using TCE could always convert to PERC since the company has machines designed for use with both solvents but they might not be able to convert to any other solvent unless one of the other manufacturers could step in and modify the machine for the changes. What this also means is that users with a universal machine from Pero would be the most fortunate if EPA were to ban TCE. They would have the choice of converting to any alternative without making costly changes. Users with Serec machines could also convert to any alternative but physical changes in the machines could be necessary depending on which machine type the user had.

Taking this information into account, IRTA assumed that all users of TCE machines would try to continue using their systems and that they would prefer using halogenated solvents of one kind or another because of the more extensive modification that would be necessary for converting to hydrocarbons. Thus, of the 120 TCE systems, the majority, or 65% would likely convert to nPB because the conversion could be done with virtually no system changes. Although users may be concerned about nPB toxicity, they could reason they would be using the solvent in an enclosed system with very little worker exposure. Some of the remaining users, perhaps 15%, would convert to PERC; in some of these cases, no modifications would be necessary but in others, a larger heater would be required. Perhaps as many as 15% would convert to the fluorinated solvents which would require adding more refrigeration; these would be the users concerned about toxicity. Even though these solvents are much more expensive, their losses would be minimized in the enclosed systems. The remaining 5% would convert to hydrocarbons and they would have to make significant changes to the heating system. These would be the users that are tired of switching from one halogenated solvent to another and simply want to use a not-in-kind material. More users would likely make the switch to hydrocarbon but the largest manufacturer would probably not be willing to convert machines to use the material.

This information is summarized in Table 2. These estimates are very uncertain. Many users in the market are trying to move away from nPB because of its toxicity and PERC is no longer a solvent most users consider adopting. IRTA is assuming that users of the high cost enclosed systems would not want to scrap their system and start over and that that position would probably outweigh toxicity concerns.

Table 2 Estimates of Alternatives to TCE in Vacuum Systems		
Alternative Solvent or Solvent Type	**Percent of Vacuum Degreasers**	**Number of Vacuum Degreasers**
nPB	65%	78
PERC	15%	18
Fluorinated solvents	15%	18
Hydrocarbon solvents	5%	6
Total	100%	120

2.4 Case Studies for Vacuum Systems

Vacuum systems are often referred to as airless/airtight systems. The systems generally operate in a vacuum except when the solvent is introduced for the cleaning step. Because the systems operate in a vacuum environment, the options for using alternatives are expanded. In addition to halogenated solvents which have no flashpoint, these systems can rely on hydrocarbons or modified alcohols which are generally combustible solvents and other solvents like acetone or isopropyl alcohol which are flammable. IRTA evaluated two different case studies for vacuum systems. These included using TCE as a baseline and considered a conversion to:

- nPB
- PERC
- Fluorinated solvents
- Hydrocarbon solvent

One of the U.S. suppliers indicates that perhaps as many as 85% of his systems used in the U.S. are custom designed and are often very large. Other manufacturers generally sell standard units but they are also often large. They can range in size up to 8,000 gallons. Tube machines are commonly the largest. IRTA decided to select two different sizes of degreasers as case studies. One of these is a 3.5 cubic foot chamber 70 gallons system and the other is a 30 cubic foot 400 gallon system. When these units are purchased new, the 70 gallon system might range in cost from $140,000 to $225,000 and the 400 gallon system would cost $320,000 to $600,000. Universal systems are generally in the higher cost range.

2.4.1 Case Study #1

The 70 gallon system would have a 3.5 cubic foot chamber. It was assumed that the user would run the system eight hours per day. A typical operation might be five cycles per hour with 12 minutes per cycle. These systems have internal distillation and the still bottom, which may contain only 3 to 10% of the solvent, is removed periodically. The solvent itself does not need to be changed out. Many systems have operated for more than 12 years without requiring a full changeout of the solvent.

IRTA estimates the emissions of TCE from the 70 gallons system at about one drum or 55 gallons per year. The loss comes from solvent dragout on the parts, solvent loss during maintenance and solvent loss during filter changes. Thus, the user needs to purchase 55 gallons per year of virgin solvent to replace the losses. There is also a loss of solvent from the waste. The vacuum system has internal distillation so the waste from the system is the still bottom. The still bottom may contain as much as 10% liquid solvent but is generally oil and solids. Assuming the case study has fairly heavy oil loading, the user would generate about one-tenth of a drum of solids per month from the distillation process. This amounts to 66 gallons per year. The solvent content in this waste would be 6.6 gallons (see Equation (1)). The total solvent loss that needs to be replaced is 61.6 gallons per year (55gal + 6.6gal = 61.6gal). IRTA uses a price of $24 per gallon of TCE, thus the cost of solvent replacement would be $1,478 annually.

$$\text{Loss of Solvent from Waste gal} = \left(\frac{\left(\left(\frac{1}{10}\right)\cdot\left(\frac{55\text{ Gallon}}{\text{Drum of Solids}}\right)\right)}{\text{Month}}\right)\cdot\left(\frac{12\text{ Months}}{\text{Year}}\right)\cdot\left(\frac{10\%\text{ Liquid}}{\text{Solvent}}\right)\rightarrow \left(\frac{(5.5\text{ gal})}{\text{Month}}\right)\cdot\left(\frac{12\text{ Months}}{\text{Year}}\right)\cdot\left(\frac{10\%\text{ Liquid}}{\text{Solvent}}\right) = 6.6\text{ gal} \quad (1)$$

Because vacuum system waste does not contain enough liquid to make recovery cost effective, the waste would require incineration and the disposal cost would amount to the solids disposal cost of $1.10 per pound. Assuming a solids density of eight pounds per gallon, the cost of disposal would be $523 (see Equation (2)). IRTA calculated the waste disposal cost for the case study but it does not vary across solvents so it would be essentially the same in the cost comparison.

$$\text{Waste Disposal Cost } \$ = \left(\frac{\left(\left(\frac{1}{10}\right)\cdot\left(\frac{55\text{ Gallon}}{\text{Drum of Solids}}\right)\right)}{\text{Month}}\right)\cdot\left(\frac{12\text{ Months}}{\text{Year}}\right)\cdot\left(\frac{90\%\text{ Solid}}{\text{Waste}}\right)\cdot\left(\frac{\text{Solids}}{\text{Density}}\frac{\text{lb}}{\text{gal}}\right)\cdot\left(\frac{\text{Disposal}}{\text{Cost}}\frac{\$}{\text{lb}}\right) \rightarrow \left(\frac{(5.5\text{ gal})}{\text{Month}}\right)\cdot\left(\frac{12\text{ Months}}{\text{Year}}\right)\cdot\left(\frac{90\%\text{ Liquid}}{\text{Solvent}}\right)\cdot\left(8\frac{\text{lb}}{\text{gal}}\right)\cdot\left(\frac{\$1.10}{\text{lb}}\right) = \$523 \quad (2)$$

According to equipment manufacturers and based on kW ratings for equipment, the electric load for this machine would be about 25 kW. Assuming the unit operates eight hours per day, five days per week and 52 weeks per year, the total electricity use would be 52,000 kWh per year. Assuming an electricity cost of 12 cents per kWh, the annual electricity cost would be $6,240.

One worker would operate the system for eight hours per day. Assuming a labor rate of $20 per hour, the labor cost would be $41,600 per year.

Converting to PERC

The boiling point of PERC, at 250 degrees F, is higher than the boiling point of TCE which is 189 degrees F. Unless it is a custom designed unit, companies sell one vacuum degreaser for TCE and it can also be used with PERC. In effect, these degreasers are sold with enough heating capacity to allow the user to use either TCE or PERC in the machine and they also have the refrigeration required.

It is likely the user purchased a system with a heater that can achieve the PERC boiling point and a large enough chiller to condense PERC. In that event, there would be no need to add additional heating or chiller capacity. If the user did not purchase such a system, however, the degreaser might require four additional heating elements and a condenser for a parts cost of $5,000. Labor for installing the parts is estimated at $5,000. The total modification cost would be $10,000.

