Alternatives to n-Propyl Bromide in Cleaning Applications

September 2021

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Prepared for: Pollution Prevention Resource Center (PPRC)

Funded by: U.S. Environmental Protection Agency
Under Source Reduction Assistance Grant X9-01J34101

DISCLAIMER

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ACKNOWLEDGMENTS

The Pollution Prevention Resource Center (PPRC) acknowledges Katy Wolf, Ph.D. for the thorough analysis of safer cleaning alternatives presented herein, along with the technical assistance she provided to participating companies in this project, and assisting PPRC disseminate important learnings from this project to technical assistance providers and manufacturers throughout the U.S.

The analysis in this report benefited considerably from the efforts of many persons within and outside PPRC. Katy Wolf, author, and PPRC particularly acknowledge the valuable contributions made by the companies who participated in the project, particularly MAPSCO and Exotic Metals Forming Company.

The author and PPRC are also especially grateful to the water-based cleaning formulator/manufacturing, Brulin, who conducted testing and developed and tested new products, and to the equipment suppliers, particularly CT Technologies and Ramco, who conducted equipment testing.

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EXECUTIVE SUMMARY

The Pollution Prevention Center (PPRC) is a nonprofit organization located in the Seattle area. PPRC works with companies to assist them in adopting safer alternatives in many different types of processes. EPA Region 10 sponsored this project under a Source Reduction Assistance Agreement. As part of that project, PPRC's consultant worked with four companies to assist them in converting to safer alternatives to n-propyl bromide (nPB).

nPB is a carcinogen, it can affect the nervous system and it is a reproductive toxin. It is used extensively in vapor degreasing operations by a range of different companies throughout the country. The PPRC consultant worked with four companies in the Seattle and Portland area to find appropriate alternatives. Three of the companies are aerospace facilities and one is a job shop providing plating and coating services. One of the aerospace companies, MAPSCO, offers non-non-destructive testing (NDT) processing to other companies. Another aerospace company, Exotic Metals Forming, makes ducting of all types for aerospace and industrial applications. The other aerospace company, Anonymous Tube Manufacturer or ATM, makes small diameter tubing for transferring liquids and gases in aircraft. The plater also wanted to remain anonymous and is referred to as Anonymous Plating Company or APC.

There are many potential alternatives to nPB in vapor degreasing operations. Their advantages and disadvantages are discussed in Section 2. Table E-1 provides a brief summary of these alternatives including the issues that arise during their use and a rating by the consultant of their acceptability. As the table indicates, many of the solvent alternatives pose health and environmental problems and they may be regulated in the future. In some cases, they are also very expensive to implement or may not be as effective as needed in the process. Such alternatives are not likely to be a permanent solution for companies. The best and most viable alternatives are listed in the table and they include soy-based cleaners, water-based cleaners and non-chemical methods. These options are likely to be a permanent solution for the companies who adopt them.

Table E- 1
Characteristics of Potential Alternatives to nPB in Vapor Degreasing

Potential Alternatives	Issues	Rating
Chlorinated solvents, fluorinated solvents, other solvents	Toxicity, global warming, expensive solvents, expensive equipment, less effective cleaning	Probably not a permanent solution
Soy-based cleaners, water-based cleaners, non-chemical methods	Good health and environmental characteristics, lower cost	Likely to be a permanent solution

The consultant worked with the companies participating in the project to find the most suitable alternative for their process. MAPSCO converted to a water-based cleaner and the company purchased a used immersion agitation system. Exotic Metals Forming converted to a water-based cleaner used in an existing immersion agitation system the company had on-site. The other two companies did not convert to the most viable alternative system within the timeframe of the project. The consultant tested alternatives with both companies and water-based cleaners were determined to be the best alternatives.

The consultant helped the companies obtain quotes on alternative systems and a spray cabinet is the best option for the tube manufacturer and an ultrasonic system is the best option for the plating company.

The consultant conducted a cost analysis and comparison for the vapor degreasing and the water cleaning process in all four cases. Table E-2 summarizes the results. As the values indicate, in three cases the companies reduced or would reduce the cost of using the water cleaning alternative significantly. In one case, the company would increase their cost through the conversion.

Table E- 2
Summary of Annualized Costs for Participating Companies

Company	Vapor Degreasing Process	Water-Based Cleaning Process (10 Year System Life)	Water-Based Cleaning Process (20 Year System Life)
MAPSCO	$67,415	$49,768	$46,417
Exotic Metals Forming Company	$188,615	$35,741	$34,991
APC (plating company)	$54,814	$29,183	$27,870
ATM (tube manufacturer)	$13,929	$18,556	$15,443

One participating company, the ducting manufacturer, also converted another related process that would affect the cleaning during the project. In this operation, the company converted from an nPB anti-spatter to a water-based anti-spatter formulation used in a laser cutting operation. Table E-3 summarizes the cost comparison for the conversion. As the figures show, the company reduced their costs substantially.

Table E-3
Annual Cost Comparison for nPB and Water-Based Anti-Spatter for Exotic Metals Forming

Cost Element	nPB Anti-Spatter	Water-Based Anti-Spatter
Total	$95,885	$28,052

In addition to the four companies participating in the project, the consultant worked with a company in another project that used nPB in a vapor degreasing process for precision cleaning of optical components. The best option for this company is a soy-based cleaning process. The examples of five different companies represent the wide range of different cleaning challenges where safer alternatives are technically viable and cost effective. Companies using solvents other than nPB in vapor degreasing with similar processes could also convert to safer alternatives.

1.0 INTRODUCTION AND BACKGROUND

n-Propyl bromide (nPB), also known as 1-bromopropane, is a solvent that has been used extensively in a variety of applications for many years. It is used widely across the country by companies manufacturing and assembling products of all kinds in vapor degreasing, cold cleaning, aerosol cleaning, handwipe cleaning, adhesive formulations and adhesive removers. The largest use for the chemical is vapor degreasing, a cleaning application used in aerospace, industrial, precision and electronic component processes.

nPB causes cancer in laboratory animals. Animals exposed to air and drinking water containing nPB were found to have increases in lung, intestine and skin cancers. One agency, the National Toxicology Program (NTP) states that nPB is "reasonable anticipated to be a human carcinogen." nPB can harm the nervous system with short- and long-term exposures. Workers exposed to the chemical on the job have experienced long-term adverse effects on the brain and peripheral nervous system. nPB also harms the reproductive system in male and female animals. nPB is listed on California's Proposition 65 as known to cause cancer, and reproductive and developmental toxicity. More information on nPB and the precautions for using it are available in this Hazard Alert prepared by the Hazard Evaluation System & Information Service (HESIS) in California.

EPA has accepted petitions to add nPB to the Hazardous Air Pollutants (HAP) list developed by the agency under the Clean Air Act Amendments but EPA has not yet acted. EPA is currently evaluating the chemical under the Toxic Substances Control Act (TSCA) Amendments adopted by Congress in 2016. It is one of the first ten priority chemicals listed by the agency. Under the amendments, EPA is charged with evaluating the risk posed by the chemicals and adopting regulations for those applications where the priority chemicals pose an unreasonable risk. EPA has completed the Risk Evaluation for 1-Bromopropane (aka nBP) and has found that nearly all of the applications, including vapor degreasing, pose an unreasonable risk.

In California, the Cal/OSHA (Division of Occupational Health and Safety) has established a five ppm exposure limit for nPB in the workplace. Other regulatory agencies, including the South Coast Air Quality Management District (SCAQMD) in southern California, also have regulations that affect nPB. SCAQMD adopted regulations that restrict the volatile organic compound (VOC) content of chemicals used in open-top vapor degreasers, cold cleaning and handwipe applications. Since nPB is classified as a VOC, and, with certain exemptions, it cannot be used in these applications.