With the equipment changes (or without these changes if they were not necessary), the system would be operating optimally. The emissions of PERC would be slightly lower than emissions of TCE, perhaps 10% lower at 49.5 gallons per year (see Equation (3)). In tighter systems, the emissions of different solvents do not vary much, not as much as in more emissive open top units. Adding the 6.6 gallons per year from the waste which would not change, the total loss would be 56.1 gallons per year (49.5gal + 6.6gal = 56.1gal). The cost of PERC is about $29 per gallon. On this basis, the solvent cost would amount to $1,627 annually.

$$\underset{\text{Emissions}}{\text{Drop-in}}\,\text{gal} = \left(\underset{\text{Emissions}}{\text{Baseline TCE}}\,\text{gal}\right) \cdot \left(100\% + \underset{\text{Emissions}}{\text{Change in}}\,\%\right) \quad (3)$$

$$\underset{\text{Emissions}}{\text{PERC}}\,\text{gal} = (55\text{ gal}) \cdot (100\% + {}^{-}10\%) = 49.5\text{ gal}$$

Because of the added heating and cooling capacity, the electric load on the system would be 10 to 15% higher. Assuming the midpoint of 12.5%, the electric load would be about 28 kW. Assuming the same operating schedule as for TCE, the annual kWh would be 58,500. Again, assuming an electricity price of 12 cents per kWh, the electricity cost would amount to $7,020 annually.

The cost of disposal of the hazardous waste would be the same as for TCE. The labor cost would also be the same.

Converting to nPB

The same system used for TCE could be used with nPB without any modifications. Emissions of nPB might be slightly higher, perhaps by 10%. On this basis, emissions would be 60.5 gallons annually (see Equation (3) for details on this calculation). The waste emissions would be an additional 6.6 gallons for a total of 67.1 gallons. Assuming the same price for nPB as before, $47 per gallon, the cost of purchasing the solvent would amount to $3,154 annually.

The cost of handling the disposal of the waste would not change for nPB. Although nPB is not a listed hazardous waste under RCRA, it would be handled as a hazardous waste by haulers. The amount of the solids and oil in the waste would not change, so the cost of disposal is the same as for TCE users. There would be no change in the electricity cost and no change in the labor cost.

Converting to Fluorinated Solvents

In this case, IRTA assumed the user could convert to Vertrel which is a blend of an HFC and 1,2,-trans-dichloroethylene. The user could also convert to a Novec 3M HFE blend with 1,2-trans-dichloroethylene (DCE) and the cost would be similar. A new solvent called Sion has recently entered the market and users could convert to it as well. It is an HFO blended with 1,2-trans-dichloroethylene at more than 90% concentration. This new solvent, because of the high concentration of the DCE, is only about half the price of the other two HFC and HFE blends. Although the HFO blend does not seem to be readily available yet (IRTA could not find an SDS), it is likely to be available soon.

The fluorinated solvents have lower boiling points and one or two of the heating elements would need to be disconnected. Refrigeration capacity would have to be added. The cost of adding compressors and condensers would be $8,000. This is treated as a capital cost and, assuming a 10 year life and a cost of capital of 4%, the annual cost would be $832.

Solvent emissions, in this case, are estimated to be 20% higher than TCE emissions. Thus emissions would amount to 66 gallons per year (see Equation (3) for details on this calculation). Adding the waste contribution, the total solvent consumption is 72.6 gallons per year. Using the cost of $218 per gallon for Vertrel IRTA used in other tasks, the cost of purchasing Vertrel amounts to $15,827 per year.

The kW for the system would remain the same; this follows from the fact that heating capacity is being removed offsets the addition of the refrigeration capacity. Thus the cost of electricity would be the same. The labor costs and the disposal costs would remain the same as those for TCE as well.

Converting to Hydrocarbon

The hydrocarbon, Isopar L, has a much higher boiling point and much lower vapor pressure than the halogenated solvents considered here. As a result, emissions are likely to be lower, perhaps 20% lower in this system. Thus emissions of the hydrocarbon would be 44 gallons per year (see Equation (3) for details on this calculation). Emissions from the waste would remain at about 6.6 gallons per year. This implies that solvent usage would be 50.6 gallons per year. One solvent supplier indicates that the price of the Isopar L is about $13.50 per gallon. On this basis, the cost of purchasing solvent would be $683 per year.

The hydrocarbon has a much higher boiling point and lower vapor pressure than the other solvents. The operating system would have to be changed to run at lower pressure. The water separator and many of the pumps, seals and valves would have to be changed out. The heater would need to be capable of achieving a much higher boiling temperature and more refrigeration capacity would be required. An estimate of the increased cost of these changes is $60,000.

Because of the system changes that are required, the kW of the system would be higher by perhaps 20%. On this basis, the electrical requirement would be 30 kW. Again assuming the unit is operated eight hours per day five days per week and 52 weeks per year, the annual electricity use is 62,400 kWh per year. Assuming the cost of 12 cents per kWh, the annual electricity cost is $7,488.

The cost of disposing of hydrocarbon waste can be very different from the cost of disposing of halogenated solvent waste. The hydrocarbon waste has high BTU and can be burned efficiently. In this case, however, the waste is almost entirely solids. It may be slightly lower in cost to dispose of the hydrocarbon waste but the difference would be negligible. The disposal cost, in this case, would not change. The labor cost would also be the same.

Summary of Case Study Costs

All costs are presented as first year, recurring, and annualized using a discount rate of 3 percent over a period of 10 and 20 years. Many of the users of vacuum systems either have a system that can use both TCE and PERC without modification or a universal system. Other units have a system that is custom designed for their process to use TCE. Table 3 below summarizes the costs for the custom designed unit, which is discussed above for this case study.

The lowest cost option in the table is to continue using TCE. The lowest cost alternative options are to convert to nPB or PERC. The next lowest cost option is to convert to hydrocarbon. The highest cost option is to convert to a fluorinated solvent because of the high solvent cost. The reasons that the costs for using any of the solvents are so close is that the labor cost dominates the total cost and that the machines are so tight that the cost of purchasing the solvent has little effect on the total cost of using any one of the solvents in particular.

Table 3: Annual Cost Comparison for TCE Baseline and Alternatives for Custom Designed System					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
TCE Baseline	-	$1,478	$6,240	$41,600	$523
PERC	$10,000	$1,627	$7,020	$41,600	$523
nPB	-	$3,154	$6,240	$41,600	$523
Fluorinated	$8,000	$15,827	$6,240	$41,600	$523
Hydrocarbon	$60,000	$683	$7,488	$41,600	$523
Cost Summaries					
Cleaning Agent		**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline		$49,841	$49,841	$44,611	$46,702
PERC		$60,770	$50,770	$46,492	$48,202
nPB		$51,517	$51,517	$46,111	$48,272
Fluorinated		$72,190	$64,190	$58,294	$60,651
Hydrocarbon		$110,294	$50,294	$51,312	$50,905

IRTA also considered the case where a user has a machine that can use either TCE or PERC . In this case, as summarized in Table 4 below, the only cost that would vary is the cost of replacing the solvent lost through emissions and waste. No capital cost is required because the machine was designed for either solvent. The energy costs for the system would be the higher energy cost for PERC since the system was designed with the kW to accommodate PERC. The difference in cost in using the two solvents in this type of system is negligible.

Table 4: Annual Cost Comparison for TCE Baseline and PERC for TCE/PERC Convertible System					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
TCE Baseline	-	$1,478	$7,020	$41,600	$523
PERC	-	$1,627	$7,020	$41,600	$523
Cost Summaries					
Cleaning Agent		**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline		$50,621	$50,621	$45,309	$47,433
PERC		$50,770	$50,770	$45,442	$47,572

IRTA also considered the case where the user has a universal machine but is using TCE currently. Table 5 below shows this cost comparison for this case. In this case, no equipment changes would be necessary since the machine was designed to handle all solvents. The cost of replacing solvent emissions and solvent lost through waste will differ depending on the price of the solvent. The electricity cost for all solvents will be the electricity cost for hydrocarbon which has the highest energy cost. This follows from the fact that the system was designed to use any one of the solvents so it has to accommodate the electrical load for hydrocarbon. The labor and disposal costs are the same for all solvents.