This project was sponsored by U.S. EPA Region 10 under a Source Reduction Assistance agreement and was conducted by the Pollution Prevention Resource Center (PPRC), a nonprofit organization in Seattle, Washington. PPRC worked with a consultant (consultant) experienced in assisting companies in converting away from toxic solvents to safer alternatives. During the project, the consultant worked with four companies in the Pacific Northwest who were using nPB in vapor degreasing processes. One of the companies was also using the chemical in an anti-spatter formulation. In all four cases, the consultant worked with the companies to find and test safer alternatives. In two cases, the companies adopted alternatives and in two cases, although all the testing was completed, the companies did not make the conversion within the timeframe of the project.

This document first discusses in Section 2 the vapor degreasing process and summarizes the categories of alternatives to nPB in degreasing applications and discusses the advantages and disadvantages of several specific alternatives. Many of the alternatives are also regulated by various entities or are likely to be regulated in the future. Section 3 of the document discusses another application of nPB the consultant encountered when working with one of the companies during the project. It involves an anti-spatter process that required an alternative as part of the vapor degreasing conversion. Section 4 presents information on the cost analysis and comparison methods used by the consultant for the degreasing alternative processes. Section 5 summarizes the work the consultant conducted with four candidate companies using vapor degreasers that participated in the project. The nPB processes the companies used and the alternatives they adopted are presented and discussed in case studies. These case studies include a cost analysis and comparison for each company for using the nPB vapor degreaser and using the alternative process. Section 6 briefly describes one additional company the consultant worked with in another project. Finally, Section 7 of the document summarizes the results of the project.

2.0 POTENTIAL ALTERNATIVES TO n-PROPYL BROMIDE IN VAPOR DEGREASING APPLICATIONS

This section first provides a discussion of the historical record of solvent use based on regulations that were adopted at the federal level. It then focuses on a list of the potential alternatives to nPB in cleaning applications. It describes the conditions for using the alternatives based on their characteristics and the regulatory restrictions.

2.1 Historical Solvent Use

Vapor degreasing began to be used after World War II. The solvent that was first used was trichloroethylene (TCE). Some years later, two other solvents, perchloroethylene (PERC) and methylene chloride (MC), began to be used. All three of these chlorinated solvents are carcinogens and they pose other health and environmental effects as well. As more evidence for their toxicity emerged, government agencies began to develop regulations on the three solvents. nPB, a brominated solvent, entered the market in the 1990s and, since little was known about its health effects at the time, it began replacing the other solvents.

Figure 2-1 shows a simple schematic of a vapor degreaser. In vapor degreasing, solvents are heated to their boiling point in a stainless steel tank. It contains a heater and one or more sets of cooling coils around the top of the tank. Solvent is placed in the tank and heated to its boiling point. The heated liquid solvent forms a vapor zone above the liquid level where the solvent is evaporating from the surface of the bath. The cooling coils at the top of the vapor zone cool the solvent and cause it to continuously condense back into the liquid bath below. The vapors would exit the degreaser if not for the cooling coils which act to hold the solvent in the vapor degreaser.

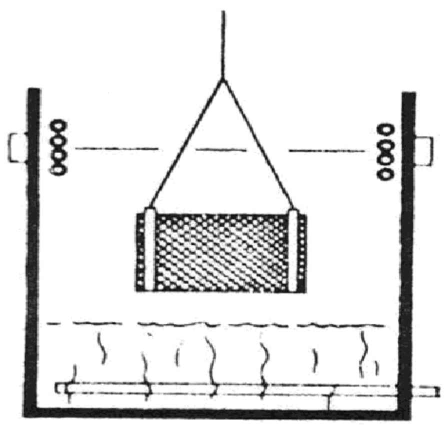

Figure 2-1. Simple Schematic of a Vapor Degreaser

Solvents that have flash points cannot be used in open-top vapor degreasers. Such solvents, when heated, would reach their flash point before they reached their boiling point. If there is a source of ignition, the solvent could cause a fire or an explosion in the degreaser which is open to the atmosphere. The solvents without flash points are generally halogenated solvents. Halogens like chlorine, bromine and fluorine tend to suppress flammability and many halogenated solvents have no flash point. All four of the solvents most commonly used in open-top vapor degreasers, TCE, PERC, MC and nPB, have no flash point.

In 1990, EPA adopted the [Clean Air Act Amendments] which established a list of chemicals that were considered hazardous and were added to the Hazardous Air Pollutant (HAP) list. The amendments charged EPA with developing National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations for HAP listed chemicals.

One of the first regulations, finalized in 1994, was the Halogenated Solvents Cleaning NESHAP. This NESHAP regulation covered vapor degreasing and cold cleaning applications that used several solvents including TCE, PERC, MC, 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. Chloroform and CT were not really used for vapor degreasing or cold cleaning at that time and EPA included them in the regulation simply for completeness. The regulation also specified certain recordkeeping and reporting requirements. EPA revised the NESHAP in 2008 primarily to exempt certain types of operations from the regulation[1].

In 1997, the Montreal Protocol, an international agreement, was adopted worldwide and EPA developed regulations implementing it in the U.S.[2]. It called for a ban on the production of certain stratospheric ozone depleting substances (ODS) that went into effect in 1996. The production ban applied to the chlorofluorocarbons (CFCs). One of the CFCs, CFC-113, was used extensively as a solvent in vapor degreasing and it was included in the production ban. Two other solvents, CT and TCA, also cause depletion of the ozone layer and they were included in the ban as well.

Around the same time, suppliers began offering alternatives to the chlorinated solvents and CFC-113 because they perceived that the NESHAP regulation and the ozone depleting substance ban would create a very large demand. One of the solvents that was introduced to the market at that time was nPB. 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 regulation's equipment requirements and their production needs were high enough so they could not meet the overall loss rate. Some companies, at that stage, converted to alternatives in their existing equipment that were not covered by the NESHAP regulation. Some eliminated their degreasers and purchased other equipment for use with alternatives and some companies upgraded their degreasers to comply with the standards and continued to use one of the NESHAP regulated solvents.

nPB was not included in the original NESHAP because it had not yet entered the market and was not one of the chemicals for which production was banned in the ODS regulation. Many companies in the country converted to the solvent so they would not have to purchase new equipment to comply with the NESHAP. Some of the vapor degreasers in use at the time were extremely old and they did not have features that would offer adequate protection to workers using them or to people in the surrounding communities. Still other users converted to nPB when the ODS were phased out during the late 1990s, and in the early 2000s when TCA in particular was no longer available. Over the next several years, other alternatives entered the market and some of these posed problems of their own and were also eventually regulated. The hydrochlorofluorocarbons (HCFCs), for example, contributed to ozone depletion but not as strongly as those first regulated. Production of the HCFCs was also phased out later.

nPB was considered by many companies to be the best alternative from a technical point of view. It was not yet on any toxics lists, it could be used in the same equipment as the NESHAP listed and ozone depleting solvents, and it was a good cleaner. As the NESHAP listed solvents were increasingly regulated at the federal and state levels, many users were encouraged by government agencies and one university pollution prevention provider to convert to nPB.

[1] U.S. EPA. Halogenated Solvent Cleaning: NESHAP.

[2] U.S. EPA. International Actions – The Montreal Protocol on Substances that Deplete the Ozone Layer

2.2 Alternative Cleaning Categories and Methods

The EPA NESHAP regulation and the ODS ban created a substantial market for alternatives. These actions provided encouragement to chemical and equipment manufacturers and suppliers to work intensively on methods of using and implementing alternatives to HAP listed and ozone depleting solvents. In 2011, a report from the National Toxicology Program (NTP) detailed a chronic toxicity study for nPB; it found that the chemical caused cancer in laboratory animals.

California began to regulate nPB more heavily and California is often considered a leader in toxic chemical policies. nPB was listed on California's Proposition 65 as both a carcinogen and a reproductive and developmental toxin. It was also more stringently regulated by Cal/OSHA's Permissable Exposure Limits for Chemical Contaminants, and added to the state's Toxic Air Contaminants (TAC) list.

nPB was designated as one of the first ten priority TSCA listed chemicals by EPA as part of the amendments to TSCA enacted in 2016. There is increasing awareness in the user community that nPB is a very toxic chemical.