This case is interesting because using the hydrocarbon solvent is the lowest cost option. The costs of using TCE, PERC or nPB in the equipment are very close. This is because the emissions and waste loss are so low that the price of the solvent has little influence on the total cost. It is important to note, however, that the capital cost of purchasing the system in the first place where it is a universal system is likely to be higher.

Table 5: Annual Cost Comparison for TCE Baseline and Alternatives for Universal System

Cleaning Agent	Equipment	Cleaner	Electricity	Labor	Disposal
TCE Baseline	-	$1,478	$7,488	$41,600	$523
PERC	-	$1,627	$7,488	$41,600	$523
nPB	-	$3,154	$7,488	$41,600	$523
Fluorinated	-	$15,827	$7,488	$41,600	$523
Hydrocarbon	-	$683	$7,488	$41,600	$523

Cost Summaries

Cleaning Agent	1st Yr.	Recurring	3% Annualized over 10 years	3% Annualized over 20 years
TCE Baseline	$51,089	$51,089	$45,728	$47,871
PERC	$51,238	$51,238	$45,862	$48,011
nPB	$52,765	$52,765	$47,228	$49,442
Fluorinated	$65,438	$65,438	$58,572	$61,317
Hydrocarbon	$50,294	$50,294	$45,017	$47,126

2.4.2 Case Study #2

In this case, the system is a 400 gallon capacity machine that uses TCE. The chamber is 30 cubic feet and it, like the first case study machine, runs eight hours per day. The losses of TCE in this system amount to about six drums or 330 gallons per year. The waste generated from this operation is estimated at about one drum or 55 gallons per month or 660 gallons per year. This waste is again virtually all solids but it could have up to 10% solvent content. Assuming 10% of the waste is solvent, the TCE in the waste is 66 gallons per year (see Equation (4)). The total solvent consumption is 396 gallons per year (330gal + 66gal = 396gal). The cost of purchasing replacement solvent, at $24 per gallon for TCE, is $9,504 annually.

$$\begin{matrix}\text{Loss of} \\ \text{Solvent} \\ \text{from Waste}\end{matrix}\ \text{gal} = \left(\frac{\text{55 Gallon}}{\text{Drum of Solids}}\right) \cdot \left(\frac{\text{12 Months}}{\text{Year}}\right) \cdot \left(\frac{\text{10\% Liquid}}{\text{Solvent}}\right) \rightarrow \tag{4}$$

$$\left(\frac{(\text{55 gal})}{\text{Month}}\right) \cdot \left(\frac{\text{12 Months}}{\text{Year}}\right) \cdot \left(\frac{\text{10\% Liquid}}{\text{Solvent}}\right) = \text{66 gal}$$

The electric load on this system is estimated at 150 to 160 kW. Assuming the midpoint of 155 kW and that the equipment operates eight hours per day, five days per week and fifty-two weeks per year, the electricity use is 322.400 kWh. At a price of electricity of 12 cents per kWh, the cost of purchasing electricity is $38,688 per year.

The equipment operates for eight hours per day and one worker devotes eight hours to the operation. On this basis, assuming a $20 per hour labor rate, the labor cost is $41,600 annually.

The waste generated in the operation is 90% solids or 594 gallons per year. Assuming a cost for solids disposal of $1.10 per pound and a density for the solids of eight pounds per gallon, the annual cost of hazardous waste disposal is $5,227 (see Equation (5)).

$$\begin{matrix}\text{Waste}\\ \text{Disposal}\\ \text{Cost}\end{matrix}\ \$ = \left(\begin{matrix}\text{55 Gallon}\\ \text{Drum of Solids}\end{matrix}\right)\cdot\left(\frac{\text{12 Months}}{\text{Year}}\right)\cdot\left(\begin{matrix}\text{90\% Liquid}\\ \text{Solvent}\end{matrix}\right)\cdot\left(\begin{matrix}\text{Solids}\\ \text{Density}\end{matrix}\ \frac{\text{lb}}{\text{gal}}\right)\cdot\left(\begin{matrix}\text{Disposal}\\ \text{Cost}\end{matrix}\ \frac{\$}{\text{lb}}\right)$$

$$\rightarrow\left(\frac{(55\text{ gal})}{\text{Month}}\right)\cdot\left(\frac{\text{12 Months}}{\text{Year}}\right)\cdot\left(\begin{matrix}\text{10\% Liquid}\\ \text{Solvent}\end{matrix}\right)\cdot\left(8\,\frac{\text{lb}}{\text{gal}}\right)\cdot\left(\frac{\$1.10}{\text{lb}}\right) = \$5{,}227 \qquad (5)$$

Converting to PERC

Assuming the equipment is not a universal system, it would need additional heating and cooling capacity to use PERC. The cost of adding the new equipment is estimated at $20,000.

If the chiller were adequate or augmented and the system was optimal, the emissions of PERC would be about 10% lower than emissions of TCE, about 297 gallons per year (see Equation (6)). The contribution of the waste emissions would remain the same at 66 gallons per year. Total emissions are therefore 363 gallons per year (297gal + 66gal = 363gal). The price of PERC is about $29 per gallon. On this basis, the solvent cost is $10,527 annually.

$$\begin{matrix}\text{Drop-in}\\ \text{Emissions}\end{matrix}\text{gal} = \left(\begin{matrix}\text{Baseline TCE}\\ \text{Emissions}\end{matrix}\text{gal}\right)\cdot\left(100\% + \begin{matrix}\text{Change in}\\ \text{Emissions}\end{matrix}\%\right)$$

$$\begin{matrix}\text{PERC}\\ \text{Emissions}\end{matrix}\text{gal} = (330\text{ gal})\cdot(100\% + {}^{-}10\%) = 297\text{ gal} \qquad (6)$$

Because of the equipment modifications, the electrical rating of the equipment would be higher by 12.5% at about 174 kW. Assuming the same operating schedule as for TCE and a price of 12 cents per kWh, the annual electricity cost would be $43,524.

The cost of disposal of the hazardous waste and the labor cost would be the same as for TCE.

Converting to nPB

The same system used for TCE could be used with nPB without any modifications. Emissions of nPB might be higher by 10% or 363 gallons per year (see Equation (6) for details on this calculation). The emissions from the waste would remain the same as for TCE at 66 gallons per year. The total amount of solvent losses would be 429 gallons per year. Assuming the same price for nPB as before, $47 per gallon, the cost of purchasing the nPB would amount to $20,163 annually.

The cost of handling the disposal of the waste would not change for nPB. The labor cost and the electricity cost would also remain the same as for TCE.

Converting to Fluorinated Solvents

For this case study, one or two of the heating elements would need to be disconnected and additional refrigeration cooling would be required. The capital cost of modifying the system would range from about $18,000 to $19,000. Assuming the midpoint, at $18,500 and treating it as a capital cost, the annualized cost of the modification would be $1,924.

In this case, emissions might increase 20%, to 396 gallons per year (see Equation (6) for details on this calculation). The waste loss would be the same as for TCE or 66 gallons per year. The total loss of solvent would be 462 gallons per year. Using the price for Vertrel of $218 per gallon, the cost of purchasing solvent would be $100,716.

The costs of waste disposal, electricity use and labor would be the same as for the TCE system.

Converting to Hydrocarbon

Suppliers indicate that it is not reasonable to modify the equipment for use with hydrocarbon in the case of the larger system. It would be such a high cost that a better option would be to simply purchase a new hydrocarbon or universal system. If a modification were actually undertaken, it is likely the equipment would never function properly.

IRTA did evaluate the individual cost components without assuming a modification, however, so the case where the user originally purchased a universal machine could be considered later. Emissions from case study #1 for the hydrocarbon were estimated to be 20% lower than TCE emissions. Instead of 330 gallons, emissions of hydrocarbon would be 264 gallons per year (see Equation (6) for details on this calculation). The total losses of solvent are 330 gallons per year taking into account the waste losses. Assuming the price of $13.50 per gallon for Isopar L, the cost of solvent purchases is $4,455.

The electrical load on the machine is 20% higher than the electric load on the TCE machine. On this basis, the machine electric load is 186 kW instead of 155 kW for TCE. Assuming the eight hour day operation and an electricity cost of 12 cents per kWh, the electricity cost is $46,426.

The labor cost and the cost of waste disposal would be the same as for the other solvents.

Summary of Case Study Costs

All costs are presented as first year, recurring, and annualized using a discount rate of 3 percent over a period of 10 and 20 years. Table 6 shows the cost comparison for this system using TCE as the baseline and the alternatives. In this case, hydrocarbon is not included because it is not economic to upgrade the system. The values of the Table 6 show that the lowest cost alternative is to use PERC and nPB is also a low cost option. The cost of using the fluorinated solvents is, again, the highest cost option. This is because of the high price of the fluorinated solvents.

Table 6: Annual Cost Comparison for TCE Baseline and Alternatives for Custom Designed System					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
TCE Baseline	-	$9,504	$38,688	$41,600	$5,227
PERC	$20,000	$10,527	$43,524	$41,600	$5,227
nPB	-	$20,163	$38,688	$41,600	$5,227
Fluorinated	$18,500	$100,716	$38,688	$41,600	$5,227
Cost Summaries					
Cleaning Agent		**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline		$95,019	$95,019	$85,049	$89,034
PERC		$120,878	$100,878	$92,392	$95,784
nPB		$105,678	$105,678	$94,589	$99,022
Fluorinated		$204,731	$186,231	$168,631	$175,667

As before, IRTA also examined the case where the user originally purchased a system that could use either TCE or PERC. In this case, the electric load on the system would be the electric load for PERC which is higher than the electric load for TCE. Table 7 summarizes the costs for using the two solvents. The cost of converting to PERC is comparable to the cost of continuing to use TCE. This is because the only difference is in the cost of the solvent.

Table 7: Annual Cost Comparison for TCE Baseline and PERC for TCE/PERC Convertible System					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
TCE Baseline	-	$9,504	$43,524	$41,600	$5,227
PERC	-	$10,527	$43,524	$41,600	$5,227
Cost Summaries					
Cleaning Agent		**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline		$99,855	$99,855	$89,377	$93,566
PERC		$100,878	$100,878	$90,293	$94,524

Also as before, IRTA considered the cost comparison for the case where the user originally purchased a universal machine (see Table 8). In this instance, the user could convert to hydrocarbon since the system is universal. In this instance, as before, the user has a choice of all alternative solvents for the conversion. Also, as before, the lowest cost option is to convert to hydrocarbon. It should again be taken into account that the original purchase price of the equipment may have been higher for the universal system.

Table 8: Annual Cost Comparison for TCE Baseline and Alternatives for Universal System					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
TCE Baseline	-	$9,504	$46,426	$41,600	$2,376
PERC	-	$10,527	$46,426	$41,600	$5,227
nPB	-	$20,163	$46,426	$41,600	$5,227
Fluorinated	-	$100,716	$46,426	$41,600	$5,227
Hydrocarbon	-	$4,455	$46,426	$41,600	$5,227
Cost Summaries					
Cleaning Agent		**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
TCE Baseline		$99,906	$99,906	$89,423	$93,614
PERC		$103,780	$103,780	$92,890	$97,244
nPB		$113,416	$113,416	$101,515	$106,273
Fluorinated		$193,969	$193,969	$173,616	$181,752
Hydrocarbon		$97,708	$97,708	$87,456	$91,554

3. TCE Use in Conveyorized Degreasers

There are several systems in use today that could be classified as conveyorized systems and these are discussed below. IRTA also provides rough estimates of the number of conveyorized degreasers in the market and estimates the percentage of these systems that use TCE.

3.1 Description of Conveyorized Degreasers

There are very few if any remaining manufacturers who sell the type of in-line or conveyorized vapor degreasers that were somewhat widely used in the midwest rust belt many years ago. Some of these old monorail, cross-rod, vibra and ferris wheel vapor degreasers may still be operating but they are rarely if ever sold today. TCE is probably still used in a few of these remaining systems.

There are three types of conveyorized systems sold today. The first type is strip degreasers which are used for the continuous processing of strips of metals or cloth and are often integrated into other plant operations. The feedstock for stamping, forming, welding or bonding can be cleaned this way. Different types of agitation, including spray, immersion, brushes or ultrasonics can be used in the machines. The stock is loaded on a feed reel and taken off on a reel at the exit port. The degreasers are generally relatively enclosed. TCE is likely to be used in some of these systems.

The second type of system sold today is essentially a conveyorized batch vapor degreasing system. Again, these systems are largely enclosed. The parts are fed to the degreaser on a conveyor line and are placed into baskets for cleaning in an ultrasonic, spray and/or immersion tank as appropriate. The parts may move through more than one tank with specific agitation on a programmed set of hoists. The parts, when they have moved through the programmed cycle, exit the degreaser on a conveyor belt. TCE may be used in some of these systems.

The third type of system is a conveyorized vapor degreaser designed to clean printed circuit (PC) boards. The boards move on a conveyor line through a set of spray nozzles. In general, TCE is not used in these systems because it is too aggressive for many of the materials used in PC board manufacture. Users generally select other solvents for these applications. In addition, flux is best removed with an alcohol component and TCE is not generally combined with alcohols. IRTA assumed that TCE is used in only a few of these systems, as other solvents are a better choice.

3.2 Number of Conveyorized Degreasers Using TCE

Taking into account some estimates made by suppliers IRTA spoke with, there are likely to be more than 1,000 conveyorized systems in use today. Although there may be significant error in the number, for analysis purposes, IRTA estimates there are 1,000 such systems.

According to one supplier of these systems, nPB is used in about 80% of them, although many of these systems are being converted to fluorinated solvents. TCE is the most widely used solvent next to nPB and it may be used in 15% of the systems or about 150 units.

3.3 Conversion From TCE to Alternatives in Conveyorized Systems.

Water-based cleaners are cost effective alternatives in printed circuit board defluxing but most TCE users of conveyorized systems are not defluxing circuit boards. As a result, it is unlikely that many current TCE users would convert to water-based processes. They would have to purchase new equipment to make that conversion, so IRTA assumed that nearly all companies with conveyorized systems using TCE would opt to continue using their current equipment.

Many of the users of nPB concerned about the more recent toxicity information are moving away from nPB to the designer solvents. For users of TCE in conveyorized systems, this is also an option. In many cases, an investment would have to be made to upgrade the equipment because of the expense of the fluorinated solvents. Users would have to adopt more refrigeration and higher freeboards to better contain the solvent losses so the cost of using the solvents would be lower. Even so, many users would be put off by the high price of the solvents.

In some cases, users might convert to PERC, but PERC has become a very unpopular solvent in recent years (also see section below). Because of its higher boiling point, equipment might have to be upgraded to use this solvent as well.

The most obvious conversion, if TCE were restricted, would be from TCE to nPB since nPB is the most widely used solvent in conveyorized equipment today. Since nPB users are also trying to find alternatives, this would likely be the best of the bad choices for users of TCE.

Taking all of these factors into account, IRTA made estimates, which have a very high error band, of the choice of substitute solvents TCE users would adopt if TCE were restricted in conveyorized systems. Table 9 presents these estimates.