The potential alternatives to nPB in cleaning applications are summarized and discussed in what follows.

- Drop-in Vapor Degreasing Alternatives—Chlorinated Solvents
    - Perchloroethylene (PERC)
    - Trichloroethylene (TCE)
    - Methylene chloride (MC)
- Non-Drop-in Vapor Degreasing Alternatives—Fluorinated Solvents
    - Hydrofluorocarbons (HFCs)
        - HFC-43-10 and blends
        - Various other HFCs and blends
    - Hydrofluoroethers (HFEs)
        - HFE-7100 and HFE-7200 and blends
    - Hydrofluoroolefins
        - HFO-1233zd
- Other Solvents—Vapor Degreasing and Cold Cleaning
    - Oxygenated solvents
    - Hydrocarbon solvents
    - Terpene Based solvents
    - Parachlorobenzotrifluoride (PCBTF)
    - Volatile Methyl Siloxane (VMS)
- Soy-Based Cleaners
- Water-Based Cleaners
- Alternative Cleaning Methods—Non-Chemical Alternatives

Each of the alternative classes and the specific alternatives are discussed in more detail below.

2.2.1 Drop-In Alternatives: Chlorinated Solvents

In principle, the three chlorinated solvents are drop-in alternatives and can be used in the same piece of equipment users already have and are using with nPB. In practice, however, since the chlorinated solvents do have different physical properties, modifications to the existing degreasers could be necessary to use them optimally but this is not necessarily required. In addition, the three solvents and nPB have somewhat different material compatibilities and some of them might not be suitable for cleaning parts made of certain materials. The other three solvents are also more stable to hydrolysis than nPB so that does offer a technical advantage. This means that if water gets into the vapor degreaser, the solvent can form acid which can be corrosive and could potentially cause a serious accident that would expose workers.

The main argument against using any of these alternative solvents, however, is that they are even more heavily regulated than nPB. As discussed earlier, all three are carcinogens. They are on the EPA HAP list, California's Proposition 65 list and California's TAC list. All three of these alternatives are also included on the list of the first 10 priority TSCA listed chemicals. TCE is classified as a VOC and is regulated for that reason in California and some other locations in the U.S. Certain states, including Minnesota and New York, have also recently adopted regulations on TCE. Minnesota enacted a ban May 16, 2020. New York's restrictions on TCE are set to take effect in December 2022.

2.2.2 Non-Drop-In Alternatives: Fluorinated Solvents

This category includes HFC blends, HFE blends and HFOs; all three of these types of solvents contain fluorine and they do not have flash points. These alternatives could, in principle, be used in the open top vapor degreasing equipment currently used for nPB. The HFE and HFC solvents are very poor cleaners, however, and would not be suitable alone in most applications.

As a consequence, these fluorinated solvents are nearly always combined with another more aggressive solvent, 1,2-trans-dichloroethylene (DCE), to increase their cleaning capability. DCE has a flash point so it cannot be used alone in an open-top vapor degreaser. The fluorinated solvents, when combined with DCE, suppress its flash point and the combination can clean more effectively since DCE is a relatively aggressive solvent. The HFO is a somewhat more aggressive solvent and can be used alone for certain types of processes.

The fluorinated solvents have high vapor pressures and low boiling points so they evaporate readily and are also extremely expensive. 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. Enclosed equipment like airless/airtight ("tight") or vacuum degreasers should be used with these vapor degreasing solvents with the exception of the HFO. Such equipment is very expensive and would cost at least $100,000 for a very small system. For typically sized parts, the cost of these systems can range from $400,000 to $1 million. This is much more expensive than more traditional open-top vapor degreasers. The HFO is generally not used in a vacuum system but is used in special tight open-top equipment designed specifically for use with the solvent. This specialized equipment is also relatively expensive.

The HFCs and HFEs contain no chlorine so they do not contribute to ozone depletion. Since they do contain fluorine, they are relatively stable and they do contribute to global warming. The HFCs have higher global warming potential than the HFEs, and EPA is moving forward to phase them out[3]. The HFEs are also likely to be regulated eventually when general global warming regulations are adopted. The HFO does not contribute to global warming but is likely to be cardiotoxic. The HFCs, HFEs and HFOs are exempt from VOC regulation and they are not considered VOCs.

DCE has not been tested in two-year animal tests but it is structurally similar to PERC, TCE and vinyl chloride, all of which are carcinogens. In addition, DCE is on the second list of 20 priority listed chemicals defined by EPA under the TSCA amendments and it could be regulated in the future. DCE is also classified as a VOC so it is regulated for this reason in some U.S. locations.

2.2.3 Other Solvent Vapor Degreasing and Cold Cleaning

A range of different solvents, including hydrocarbons, alcohols, acetone and glycol ethers, can be used for vapor degreasing, but only in a vacuum system. These solvents all have flash points so they can ignite if oxygen is present when heated to their boiling point if a source of ignition is present. The equipment for use with the solvents must be operated in a vacuum. Again, these systems are expensive and the cost for typically sized parts can range from $400,000 to $1 million. The cost of the equipment is the major deterrent to using these alternatives. In extremely limited cases, where solvents must be used, this may be the best alternative option, however, since some of these solvents are low in toxicity. Exposure to workers and the community would be low in these cases as well since emissions from the equipment are minimal because of the vacuum.

Many of these solvents could also be used in batch-loaded cold cleaning equipment that is not heated. Most operations currently using nPB in vapor degreasing could not achieve adequate cleaning in a cold cleaning operation, however. Applicability of cold cleaning as an alternative is therefore quite limited, although in certain cases, cold cleaning might preform adequately. With the exception of acetone, PCBTF and VMS, the solvents listed above are all classified as VOCs. Acetone could be used in a batch loaded cold cleaner but its flash point is very low so only a very small unit would be safe to use. The other solvents in this category like terpenes, PCBTF and VMS would also generally be used in cold cleaning equipment.

Some of the other solvents have toxicity problems so they would not be good choices as alternatives in either a vapor degreasing or cold cleaning process. Certain alcohols and glycol ethers are toxic and many hydrocarbon solvents contain aromatic components like benzene, toluene and xylene, all of which are toxic. PCBTF and the major VMS (called D5) are both carcinogens. PCBTF has been added to California's Proposition 65 list.

2.2.4 Soy-Based Cleaners

These cleaners are composed of methyl esters. They have extremely low vapor pressure and do not evaporate readily. The solvents have very high flash points so they can be heated to temperatures below their flash points which allows them to clean more aggressively. They are very effective in cleaning certain types of contaminants like adhesives, adhesive residues, pitch, wax and certain oils.

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[3] Proposed Rule - Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program under the AIM Act

Soy-based cleaners, because of their very low vapor pressure, will leave a residue on the parts. This is generally unacceptable to companies with the types of processes that currently rely on nPB vapor degreasers. The soy-based cleaners can be rinsed from the parts either with plain deionized or tap water if the soy products contain high levels of surfactants, or with a water-based cleaner if they do not contain surfactants.

2.2.5 Water-Based Cleaners

Water-based cleaners are the best alternatives to nPB used in a vapor degreaser. These cleaners are very versatile and many companies supply a variety of water-based cleaners appropriate for different types of cleaning processes.

Water-based cleaners are supplied in concentrate form and they are diluted, generally to between 5 and 20%, depending on the application. They must be heated in the range of 120 to 180 degrees F, again depending on the process, to be effective. The cleaners are composed of surfactants or soaps, rust inhibitors and many other components suitable for certain applications. The cleaners will leave a residue if they are not rinsed off with deionized or tap water and, in many processes, the parts may need to be dried as well. Water-based cleaners rely more on mechanical agitation than do solvents so many different types of equipment are available and are process specific. Given the proper equipment, concentration and temperature for a specific process, they are very aggressive cleaners and can remove many different types of contaminants.