Table 9: Estimates of Alternatives to TCE in Conveyorized Vapor Degreasers		
TCE Alternative	**Percentage of Systems Converted**	**Number of Systems Converted**
nPB	60%	90
Fluorinated Solvents	25%	37
PERC	10%	15
Not-In-Kind (water, other)	5%	8
Total	100%	150

3.4 Case Studies for Conveyorized/Enclosed Systems

The systems of this type sold today are relatively tight systems compared with the systems that were used in the 1990s or the emissive typical open top vapor degreasers still sold today. IRTA evaluated two different case studies for these systems. The first type is a conveyorized strip machine and the second is a batch enclosed machine. The enclosed machine is not operated in a vacuum; rather the manufacturers included more emission control features than the more emissive traditional open top machines. The parts may be put in to the machine and may exit the machine on a conveyor. Inside the machine, the parts are moved through the baths with automation. An alternative similar system and the one IRTA considered here, might be an open top degreaser with a top that slides open so the parts can be placed in the machine. The cleaning cycle is run while the top is closed using an automated hoist. When the cycle is complete, the top slides open so the parts can be removed. IRTA again used TCE as a baseline and considered a conversion to:

- PERC
- nPB
- Fluorinated solvents
- Water-based cleaner

The case studies are considered below.

3.4.1 Strip Machine Case Study

The case study strip machine is designed to hold 300 gallons of solvent and is representative of a system that may have been sold five years ago at a price of about $180,000. The machine is enclosed and has an entrance and exit slot for the stainless steel strip of metal that enters and exits the machine. The continuous strip is 4 feet wide and the machine is about 20 feet long. The strip goes through a two-tank system consisting of a boil sump where it encounters vapor and an immersion bath where it is cleaned with liquid. Including the heater and the chiller, the load on the system is 30 kW and it is operated eight hours per day.

In the baseline case, TCE is used in the strip machine. Emissions from the machine amount to 1.5 drums per month or about 82.5 gallons; annual emissions are 990 gallons. Assuming a price of $24 per gallon for TCE, the annual cost of purchasing replacement solvent for the lost emissions amounts to $23,760. The tanks become contaminated with the oil removed from the strip and they are changed out three times per year. The company must replace the 300 gallons of solvent in the tank. The cost of replacing the solvent is $21,600. The total solvent purchase costs are $45,360.

The machine is operated eight hours per day. Assuming the company uses the machine five days a week and 52 weeks per year and that the load is 30 kW, the total annual electrical requirement is 62,400 kWh. Assuming a cost of electricity of 12 cents per kWh, the total annual electricity cost is $7,488.

One worker operates the system for eight hours each day. Using a burdened labor rate of $20 per hour, the total annual labor cost amounts to $41,600.

The solvent is changed out every four months. Thus, 900 gallons of hazardous waste or about 16.4 drums must be disposed of 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 $1.10 per pound. Assuming a contamination level of 30% and the midpoint of the range ($362.50/drum), the cost of the liquid disposal is $5,932 (900gal · (55gal/drum) · ($362.5/drum) = $5,932). The cost of the solids disposal, assuming a density of eight pounds per gallon, is $3,394 (see Equation (7)). The total cost of waste disposal amounts to $9,326 annually.

$$\begin{matrix}\text{Disposal}\\ \text{Costs}\\ \text{Solids}\end{matrix}\ \$ = \left(\frac{\begin{matrix}\text{Hazardous}\\ \text{Waste}\end{matrix}\,\text{gal}}{\left(100\% - \begin{matrix}\text{Oil}\\ \text{Contamination}\\ \text{Level}\end{matrix}\,\%\right)} - \begin{matrix}\text{Hazardous}\\ \text{Waste}\end{matrix}\,\text{gal} \right) \cdot \left(\begin{matrix}\text{Oil and Solids}\\ \text{Density}\end{matrix}\,\frac{\text{lb}}{\text{gal}}\right) \cdot \left(\begin{matrix}\text{Solids}\\ \text{Disposal}\\ \text{Cost}\end{matrix}\,\frac{\$}{\text{lb}}\right) \rightarrow \quad (7)$$

$$\left(\frac{900\ \text{gal}}{(100\% - 30\%)} - 900\ \text{gal}\right) \cdot \left(8\,\frac{\text{lb}}{\text{gal}}\right) \cdot \left(\frac{\$1.10}{\text{lb}}\right) = \$3{,}394$$

Converting to PERC

If the user converted to PERC, there would be changes to the equipment. The heat would have to be increased to accommodate the higher boiling point of PERC but this could be done with the existing heater. A refrigerated freeboard chiller would have to be added at a cost of $35,000 to $40,000. Assuming the midpoint, the cost of the additional refrigeration would be $37,500. Amortizing the cost over 10 years and assuming a cost of capital of 4%, the annualized cost would be $3,900.

In this machine, PERC emissions are likely to be about 10% lower than TCE emissions. Instead of 990 gallons of emissions for TCE, PERC emissions would amount to 891 gallons per year (see Equations (3) and (6) for details on this calculation). Assuming a price for PERC of $29 per gallon, the cost of emissions replacement would be $25,839 annually. The generation of waste, in the case of PERC, would be the same as for TCE. Thus, 900 gallons of solvent at a total cost of $26,100 would be required when the tanks are changed out. The total solvent purchase cost is $51,939 per year.

The amount of waste generated and the cost for shipping it off-site would not change in this case study. The labor required to operate the degreaser would also remain the same. Even with the addition of the refrigerated chiller capacity, the kW of the machine would remain the same. Since the machine operating hours do not change, the electricity cost does not change for this conversion.

Converting to nPB

If the user converted to nPB, the machine would not have to be altered. Emissions of nPB would be higher than emissions of TCE in this machine by about 10%. Emissions of nPB from the machine would be 1,089 gallons per year (see Equations (3) and (6) for details on this calculation). Replacing the solvent in the tank would remain the same, at 900 gallons per year. Assuming the price for nPB of $47 per gallon, the cost of purchasing solvent would be $93,483 annually.

In the case of nPB, the electricity cost, the waste disposal cost and the labor cost would all remain the same as for the baseline case with TCE.

Converting to Fluorinated Solvents

The fluorinated solvents generally boil at a lower temperature so the user might have to cut back on the heat. In some cases, this could be done in the facility; in other cases, it might require a contractor at an estimated cost of $5,000. Just as for PERC, these solvents would require additional refrigeration at an estimated cost of $37,500. IRTA considered the case where a contractor would be required to remove heating capacity. The total cost of modifying the machine would be $42,500.

Emissions from the machine for the fluorinated solvents would be higher by 20% because of their low boiling points and high vapor pressure. On this basis, emissions of Vertrel would amount to 1,188 gallons per year instead of 990 gallons for TCE (see Equations (3) and (6) for details on this calculation). The waste generation would remain the same and changing out the tank would require replacement of 900 gallons per year. The total solvent purchase amounts to 2,088 gallons per year. The price of Vertrel is much higher, at $218 per gallon. On this basis, the cost of purchasing solvent would be $455,184 per year. If users converted to Sion, the new solvent instead, the cost increase for solvent purchases would be much less.

For this case, there would be no change in the electricity, waste disposal or labor cost.

Converting to Water-Based Cleaning

In this case, the user would need to purchase new equipment for use with a water-based cleaner. One option would be to use a vertical machine where the strip is conveyed upwards vertically through a spray. IRTA did not cost out that option, however, because it may have required more information about the specific operation where it would be used to design it. The other option is to use a more traditional horizontal machine with various modules and that is the machine IRTA considered.

IRTA worked with a supplier and distributor of water cleaning equipment to develop estimates for a few different types of equipment that might be used for cleaning stainless steel strips. The strips, once they are cleaned of the oil added by the strip supplier, would go on through the plant for additional processing. Taking that into account, the strips likely would only need to be cleaned and dried. If the next operation required a completely residue free part (a very unlikely scenario), they might need to be cleaned, rinsed and dried. IRTA considered both cases to be conservative. The machine could be constructed of mild steel or stainless steel which would be more expensive. IRTA also considered both of these options. The equipment also has several other features including an oil skimmer, a steam exhaust system, and an automatic timer. The machine without the rinse would be about 10 feet long; the machine with the rinse would be 13 feet long.

The cost of a mild steel system without a rinse is estimated at $114,320. If a rinse module is added, the cost would be higher by $40,000 at $154,320. The cost of a stainless steel unit without a rinse is estimated at $148,320; if a rinse is included, the cost would be $205,320. Amortizing the capital cost of the systems over 10 years assuming a 4% cost of capital, the annualized capital cost of the mild steel system without and with a rinse would be $11,889 and $16,049 respectively. The values for the stainless steel unit are $15,425 and $21,353 respectively.

The wash bath of the system includes a spray module with a 15 HP pump and a 72 kW electric heater. The blowoff module has a 20 HP regenerative blower. The rinse module includes a 48 kW electric heater and a 10HP pump. Assuming the system is used eight hours per day, five days per week and fifty-two weeks per year, the total electricity requirement for the wash/dry system is 98 kWh and for the wash/rinse/dry system, it is 154 kWh. Assuming an electricity cost of 12 cents per kWh, the annual electricity cost would be $24,461 for the wash/dry system and $38,438 for the wash/rinse/dry system.

A cleaner that would be appropriate to use in this system is Brulin 3887. The price of the cleaner is $20 per gallon. The wash bath holds 400 gallons and the cleaner, in this application because of the high pressure spray, could be used at about an 8% concentration. The wash bath would likely need to be changed out four times per year. On this basis, assuming the 8% concentration, the cost of purchasing the cleaner is $2,432 annually (see Equation (8)).

$$\begin{matrix}\text{Cost of}\\ \text{Water-based}\\ \text{Cleaner}\end{matrix}\ \$ = \left(\begin{matrix}\text{Wash Bath}\\ \text{Volume}\end{matrix}\,\text{gal}\right)\cdot\left(\begin{matrix}\text{Changeout}\\ \text{Rate}\end{matrix}\,\frac{\text{times}}{\text{yr}}\right)\cdot\left(\begin{matrix}\text{Cleaner}\\ \text{Concentration}\end{matrix}\,\%\right)\cdot\left(\begin{matrix}\text{Cost of}\\ \text{Cleaner}\end{matrix}\,\frac{\$}{\text{gal}}\right)\rightarrow \tag{8}$$

$$(400\ \text{gal})\cdot\left(4\ \frac{\text{times}}{\text{yr}}\right)\cdot(8\%)\cdot\left(\frac{\$20}{\text{gal}}\right) = \$2{,}432$$

The recirculating rinse, if it were used in the system, would not have to use deionized water because the parts do not require a high level of cleanliness. No costs for using deionized water beds would be necessary.

One worker would be required for eight hours per day to operate and maintain the system. The labor cost would be the same as for the solvent system.

When the wash bath is changed out, the spent material is sent offsite for disposal. The cost is $2 per gallon so the total cost of disposing of the spent cleaner is $3,200 per year (see Equation (9)). The cost of disposing of the oil from the skimmer is $400 per year. The total cost of disposal is $3,600 ($3,200 + $400 = $3,600).

$\text{Disposal Cost Water-based Cleaner } \$ = \left(\text{Wash Bath Volume}\ \text{gal}\right) \cdot \left(\text{Changeout Rate}\ \frac{\text{times}}{\text{yr}}\right) \cdot \left(\text{Disposal Cost}\ \frac{\$}{\text{gal}}\right) \rightarrow$ $(400\ \text{gal}) \cdot \left(4\ \frac{\text{times}}{\text{yr}}\right) \cdot \left(\frac{\$2}{\text{gal}}\right) = \$3{,}600$	(9)

The costs of using the different types of water cleaning systems are summarized in Table 10 below. The lowest cost option is to use the mild steel system with no rinse and the highest cost option is to use the stainless steel system with the rinse included. Adding the rinse module increases the cost of electricity substantially. As mentioned above, however, it is unlikely the strip would require rinsing. The next operation the strip undergoes would probably be a stamping or forming operation and it would involve using oil that would be added to the parts.

Table 10: Cost of Using Different Types of Water Cleaning Systems					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
Mild steel-no rinse	$114,320	$2,560	$24,461	$41,600	$3,600
Mild steel-rinse	$154,320	$2,560	$38,438	$41,600	$3,600
Stainless steel-no rinse	$148,320	$2,560	$24,461	$41,600	$3,600
Stainless steel-rinse	$205,320	$2,560	$38,438	$41,600	$3,600
Cost Summaries					
Cleaning Agent		**1st Yr.**	**Recurring**	**3% Annualized over 10 years**	**3% Annualized over 20 years**
Mild steel-no rinse		$186,541	$72,221	$76,638	$74,872
Mild steel-rinse		$240,518	$86,198	$93,346	$90,489
Stainless steel-no rinse		$220,541	$72,221	$80,206	$77,014
Stainless steel-rinse		$291,518	$86,198	$98,697	$93,701

Summary of Costs from Strip Cleaning Machine

Table 11 summarizes the costs for the different options for the conveyorized strip machine. All costs are presented as first year, recurring, and annualized using a discount rate of 3 percent over a period of 10 and 20 years. All four of the water-based cleaning systems are included in the table. When annualized over a period of 10 years, two of the water-based cleaning options are lower in cost than using any solvent in the vapor degreaser. This is the case even though the user must purchase an expensive new system. The highest cost option is to convert the system to use a fluorinated solvent. When annualized over a period of 20 years, all of the water-based cleaning options are lower in cost than using any solvent in the vapor degreaser. This is the case even though the user must purchase an expensive new system. The highest cost option remains to convert the system to use a fluorinated solvent. The costs of compliance for using a solvent (emissions reporting, permitting, NESHAP reporting) were not included in the analysis. If these costs were included, it is likely that the cost of using the water cleaning systems with a rinse would be lower than continuing to use TCE when annualized over a period of 10 years.

Table 11: Annual Cost Comparison for TCE Baseline and Alternatives for Conveyorized Strip Machines					
Cleaning Agent	**Equipment**	**Cleaner**	**Electricity**	**Labor**	**Disposal**
TCE Baseline	-	$45,360	$7,488	$41,600	$9,326
PERC	$37,500	$51,939	$7,488	$41,600	$9,326
nPB	-	$93,483	$7,488	$41,600	$9,326
Fluorinated	$42,500	$455,184	$7,488	$41,600	$9,326
Water-mild steel-no rinse	$114,320	$2,560	$24,461	$41,600	$3,600
Water-mild steel-rinse	$154,320	$2,560	$38,438	$41,600	$3,600
Water-stainless steel-no rinse	$148,320	$2,560	$24,461	$41,600	$3,600
Water-stainless steel-rinse	$205,320	$2,560	$38,438	$41,600	$3,600

Cost Summaries

Cleaning Agent	1st Yr.	Recurring	3% Annualized over 10 years	3% Annualized over 20 years
TCE Baseline	$103,774	$103,774	$92,885	$97,238
PERC	$147,853	$110,353	$102,709	$105,765
nPB	$151,897	$151,897	$135,958	$142,330
Fluorinated	$556,098	$513,598	$464,166	$483,927
Water-mild steel-no rinse	$186,541	$72,221	$76,638	$74,872
Water-mild steel-rinse	$240,518	$86,198	$93,346	$90,489
Water-stainless steel-no rinse	$220,541	$72,221	$80,206	$77,014
Water-stainless steel-rinse	$291,518	$86,198	$98,697	$93,701

3.4.2 Batch Enclosed Machine

The case study batch enclosed system is similar to a batch open top vapor degreaser except it has an automated lid that is used during the entire cleaning cycle so it is much less emissive. The degreaser is two-sump system, 4 feet by 2 feet, and it holds a total volume of 100 gallons of solvent. The boiling sump holds 35 gallons. The cost of this system is higher than the cost of a simple open top degreaser of the same size, at $65,000 to $70,000. The parts are loaded in a basket which is positioned above a sliding lid, the user pushes a button and walks away. The lid opens and the hoist moves into the degreaser and the lid closes. The cleaning cycle then starts to operate. The user is cleaning screw machine parts which have relatively heavy oil loading. The system uses TCE.