2.2.6 Alternative Cleaning Methods: Non-Chemical Methods

Non-chemical methods may be appropriate for certain types of operations. One example is blasting using various abrasive media. Blasting media can be used for cleaning heavily contaminated parts brought in from the field by companies refurbishing them. Another example is application of high heat or cold temperatures, if the contaminant is sensitive to these conditions. For example, some adhesives or adhesive residues can be removed with heat or cold. A third example, for companies that assemble printed circuit boards, is converting to a no-clean flux which does not require cleaning at all. Whether these methods are useful is very process dependent.

2.3 Summary of Alternatives

Table 2-1 shows the general categories of alternatives to nPB in the different cleaning applications where the chemical is used. It also identifies specific alternatives in the general categories and describes their advantages and disadvantages. Alternatives that are appropriate in a given situation can be process specific. The section above on historical substitution illustrates that continually switching from chemicals when they are regulated to chemicals that may be regulated in the future, requires companies to reevaluate their process every few years. The best alternatives are those that provide a permanent solution and these include water-based cleaners which are the most appropriate alternative for nearly all of the vapor degreasing process that use nPB today. Soy-based cleaners are suitable in certain situations like optical component manufacturing since they are especially good at removing the pitch and wax used in the polishing step. Non-chemical methods can apply if they are appropriate.

Table 2-1 Alternatives to nPB

Category	**Application**	**Alternative**	**Advantages**	**Disadvantages**
Drop-in	Vapor Degreasing	Chlorinated solvents: PERC TCE MC	Can use existing equipment	- All solvents have toxicity concerns - All solvents are heavily regulated
Non-Drop-In	Vapor Degreasing	Fluorinated solvents: HFCs HFEs HFOs Blends	Can continue to use vapor degreasing	- Solvents are extremely expensive - New, expensive airtight equipment required - Some solvents cause global warming - Some solvents may have toxicity concerns - Some solvents may be regulated in the future - Blends regulated as VOCs in some locations
Other Solvents	Vapor Degreasing	Oxygenated solvents Hydrocarbon solvents Terpene based solvents PCBTF VMS	Can continue to use vapor degreasing	- New, expensive airtight equipment required - Solvents have toxicity concerns - Some solvents may be regulated in the future - Some solvents regulated as VOCs in some locations
Other Solvents	Cold Cleaning	Oxygenated solvents Hydrocarbon solvents Terpene based solvents PCBTF VMS	Not as effective as vapor degreasing	- Some solvents have toxicity concerns - Some solvents may be regulated in the future - Some solvents regulated as VOCs in some locations
Soy-Based Cleaners	Aqueous, Heated Below Boiling Point	Methyl esters Surfactants sometimes added	Can be heated for higher efficacy Effective in removing certain contaminants	- Natural product so some can be expensive - Must be rinsed with water or water-based cleaner - May require agitation
Water-Based Cleaners	Aqueous, Heated	Surfactants and other additives	Widely applicable Effective in removing nearly all contaminants	- Some additives may have toxicity or environmental concerns - Requires agitation and/or heat to be effective - Must wash and rinse
Alternative Cleaning Methods	Non-Chemical Alternatives	Blasting/abrasive processes Heat/Cold removal No-clean	Avoids use of chemicals	- Limited applicability

3.0 POTENTIAL ALTERNATIVES TO n-PROPYL BROMIDE IN ANTI-SPATTER APPLICATIONS

One of the companies participating in the project conducted another operation that required an alternative to a solvent based product. They were extensively using an anti-spatter formulation on parts that required cleaning after a laser cutting operation. The anti-spatter was traditionally removed in the nPB vapor degreaser but, when the company converted to a water-based cleaner, they needed to convert to an alternative anti-spatter product to make the cleaning easier and to reduce the disposal costs since the nPB from the anti-spatter would end up in the spent water cleaning bath.

There are two different types of processes that require the use of anti-spatter products and these are discussed below. The commercial alternatives to solvent-borne products are also discussed below. The consultant worked with the company to find an alternative anti-spatter formulation and the specific application and alternatives testing are described in Section 5.

3.1 Anti-Spatter Applications

There are two major applications where anti-spatter products are used. These include welding and cutting and, in both cases, a significant amount of heat is generated during the process. Metal welding processes are still commonly used in many industries like the automotive industry for example. Laser welding has begun replacing metal welding and, in both cases, ending up with a spatter free surface is essential. Hot metal spatter develops during metal and laser welding and, if the surface of the part is not protected, the metal spatter can burn into the sheet metal surface. This reduces the quality visually and in the areas that require assembly. It can also negatively influence corrosion protection. In laser cutting, spatter also develops because of the high heat of the laser. In this case as well, the metal surface must be protected. A variety of different formulations are available for protecting the surfaces. During welding and cutting, the spatter can also build up on work spaces and tools and formulations for protecting these are available as well.

3.2 Anti-Spatter Formulations

Historically, anti-spatter products were based on MC as the carrier solvent. The company participating in this project did not use an MC based formulation; rather they relied on an nPB formulation specifically formulated for their application. Water-based products are becoming more common and available on the marketed. Some of the solvent and water-based products contain soy lecithin and the soy is effective in coating the surface and preventing the spatter from sticking to the parts. The formulations that prevent the spatter from adhering to the metal product surface must be cleaned off after the operation so the formulations must also be easily cleaned. The soy lecithin ingredient is difficult to clean in the alternative water-based products. In the case where anti-spatter formulations are used to protect work surfaces, there is no need to clean and ceramic based products are now available for this purpose and they are not designed to be removed.

There are a variety of water-based anti-spatter formulations on the market. Many contain soy lecithin and are hard to remove in a water cleaning operation. Several of the alternative formulations also contain toxic or otherwise undesirable ingredients. As discussed later in the case study, the participating company tested many commercial formulations but they all had drawbacks and/or didn't perform well. The consultant worked with a water-based cleaner supplier to develop a water-based formulation that is easily cleaned off.

4.0 APPROACH TO COST ANALYSIS

This report includes a cost analysis and comparison for four case studies. In all four cases, water-based cleaners were tested and found to be viable alternatives. Two of the companies participating in the study converted to the alternatives that were analyzed. The two other companies did not convert to the selected alternative within the project timeframe and the costs of using the alternative had to be estimated. The cost of using the vapor degreaser with nPB as the solvent is compared with the cost of using the alternative water-based cleaner in all cases. The cost analysis for the case studies contains two elements. The first element is the capital cost and the second is the operating cost. The approach used in calculating the two types of costs is described in what follows.

4.1 Capital Cost

In three of the case studies, it was assumed that there was no capital cost of using the vapor degreaser with nPB. In these instances, the vapor degreaser was purchased a number of years ago and the cost was fully amortized at the time of the conversion. In contrast, it was assumed that the water cleaning equipment was a capital cost since it was purchased recently and is as part of the cost of conversion.

In calculating the capital cost, two different situations were considered.

- In the first instance, it was assumed that the water cleaning equipment has a life of 10 years. This is a conservative assumption since such equipment generally has a useful life much longer than 10 years when it is properly maintained.
- In the second instance, which is more realistic, it was assumed that the water cleaning equipment has a life of 20 years.

Another assumption was that the cost of capital, the discount rate, was 3%.

For the analysis, the capital cost was annualized and it was added to the annual operating costs to determine the total cost. In the case of the vapor degreaser, there is no capital cost so the sum of the annual operating costs is the total cost of using the nPB vapor degreaser. In the case of the alternative, the sum of the annualized capital cost and the annual operating cost is the total cost of using the water cleaning process.

For one of the case studies where, the company that did not make the conversion to the alternative system, it was assumed that the vapor degreaser, which was quite new, could be sold on the second hand market. In this case, the capital cost of using the water cleaning equipment was reduced by the annualized cost of the used vapor degreaser amortized over the 10 or 20 year life of the water cleaning equipment.