The emissions from the machine are estimated at 0.002 pounds per hour per perimeter foot when the degreaser is not operating (downtime). During operation, the emissions are higher at 0.02 pounds per hour per square foot of solvent air interface (SAI). The machine is assumed to be in operation mode for 2,080 hours per year (8 hr/day · 260 day/yr = 2,080 hr) and in downtime for 6,656 hours per year ([16 hr/day · 260 day/yr] + [52 week/yr · 48 hr] = 6,656 hr). Thus, the annual emissions during downtime are 27gallons per year and the annual emissions during operation mode are 13 gallons per year. Adding the two, the annual emissions are about 40 gallons of TCE. Table 12 presents the details of this calculation.

Table 12: In-line Belt Cleaner Emissions Estimates					
Machine Mode	**Emissions Factor**	**SAI (ft^2)**	**Perimeter (ft)**	**Emissions (gal)**	**Formula**
	a	**b**	**c**	**d**	
Operation Mode	0.02 lb/hr/ft^2	8		27	$\frac{a \cdot b \cdot 2{,}080\text{hr}}{12.2\frac{\text{lb TCE}}{\text{gal}}} = d$
Downtime	0.002 lb/hr/ft		12	13	$\frac{a \cdot c \cdot 6{,}656\text{hr}}{12.2\frac{\text{lb TCE}}{\text{gal}}} = d$
Total Emissions				**40**	

The machine is operated for eight hours per day and it is cleaning oil from parts for stamping. The degreaser cleans four or five loads of parts per hour and, since the oil loading is heavy, the boil sump needs to be changed out every month. Since the boil sump contains 35 gallons, the waste that is generated amounts to 420 gallons per year.

The solvent use in the machine is the sum of the emissions and the waste solvent. This operation uses 460 gallons of solvent per year. The price of TCE is $24 per gallon so the cost of solvent replacement is $11,040 annually.

For the labor, one worker spends eight hours per day operating the machine. Assuming the schedule is five days per week and fifty-two weeks per year and using the loaded labor rate of $20 per hour, the labor cost is $41,600.

The electrical load on the machine is estimated to be 18 to 20 kW. Assuming it is 19 kW and taking into account the equipment is operated for eight hours per day, the electrical requirement is 39,520 kWh. At a cost of 12 cents per kWh, the total electricity cost is $4,742 annually.

The waste solvent generated from the operation is 420 gallons per year. Assuming a 30% solids loading, the cost of disposing of the solids, at a price of $1.10 per pound and a density of eight pounds per gallon, is $1,584 per year (see Equation (10)). Some 7.64 drums of liquid waste must be disposed of each year. At a price of $362.50 per drum, the disposal cost is $2,768 annually ((420gal · (55gal/drum) · ($362.5/drum) = $2,768). The total cost of disposal is $4,352 per year.

$$\begin{matrix}\text{Disposal}\\\text{Costs}\\\text{Solids}\end{matrix}\ \$ = \left(\frac{\begin{matrix}\text{Hazardous}\\\text{Waste}\end{matrix}\text{gal}}{\left(100\% - \begin{matrix}\text{Oil}\\\text{Contamination}\\\text{Level}\end{matrix}\%\right)} - \begin{matrix}\text{Hazardous}\\\text{Waste}\end{matrix}\text{gal}\right) \cdot \left(\begin{matrix}\text{Oil and Solids}\\\text{Density}\end{matrix}\frac{\text{lb}}{\text{gal}}\right) \cdot \left(\begin{matrix}\text{Solids}\\\text{Disposal}\\\text{Cost}\end{matrix}\frac{\$}{\text{lb}}\right) \rightarrow \tag{10}$$

$$\left(\frac{420\text{ gal}}{(100\% - 30\%)} - 420\text{ gal}\right) \cdot \left(8\frac{\text{lb}}{\text{gal}}\right) \cdot \left(\frac{\$1.10}{\text{lb}}\right) = \$1{,}584$$

Converting to PERC

If the user converted to PERC, there would be changes to the equipment. The heat would have to be increased to accommodate the higher boiling point of PERC but this would just involve operating the degreaser at a higher temperature. In addition, a refrigerated freeboard chiller would have to be added at an estimated cost of $25,000.

In this machine, PERC emissions are likely to be about 10% lower than TCE emissions. Instead of 40 gallons of emissions for TCE, PERC emissions would amount to 36 gallons per year (see Equations (3) and (6) for details on this calculation). Assuming a price for PERC of $29 per gallon, the cost of emissions replacement would be $1,044 annually. The generation of waste, in the case of PERC, would be the same as for TCE. Thus, 420 gallons of solvent at a total cost of $12,180 would be required when the tanks are changed out. The total solvent purchase cost is $13,224 per year.

The amount of waste generated and the cost for shipping it off-site would not change in this case study. The labor required to operate the degreaser would also remain the same. Even with the addition of the refrigerated chiller capacity, the kW of the machine would remain the same. Since the machine operating hours do not change, the electricity cost does not change for this conversion.

Converting to nPB

Because nPB and TCE have similar boiling points and vapor pressures, the machine would not require alterations for use with nPB. Emissions of nPB would be higher than emissions of TCE in this machine by about 10% so the emissions level would be 44 gallons per year (see Equations (3) and (6) for details on this calculation). Replacing the solvent in the tank for waste disposal would remain the same, at 420 gallons per year. The nPB use would amount to 464 gallons per year. Assuming the price for nPB of $47 per gallon, the cost of purchasing solvent would be $21,808 annually.

In the case of nPB, the electricity cost, the waste disposal cost and the labor cost would all remain the same as for the baseline case with TCE.

Converting to Fluorinated Solvents

In this case, the system would not require modification to change the heat input. It would require modification to add refrigeration capability. The cost of the additional refrigeration would be the same as for PERC.

Emissions from the machine for the fluorinated solvents would be higher by 20% because of their low boiling points and high vapor pressure. Assuming an increase of 20%, emissions of Vertrel would be 48 gallons per year instead of 40 gallons for TCE (see Equations (3) and (6) for details on this calculation). The waste generation would remain the same and changing out the tank would require replacement of 420 gallons per year. The total solvent purchase would be 468 gallons per year. Assuming a price for Vertrel of $218 per gallon, the cost of purchasing solvent would be $102,024 per year. Again, the Sion solvent could be used and the cost would be half the cost of the Vertrel.

For this case, there would be no change in electricity cost, waste disposal cost or labor.

Converting to Water-Based Cleaning

The parts that require cleaning are screw machine parts. If these parts have blind holes or crevices or are intricately designed, a water-based cleaning system wash bath would need ultrasonics to clean the parts adequately. The vapor degreaser has two tanks and an equivalent system for water cleaning would have a wash bath that holds about 60 gallons of cleaner. The system would include a wash, rinse and dry and it would have both ultrasonics and agilift agitation. The rinse would be recirculating and the dryer would run on hot air.

A Ramco system like the one described above would cost about $80,000 and adding the recirculating rinse would increase the cost to $12,000. The total price of the system would be $92,000.