For the anti-spatter conversion, there was no capital equipment involved with use of either the solvent or the water-based anti-spatter

EPA's Guidelines for Preparing Economic Analyses was used as the reference for calculating the annualized capital cost. The equation used is Equation (3) on page 6-3 of the reference. It is:

$$AC = PVC \times \frac{r \times (1 + r)^n}{(1 + r)^n - 1}$$

Where:
AC = annualized cost accrued at the end of *n* periods
PVC =present value of costs
r = discount rate per period
n = duration

For the case studies:
PVC is the capital cost of the water cleaning equipment and related costs,
R is the discount rate of 3%, and
n is the period, which is 10 years in the first scenario, and 20 years in the second scenario

4.2 Operating Costs

The annual operating cost for the vapor degreaser includes several different types of costs. They include:

- Cost of purchasing nPB
- Energy cost to operate the vapor degreaser
- Labor cost of operating the vapor degreaser and changing out the solvent
- Cost of Personal Protective Equipment (PPE)
- Disposal cost for the hazardous waste

The annual operating cost for the water cleaning process has many similar types of costs. They include:

- Cost of purchasing the water-based cleaner
- Cost of filtration
- Energy cost to operate the water cleaning equipment
- Labor cost of operating the water cleaning equipment and changing out the filters and cleaner
- Disposal cost of the spent water cleaner and the rinse water

The annual operating costs for the solvent-based (nPB) anti-spatter operation include:

- Cost of purchasing the nPB anti-spatter formulation
- Application equipment cost
- Labor cost for applying the anti-spatter
- Cost of PPE

The annual operating costs for the water-based anti-spatter operation include:

- Cost of purchasing the water-based anti-spatter formulation
- Application equipment cost
- Labor cost for applying the anti-spatter

4.3 Other Costs

There are other costs that were not included in the cost analysis. In certain parts of the country, there are costs for obtaining a permit for a vapor degreaser or costs for emitting VOCs or toxics from operations. These types of costs were ignored in the analysis because practices in accounting for them differ significantly across the country.

There are other costs that are very difficult to quantify. These include social costs like medical charges for illness or death resulting from exposure to toxic chemicals like nPB. These costs could not be included in the analysis since it is not possible to estimate them. Companies and government agencies should be aware, however, that these costs, if they were included, would raise the cost of using the solvent cleaning and anti-spatter processes relative to the cost of using the alternatives.

5.0 CASE STUDIES

This project involved working with four facilities with different operations who are currently using nPB in vapor degreasing applications. The consultant worked with the four facilities to test and identify safer alternative cleaners, to assist them in obtaining equipment quotes and purchasing and installing it and in implementing the alternative process. The details of the work with each facility are summarized below.

Two of the companies, presented as Case Study 3 and Case Study 4, decided they would not purchase an alternative system at this time. In both instances, however, all of the initial testing was completed and the consultant helped the companies obtain quotes from suppliers for the alternative cleaning systems. The identity of these two companies is kept anonymous in the case studies and it was assumed they would purchase one of the water cleaning systems that was quoted. Accordingly, a cost analysis and comparison were developed for each company. The costs for using the vapor degreaser were directly obtained from the four companies and the capital cost for the water cleaning system was based on the purchased or quoted systems. The operating costs for the water cleaning system were based on the actual operating costs for the companies that converted. For the companies that did not convert, the operating costs were based on the characteristics of the cleaning systems and certain educated assumptions about the operating parameters from the consultant's experience in working with other companies with similar operations.

5.1 Case Study 1: MAPSCO

Valence Surface Technologies, located in Seattle, was founded as MAPSCO in 1981. MAPSCO is a 32,000 square foot facility that offers full service non-destructive testing (NDT), shot peen, aluminum and hard metal chemical processing and painting services. The company processes parts for many aerospace companies including Boeing, Goodrich, Spirit Aerosystems, Northrop Grumman and Raytheon. MAPSCO has two process lines for titanium, steel and aluminum processing for chemfilm and anodizing operations. The company processes more than four million parts per year.

All of the processes at MAPSCO require cleaning, and the company historically used an nPB vapor degreaser for this purpose. Over the last few years, the company has been phasing out vapor degreasing and is using a water-based cleaner on the main chemical processing lines.

MAPSCO wanted to relocate the inspection process to a nearby building which had no cleaning capability. The NDT conducted by MAPSCO is mainly magnetic particle inspection and the company processes parts ranging in size from small washers to five-foot long aircraft parts. The company did not want to move the vapor degreaser to the other building so they began investigating water-based cleaning processes and equipment for the NDT line.

The consultant worked with the company to assist in finding a suitable cleaning system and the company is using the new system for cleaning aluminum and steel. In addition to cleaning for NDT, the company is also using the new system for cleaning parts that go through the masking operations. A picture of the NDT equipment is shown in Figure 5-1.

Figure 5-1. NDT Test Equipment at MAPSCO.

The degreaser the company used historically was large, with a 130-gallon capacity. A picture of the system is shown in Figure 5-2. It processed eight loads of parts per day. The company purchased nPB in drum quantities at a cost of $1,725 per drum. In a previous year, which is representative of MAPSCO's activity, solvent purchases amounted to 13 drums. On this basis, the cost of purchasing solvent in that year was $22,425.

The degreaser was operated 16 hours per day. According to MAPSCO, the degreaser required 85,235 kWh per year. At MAPSCO's electricity rate of nine cents per kWh, the annual energy cost for the degreaser amounted to $7,671. A chiller, which was used for the most part for operating the degreaser was operated for 130 hours per week. In the summer months, about 10% of the chiller capacity was used for the anodizing process. The energy requirement for the chiller is 16 kW. Assuming the summer months represent 12 weeks, the energy use in the winter was 86,320 kWh and the energy use in the summer was 23,305 kWh. The total energy use for the chiller was 109,626 annually. Again, assuming the electricity rate at nine cents per kWh leads to an energy cost for the chiller of $9,866 annually. The total annual energy cost for operating the degreaser and the chiller amounted to $17,537.

Three workers operated the degreaser during the year and they are trained in that operation on the job. The training cost is estimated at $100 per year per employee for a total cost of $300 annually. Two of the operators cleaned out the degreaser and they devoted a total of 12 hours to the job once per year. The workers are paid a rate of $35 per hour. The labor cost for the degreaser changeout amounted to $420 per year. One worker each operated the degreaser for two shifts per day. Each worker spent 10 minutes loading the baskets for cleaning and there were eight baskets cleaned per shift. The time spent loading the baskets was 80 minutes per shift or 2.67 hours per day. Assuming the degreaser operated five days per week and 52 weeks per year, the labor hours for loading the baskets were about 693 hours annually. At the labor rate of $35 per hour, the labor cost for the basket loading amounted to $24,267 per year. The workers also spent about one hour per month adding solvent to the degreaser for a total of 12 hours per year. At the labor rate of $35 per hour, the cost for adding solvent was $420 per year. Summing the contributions from training, changeout, operation and adding solvent, the total cost was $25,407 annually.

Figure 5-2. Vapor Degreaser at MAPSCO.

The workers did not use personal protective equipment (PPE) when operating the degreaser since the system was fully enclosed.

In 2019, the company generated and disposed of seven drums of hazardous waste. The cost of disposal was $207.25 per drum plus the cost of the drum which is $35 each and the cost of transportation which is $50 per drum. The total cost for disposal was about $2,046.

The consultant worked with MAPSCO to identify an alternative water cleaning process that could replace the nPB vapor degreaser. The company successfully purchased a second-hand Ramco system from a company that carries second-hand cleaning systems called Benchmark Machine Tools. The water cleaning system has two cleaning stations, two rinse stages and a heated forced air dryer. Each clean tank includes recirculation and has filtration for solids removal. Baskets of preloaded parts are moved through the process, raised and lowered into each tank and agitated during immersion automatically. Each of the cleaning tanks has a capacity of 180 gallons and each rinse tank has a capacity of 115 gallons. A picture of the system is shown in Figure 5-3.

The cost of the system was $55,000 which included the baskets. The system was located in Arizona and the cost of transporting it to Washington was also included in the cost. MAPSCO upgraded the power to the facility to accommodate the new system. The total cost of the power upgrade was $25,000. Part of the upgrade cost supported the relocation of some other equipment in the plant and MAPSCO indicates that the upgrade cost attributable to the water cleaning equipment is 30% or $7,500.

Figure 5-3. Ramco Water Cleaning System at MAPSCO.

The company had an additional cost of $4,500 for installing power from the new panel to the water cleaning equipment. The total cost of the electrical upgrade for water cleaning amounted to $12,000. This, like the cost of the system, is a one-time capital cost item so the total capital cost of the equipment was $67,000. Assuming a life for the equipment of 10 years, and assuming a discount rate of 3%, the annualized cost of the system amounts to $7,854. Assuming a life for the equipment of 20 years, the annualized cost of the system amounts to $4,503.

The company is using a cleaner called AquaVantage™ GD 815, a water-based cleaner made by Brulin, and approved for many aerospace processes. The company wanted to use the cleaner because they use it elsewhere in other operations. Testing indicated it was an effective cleaner for this application. MAPSCO purchases the cleaner in drum quantities and the cost of the cleaner is $15.29 per gallon. The process uses a 10% concentration of the cleaner in both baths. Since each tank has a capacity of 180 gallons and assuming the tanks need to be changed out every six months, the amount of cleaner required is 72 gallons annually. On this basis, the cost of the cleaner is $1,101 per year. The company also requires cleaner as makeup periodically. The company estimates that this amounts to about 10% of the cleaner used to fill the baths. On this basis, the amount of cleaner required annually for makeup is 7.2 gallons and the annual cost is $110. The total cost of the cleaner amounts to $1,211 annually. The company uses tap water in both of the rinse baths so the cost of using water in the system is negligible. MAPSCO changes out the filters in the system periodically, at an estimated cost of $75 per year.

According to the equipment manual, electrical requirements for the heaters and the turbo/filter equipment total 51.3 kW. The equipment is operated for eight hours per day for one shift. Assuming a five-day week, the total operating hours are 2,080 per year. Using the electricity rate of nine cents per kWh, the cost of the energy for operating the system is $9,605 annually.

One operator is responsible for running the equipment and about 20 loads per day are cleaned in the system. A company representative indicates that the operator spends five minutes loading and five minutes unloading each basket. The operator performs other tasks during the cleaning cycle since the system is automated. Assuming a five-day week and one shift per day, the labor time for operating the system amounts to about 467 hours per year. Using a labor rate of $35 per hour, the annual cost of operating the equipment is $30,345. One technician analyzes the cleaner once a week in the company's internal lab to determine if more concentration is required. A MAPSCO representative estimates the time required for collecting the sample and running the test is 20 minutes. On this basis and assuming the labor rate of $35 per hour, the labor requirement for the testing is $607 annually. Labor is also required to change out the wash baths twice a year. It requires an operator one hour to do the changeout. The labor cost for this activity is $70 per year. The total labor cost for the water cleaning system is $31,023.

The company discharges the rinse water directly to the sewer. The spent cleaning baths are transferred to another adjacent plant which has a discharge permit for a batch treatment system. The bath contains no metals and is put through a simple neutralization before release to the sewer. A MAPSCO representative indicates the incremental cost of disposal is negligible.

Table 5-1 summarizes the cost comparison for the vapor degreaser and the water cleaning system. Note that there is negligible cost for the water since the company can use tap water for the rinse rather than deionized water that is often required where the water quality is poor. There is also no cost for disposal when the water cleaning bath is changed out since the company uses the water treatment system for that purpose. The figures demonstrate that switching to the water cleaning system reduced the annual cost of cleaning by 26% assuming a 10 year equipment life and 31% assuming a 20 year life for the equipment.

Table 5-1
Annualized Cost Comparison for Vapor Degreaser and Water Cleaning System for MAPSCO

Cost Element	Vapor Degreaser	Water Cleaning System (10 Year Life)	Water Cleaning System (20 Year Life)
Equipment	-	$7,854	$4,503
Cleaner	$22,425	$1,211	$1,211
Water	-	-	
Filters	-	$75	$75
Energy	$17,537	$9,605	$9,605
Labor	$25,407	$31,023	$31,023
PPE	-	-	-
Disposal	$2,046	-	-
Total	**$67,415**	**$49,768**	**$46,417**

5.2 Case Study 2: Exotic Metals Forming Company

Exotic Metals Forming Company (Exotic), located in the Seattle area, is a stand-alone division within the Parker Aerospace Group. The company specializes in the design and fabrication of sheet metal assemblies and components for commercial and military aircraft applications. Most of their parts are built with titanium and nickel alloys, which create low weight and high strength assemblies for withstanding high temperature and pressure situations. Exotic manufactures many different types of exhaust ducts, anti-ice systems ducting, engine buildup ducting, flexible duct systems and lavatory and galley system tubes and ducts for commercial and military aircraft applications. The company also provides aircraft services through a business unit within the division. The service involves manufacture and repair of ducting systems made from titanium, stainless steel and high nickel alloys.

The parts assembled to make the ducts are cleaned several times during the manufacturing process. Because of their configuration which includes many flex joints, they are difficult to clean. Pictures of some of the parts manufactured and assembled by Exotic are shown in Figure 5-4. As part of the manufacturing process, the company also relies on a laser cutting operation which requires the use of anti-spatter.

Figure 5-4. Parts Manufactured by Exotic.

5.2.1 Cleaning Cost Comparison for Exotic

Many of the manufacturing steps in Exotic's processing require cleaning and the company historically used an nPB vapor degreaser for this purpose. A picture of the vapor degreaser is shown in Figure 5-5. The degreaser is large, with a 100-gallon capacity. It has an attached still which has a capacity of 50 gallons.

Figure 5-5. Vapor Degreaser with Attached Still at Exotic.

The company purchased twenty 55-gallon drums of nPB per year on average. The cost of the nPB was $1,700 per drum. On this basis, the annual charge for Exotic's nPB amounted to $34,000.

The degreaser was operated 100 hours per week or 5,200 hours per year. The electric load on the degreaser is 36 kW for the heater and the load for the chiller for the cooling coils and refrigeration unit is 11.5 kW. The electric load for the still is 15 kW and the associated refrigeration unit is 2.3 kW. The total electric load for the system amounts to 64.8 kW. The system requires 336,960 kWh per year. The company pays six cents per kWh. On this basis, the energy cost for the degreaser and still is about $20,218 annually.

The company indicates that on-the-job training for the workers who operated the degreaser and still combination amounts to $8,000 per year. There were 11 operators on rotation with one operator loading and unloading parts and operating the degreaser per shift and there are 2.5 shifts per day. These operators were also responsible for changing out the solvent in the vapor degreaser and the still. As described earlier, the degreaser was operated 100 hours per week or 5,200 hours per year. The loaded labor rate for each worker operating the degreaser is $24.21 per hour. On this basis, the annual labor cost was $125,892.

The workers who operated the degreaser used respirators and the annual cost for respirator fit tests was $550. The company also purchased respirators as replacements or for new operators at a cost of $20 per respirator or $240 per year. Cartridges and prefilter costs were $15 each for a total annual cost of $1,800 per year. The cost of respirator medical evaluations amounted to $110 per year. The cost of gloves was $38.39 each for replacements or new operators for a total annual cost of $461 per year. Aprons for replacements or new operators are $3.90 each for a yearly cost of about $47. Summing the elements, the PPE related costs are $3,208 annually.

The company generated twelve 55-gallon drums of hazardous waste each year from the operation. The cost of disposing for the waste is $441.40 per drum which amounts to about $5,297 per year.