The water-based cleaner used in the system could be a Brulin 3887 which has a price of $20 per gallon. A 10% concentration of the cleaner would be used in the cleaning bath. The cleaning bath would have to be changed out about every month or 12 times per year. On this basis, the use of the cleaner would be six gallons per month or 72 gallons per year. At a price of $20, the cost of the cleaner is $1,440 annually (see Equation (11)).

$$\begin{matrix}\text{Cost of}\\ \text{Water-based}\\ \text{Cleaner}\end{matrix}\ \$ = \left(\begin{matrix}\text{Wash Bath}\\ \text{Volume}\end{matrix}\ \text{gal}\right)\cdot\left(\begin{matrix}\text{Changeout}\\ \text{Rate}\end{matrix}\ \frac{\text{times}}{\text{yr}}\right)\cdot\left(\begin{matrix}\text{Cleaner}\\ \text{Concentration}\end{matrix}\ \%\right)\cdot\left(\begin{matrix}\text{Cost of}\\ \text{Cleaner}\end{matrix}\ \frac{\$}{\text{gal}}\right)\rightarrow$$

$$(60\ \text{gal})\cdot\left(12\ \frac{\text{times}}{\text{yr}}\right)\cdot(10\%)\cdot\left(\frac{\$20}{\text{gal}}\right) = \$1{,}440 \qquad (11)$$

Like the solvent system, the water cleaning system would operate eight hours per day to clean the parts. One worker would spend the eight hours loading and unloading the parts and operating the machine. Assuming a labor rate of $20 per hour, the labor cost is $41,600 annually.

The electrical load on the machine amounts to 21 kW. Assuming again it operates eight hours per day, the electricity requirement is 43,680 kWh per year. At a price for electricity of 12 cents per kWh, the electricity cost would be $5,242 per year.

The waste cleaner would be shipped offsite as waste at a cost of $2 per gallon. The bath contains 60 gallons and, since it is changed out twelve times per year, 720 gallons of waste are generated each year. The annual cost of disposal for this waste is $1,440 (see Equation(12)).

$$\begin{matrix}\text{Disposal Cost}\\ \text{Water-based}\\ \text{Cleaner}\end{matrix}\ \$ = \left(\begin{matrix}\text{Wash Bath}\\ \text{Volume}\end{matrix}\ \text{gal}\right)\cdot\left(\begin{matrix}\text{Changeout}\\ \text{Rate}\end{matrix}\ \frac{\text{times}}{\text{yr}}\right)\cdot\left(\begin{matrix}\text{Disposal}\\ \text{Cost}\end{matrix}\ \frac{\$}{\text{gal}}\right)\rightarrow$$

$$(60\ \text{gal})\cdot\left(12\ \frac{\text{times}}{\text{yr}}\right)\cdot\left(\frac{\$2}{\text{gal}}\right) = \$1{,}440 \qquad (12)$$

The recirculating rinse consists of carbon and a cationic and an anionic bed and they need to be changed out periodically. In this case, they would likely need changeout every quarter at a cost of $750. The annual cost of changing out the beds would be $3,000.

Summary of Costs for Batch Enclosed System

Table 13 summarizes the options for the batch enclosed system. All 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 cost of using TCE in the existing cleaning system is the lowest cost option. Purchasing a new water-based cleaning system and using a water-based cleaner is the next lowest cost option; it is comparable in cost to continuing to use TCE. The values in the table do not include any costs of recordkeeping and reporting which would also be necessary for TCE and some of the other solvents. If these costs were included, the cost of using a new water system would be lower than the cost of continuing to use TCE. Modifying the equipment to add chiller capacity for PERC is the next lowest option. Using nPB is more costly than converting to PERC even though chiller capacity has to be added to use PERC. This is because of the higher cost of nPB and the slightly higher emissions of nPB. The highest cost option is to use fluorinated solvents. The major reason is the relatively high cost of the solvent. It's worth noting here that, even if the user converted to the new Sion solvent which is half the price of the other fluorinated solvents, it would still be a much higher cost option than the other options. When annualized over a period of 20 years, the cost of purchasing a new water-based cleaning system and using a water-based cleaner becomes the lowest cost option. The cost of using TCE in the existing cleaning system is the next lowest cost option. The highest cost option remains using fluorinated solvents because of the solvent's high cost.

Table 13: Annual Cost Comparison for TCE Baseline and Alternatives for Batch Enclosed System

Cleaning Agent	Equipment	Cleaner	Electricity	Labor	Disposal	D.I. Water
TCE Baseline	-	$11,040	$4,742	$41,600	$4,352	-
PERC	$25,000	$13,224	$4,742	$41,600	$4,352	-
nPB	-	$21,808	$4,742	$41,600	$4,352	-
Fluorinated	$25,000	$102,024	$4,742	$41,600	$4,352	-
Water-Based	$80,000	$1,440	$5,242	$41,600	$1,440	$3,000

Cost Summaries

Cleaning Agent	1st Yr.	Recurring	3% Annualized over 10 years	3% Annualized over 20 years
TCE Baseline	$61,734	$61,734	$55,256	$57,846
PERC	$88,918	$63,918	$59,834	$61,467
nPB	$72,502	$72,502	$64,894	$67,936
Fluorinated	$177,718	$152,718	$139,317	$144,674
Water-Based	$132,722	$52,722	$55,584	$54,440

4. Characteristics Determining Substitution Choices

There are three important characteristics for the enclosed and conveyorized systems that would determine the substitution choices. The first consideration is the cost of existing equipment. The vacuum systems are very expensive so firms would be inclined to keep using their systems no matter how old they are. Conveyorized systems are also relatively expensive when compared with simple open top vapor degreasers so users would tend to want to keep using them as well. This would not be as firm for companies using the very old conveyorized ferris wheel and other systems that are no longer sold except in cases where they are specified new customized systems. If the machines are that old, users might be willing to convert to a not-in-kind process. In general, however, users of vacuum systems and conveyorized systems would be less likely than users of simple vapor degreasers to convert to water cleaning systems or other not-in-kind systems that would require a whole new piece of equipment.

The second characteristic is whether or not the firm has a significant concern about toxicity. The alternatives that are considered to be toxic include PERC and nPB and some firms would not convert to these solvents on principle. In the case of open top vapor degreasers, particularly older vapor degreasers, the exposure to the workers using PERC or nPB would be much higher than for newer conveyorized degreasers or vacuum systems. Some firms using conveyorized or vacuum systems might reason that, because exposure is minimized in their systems, it would be more acceptable to convert to PERC or nPB than if they had an open top unit. Apparently, there are some new DoD and FAA restrictions that do not allow firms with contracts to use nPB; this also would act to emphasize the toxicity of alternatives.

The third characteristic is the expense of the alternative. If a firm is using an old emissive open top vapor degreaser, they may not want to use the fluorinated solvents which are much more expensive. To use these solvents and to minimize use, the company would have to spend a significant amount of money to upgrade the emissive degreaser or pay a lot for the increased solvent use. In contrast, companies who have invested in conveyorized and vacuum systems may be willing to invest in upgrading their systems to use the fluorinated solvents.

5. Applications/Firm Characteristics

Substitution of alternatives is always more difficult for small and less well capitalized firms than it is for larger firms because smaller firms are less sophisticated and cannot devote resources to testing alternatives and they are often just preoccupied with making payroll. In the case of companies vacuum and conveyorized systems, the equipment is expensive and the workers operating it must be more sophisticated. There are probably very few firms in this category that would have difficulty converting to an alternative.

6. Enclosed Systems and EPA PEL

Many firms today are not meeting the PEL or the STEL established by OSHA (100 ppm and 300 ppm respectively). In most, if not all, cases where vacuum systems are used with TCE, firms are probably meeting the OSHA PEL already. This follows from the fact the OSHA PELs are generally established for an eight hour work day. Because exposure for the workers would be so low in vacuum systems over an eight hour period and any exposure would occur only periodically, the OSHA PEL would probably not be exceeded. The STEL could possibly be exceeded. Depending on what EPA choses as a lower PEL, the firms using vacuum systems might already be capable of meeting it. In this case, where exposure is more periodic than it is continuous, a lower STEL would probably be more effective. In either case, if this strategy were adopted, most companies using TCE would simply continue using the solvent.