The consultant worked with Exotic to identify an alternative water cleaning process that could replace the nPB vapor degreaser. Because the company sells their products internationally, they have a policy to use products with ingredients that are not subject to REACH, which stands for Registration, Evaluation, Authorisation and Restriction of Chemicals. REACH is a regulation of the European Union.

Therefore, any water-based cleaners used by Exotic could not contain REACH listed ingredients. Two cleaners were considered and the company adopted a cleaner called Aquavantage 3887GD after extensive on-site testing.

The company is using a cleaning system they already have on-site and is processing the parts that formerly were cleaned in the nPB vapor degreaser through that system now. The existing system is composed of five stations. The first is a wash tank that contains a total of 727 gallons of the water-based cleaner. It is a 650 gallon immersion tank with large mechanical agitation pumps and it is integrated with another tank with 77 gallons of cleaner with filtration. The next two stations are rinse tanks that each have 650 gallons capacity. The fourth station is an optional pressure wash rinse and this is used for parts with a faying surface to make sure they contain no water cleaner residue. The last station is a forced air dryer. Pictures of the wash tanks and the two rinse tanks are shown in Figures 5-6 and 5-7.

Figure 5-6. Wash Tank at Exotic.

Figure 5-7. Rinse Tanks at Exotic.

The fourth station, the pressure washer, was added to the system to ensure the parts that previously went through the vapor degreaser contained no cleaner residue. The company has been temporarily using a pressure washer and containment that cost about $1,000. A picture of this temporary pressure washer is shown in Figure 5-8. Exotic does plan to upgrade this pressure washer with a much better pressure washer and containment that costs $15,000. Assuming the cost of $15,000 for the system, a discount rate of 3% and a 10 year life for the system, the annualized cost amounts to $1,758. Using the assumption that the system would have a life of 20 years, the annualized cost totals $1,008.

The cost of the AquaVantage cleaner is $975 per drum. The capacity of the wash tank is 727 gallons. The concentration of the cleaner in the wash bath ranges from 10% to 20% with a target concentration of 15%. Assuming the 15% value, the tank requires 109 gallons of cleaner. The tank is changed out periodically when performance declines but the schedule indicates it can be cleaned out every three months. Assuming it is changed out four times a year, the annual cleaner requirement amounts to 436 gallons of cleaner concentrate. Some of the cleaner evaporates during the cleaning and five to ten gallons are added to the tank weekly. Assuming an average of 7.5 gallons, the annual makeup cleaner concentrate requirement is an additional 390 gallons. The total amount of cleaner used each year is 826 gallons. Using the price of $975 per drum and assuming a drum contains 55 gallons, the annual cost of the cleaner is $14,643.

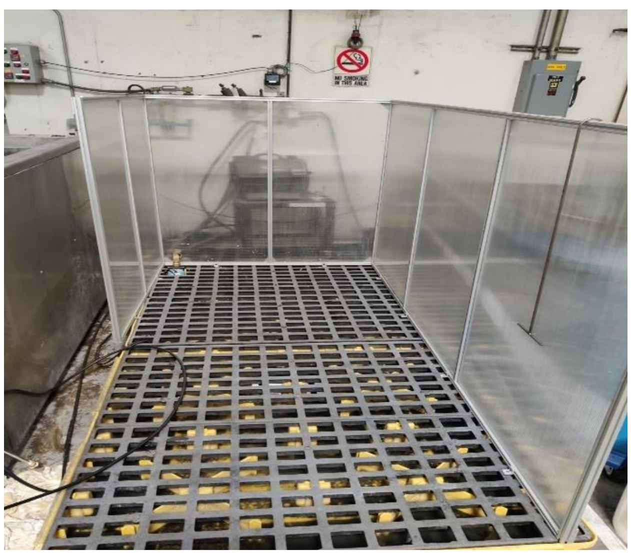

Figure 5-8. Temporary Pressure Washer at Exotic.

For the rinse systems, the company relies on tap water because the quality of the water is good. For purposes of analysis, it was assumed that the cost of the tap water is negligible.

The cleaning system uses one bag filter and one cartridge filter and they are changed out once per week or 52 times per year. The cost of the bag filter is $3.79 and the cost of the cartridge filter is $4.35. On that basis, the annual cost of purchasing the filters is $423. The filters are not considered hazardous waste so there is no cost for disposal.

The cleaning system includes three heated tanks including the wash tank and the two rinse tanks. Each tank has an 18 kW heater. A company representative indicates the heaters run for 20 hours per day five days per week for a total of 520 hours per year. The energy requirement for the three heaters is 280,800 kWh. The company pays a rate of six cents per kWh so the total annual heating cost is $16,848. Each of the three tanks has an agitation system with a 0.5 HP motor and the agitation runs 24 hours per day. On this basis, the annual energy use for the agitation systems is 10,469 kWh. This amounts to a cost of $628 per year. The total energy cost for the system is $17,476 annually.

When the parts that originally were cleaned in the vapor degreaser went through the water cleaning system, the company needed to add the pressure washer. As indicated earlier, the pressure washer used by the company currently is a temporary system. The company plans to purchase a better, permanent system in the future. The heater in the pressure washer Exotic will purchase is 48 kW and the pump requires 6 HP. The company representative estimates it will only be used one or two hours per day and it is used exclusively for rinsing the new parts going through the system. Assuming the pressure washer is used 1.5 hours per day five days per week, the energy requirement is 20,465 kW. Using the six cents per kW value, the annual energy cost of using this system is $1,228.

Exotic indicates that cleaning labor varies depending on the workload. Typically, the company has either one or two workers per shift who do the cleaning. The average number of worker hours required for cleaning is estimated at 8221.5 hours per year. The workers also spend 40 hours per year in changing out the cleaner in the system. The total labor hours amount to 8,261.50 hours. Using the labor rate of $24.21 per hour, the labor cost is $200,011 per year.

The cost of the PPE for the water-based cleaning system is much lower than for the vapor degreaser. The company requires gloves to be used and each set of gloves is $3,838 and they are replaced once a month. On this basis, the cost of the gloves amounts to $461 annually.

Table 5-2 presents the results of the cost comparison. The column entitled “Vapor Degreaser” includes the costs for using the vapor degreaser. The next column, entitled “Water Cleaning System (For All Parts),” is the total cost of using the water cleaning immersion agitation system including the parts that were previously cleaned in the water system and the additional parts that originally went through the vapor degreaser. The third column, entitled “Water Cleaning System for New Parts (10 Year Life),” is the annualized cost for the parts that previously went through the vapor degreaser assuming a 10 year life for the pressure washer. The fourth column, entitled “Water Cleaning System for New Parts (20 Year Life),” is the annualized cost for the parts that previously went through the vapor degreaser assuming a 20 year life for the pressure washer.
A company representative indicates that increasing the number of new parts going through the water cleaning system has not really had an effect on the cleaner that is being used. For all of the other operating costs, cleaning the additional parts in the system has increased the cost by an estimated 15%.

Accordingly, the operating cost parameters given in the “Water Cleaning System (For All Parts)” column, with the exception of the cleaner cost which is not included, have been multiplied by 15% to obtain the operating cost parameters in the fourth and fifth columns. This represents the incremental cost of cleaning the parts that originally went through the vapor degreaser. The energy cost of using the pressure washer—which is exclusively used for the new parts—has been added in to the energy cost shown in the last two columns.

The values of Table 5-2 demonstrate a significant savings from the conversion to the water cleaning system. The cost of using the vapor degreaser was reduced by 81% compared with the cost of using the water cleaning system assuming a life for the pressure washer of 10 years. For the conversion assuming a 20 year life for the pressure washer, the reduction was the same.

Table 5-2
Annualized Cost Comparison for Vapor Degreaser and Water Cleaning System for Exotic Metals Forming

Cost Element	Vapor Degreaser	Water Cleaning System (For All Parts)	Water Cleaning System for New Parts (10 Year Life)	Water Cleaning System for New Parts (20 Year Life)
Equipment	-	-	$1,758	$1,008
Cleaner	$34,000	$14,643	-	-
Water	-	-	-	-
Filters	-	$423	$63	$63
Energy	$20,218	$17,476	$3,849	$3,849
Labor	$125,892	$200,011	$30,002	$30,002
PPE	$3,208	$461	$69	$69
Disposal	$5,297	-	-	-
Total	**$188,615**	**$233,014**	**$35,741**	**$34,991**

5.2.2 Anti-Spatter Cost Comparison for Exotic

The consultant also worked with the company to identify, test and implement an alternative anti-spatter formulation. For many years, the company used a product based on nPB as a carrier that was specially formulated for their specific application. The company used the product in a laser cutting operation for protecting the parts from spatter. The substrates of the parts that require cutting included stainless steel, titanium and Inconel (a nickel/chromium alloy).

There were four important characteristics an alternative must have to be able to replace the nPB anti-spatter formulation at Exotic. First, it must cover the parts adequately for several hours and not run off the parts if they are placed in a vertical position. Second, the anti-spatter must dry on the parts in a short period of time and not require oven drying. Third, the anti-spatter must be able to be cleaned with the water cleaning formulation used by the company. Fourth, the parts must be able to be processed in the subsequent operations successfully and the product should meet several aerospace and testing standards. In addition to passing the test method standards, the anti-spatter should contain no ingredients that are prohibited under REACH.
The parts that go through the laser cutting operation range in size from small parts that are one-inch-cubed in size, to very large parts that might be 43 inches tall and 60 inches in diameter. About 70% of the parts processed each day will fit inside a one cubic foot envelope. The parts are used to build up assemblies and go on to welding, fastening and brazing operations.

The nPB anti-spatter contained a soy lecithin component and was applied by pouring, brushing, spraying or submerging the components depending on the configuration. Small parts like brackets and flanges could be submerged whereas long tubes would need the anti-spatter to be poured through them to coat the inside.

Figure 5-9. Spray Booth for Applying nPB Anti-Spatter at Exotic.

In some cases, with very large parts that would not fit in a dip tank, a spray gun was used to apply the anti-spatter. Figure 5-9 shows the spray booth with the spray gun used for application. Personnel would spray the parts about two hours before laser processing so the solvent would flash off, leaving the soy lecithin coat on the surface.

Figure 5-10 shows the soy lecithin buildup on a tool baseplate. In some cases where there was a heavy workload, the parts might sit after the laser process for up to a week. The soy lecithin, at that stage, was very difficult to clean, particularly after the company converted to the water-based cleaning process.

Figure 5-10. Soy Lecithin Build-up on a Tool Base Plate at Exotic.

The company has six laser sites. About 21 personnel apply the anti-spatter and there are around 75 laser operators who do the cutting operation. Respirators and nitrile gloves were used by all personnel when applying the nPB product and cutting the parts.

The company designed a fixture for testing the alternatives on the three types of metals that are processed. A picture of this fixture is shown in Figure 5-11.

Figure 5-11.
Fixture for Testing Alternative Anti-Spatter Products at Exotic

Many different water-based anti-spatter formulations that are commercially available were tested. One issue that arose with several of the products was that they were too thin and left spaces on the metal parts. Another significant issue was that many of the products did not dry without oven assistance which would make the operation very costly. Another serious issue was that several of the formulations could not be cleaned off easily after the cutting operation with the water-based cleaner. Only one formulation performed adequately enough to be considered. Its limitation, however, is that it contained an ingredient that is prohibited by REACH. The consultant discussed replacing the ingredient with the supplier and even suggested what alternative could be used but the supplier ultimately decided against taking on the reformulation.

At that stage, it was obvious that a specially formulated product would be required. The consultant and the company asked Brulin, the company supplying the water-based cleaner the company was now using in place of the nPB cleaner to see if they could formulate an anti-spatter product that would perform well. Brulin accepted the challenge. A few of the formulations tested initially did not perform well in various ways but ultimately Brulin developed a water-based product that performed extremely well. The company provided information attesting that the anti-spatter contained no REACH-prohibited ingredients and also arranged to conduct most of the tests Exotic needed to verify it was acceptable.

The new product is called 30404-55 AquaVantage™ Anti-Spatter. The product is currently being applied in the same way as the nPB anti-spatter. For spraying. Exotic is using an HVLP spray gun which has a high transfer efficiency and therefore conserves product. The atomization also seems to help with drying.

The cost of the nPB anti-spatter formulation was $1,600 per drum. Previously, the company used 45 drums of the nPB anti-spatter in one year. On this basis, the annual cost of the nPB anti-spatter was $72,000.

The cost of the water-based anti-spatter is lower, at about $660 per drum. The company has been using the new anti-spatter for a very short time so it is difficult to estimate how much they will end up using. A company representative estimates that they will end up using about one-third the amount of anti-spatter with the new process. They are confirming the basis for this estimate through testing. If the one-third estimate turns out to be accurate, then the annual cost of the anti-spatter will be $8,580.

The company representative also estimates there will be additional savings from certain other consumables like spray triggers, spray bottles and spray guns that were needed with the nPB anti-spatter operation. The cost of these items is $1,037 annually. He estimates there will be a 90% reduction in this cost with adoption of the water-based product and this amounts to a remaining cost of about $104 annually.

Twenty-one people applied the nPB anti-spatter and there has not been a change in the application process with adoption of the water-based anti-spatter. A company representative estimates the total labor for applying the anti-spatter for both the nPB and water-based products at about 800 hours per year. The labor rate is $24.21 per hour. On this basis, the labor costs amount to $40,000 annually. Although currently the manpower for applying the new anti-spatter is the same, the company is investigating new methods of racking and transferring the parts that might reduce the application time.

The cost of PPE is eliminated with adoption of the water-based anti-spatter. The company representative estimated the cost of PPE equipment for the nPB anti-spatter at $1,616 per year; including a hood and filters of various kinds. In addition, the labor cost related to the use of PPE is estimated at $1,864 annually, assuming the labor rate of $24.21 per hour. This involves cleaning and replacing filters and filling anti-spatter barrels. The total PPE reduction, including the materials and labor, amounts to $3,480 per year.

The water-based anti-spatter is much more easily cleaned in the water-based cleaning system The new anti-spatter does not contain soy lecithin so the buildup that occurred before is no longer a problem. Figure 5-12 shows a picture of the nPB and water-based anti-spatter formulations in spray bottles. The solvent formulation is on the left and the water formulation is on the right.

Figure 5-12. nPB and Water-Based Anti-Spatter in Spray Bottles at Exotic.

The annualized cost comparison for using the nPB anti-spatter on the one hand and the water-based anti-spatter on the other hand is provided in Table 5-3. The values demonstrate that there is a 71% reduction in the cost with adoption of the alternative. If the company is able to streamline the process and reduce the application labor cost in the future, there would be additional savings.

Table 5-3
Annualized Cost Comparison for nPB and Water-Based Anti-Spatter for Exotic Metals Forming

Cost Element	nPB Anti-Spatter	Water-Based Anti-Spatter
Anti-Spatter	$72,000	$8,580
Application Equipment	$1,037	$104
Labor	$19,368	$19,368
PPE	$3,480	-
Total	**$95,885**	**$28,052**

5.3 Case Study 3: Anonymous Plating Company

Anonymous Plating Company (APC) is located in the Pacific Northwest. The company offers services in anodizing, plating, powder coating, laser part marking, polishing and finishing. The company serves the medical, dental, automotive and manufacturing industries. APC processes parts made of stainless steel, copper, brass, aluminum and carbon steel. A picture of some of the parts processed by the company is shown in Figure 5-13.

The company uses a vapor degreaser containing nPB to remove the protective oil from some of the parts when they come in to the plant. Many of the parts are polished using polishing compounds which are also removed in the vapor degreaser. Periodically, the company receives new car bumpers for polishing and they clean those larger parts as well in the vapor degreaser.

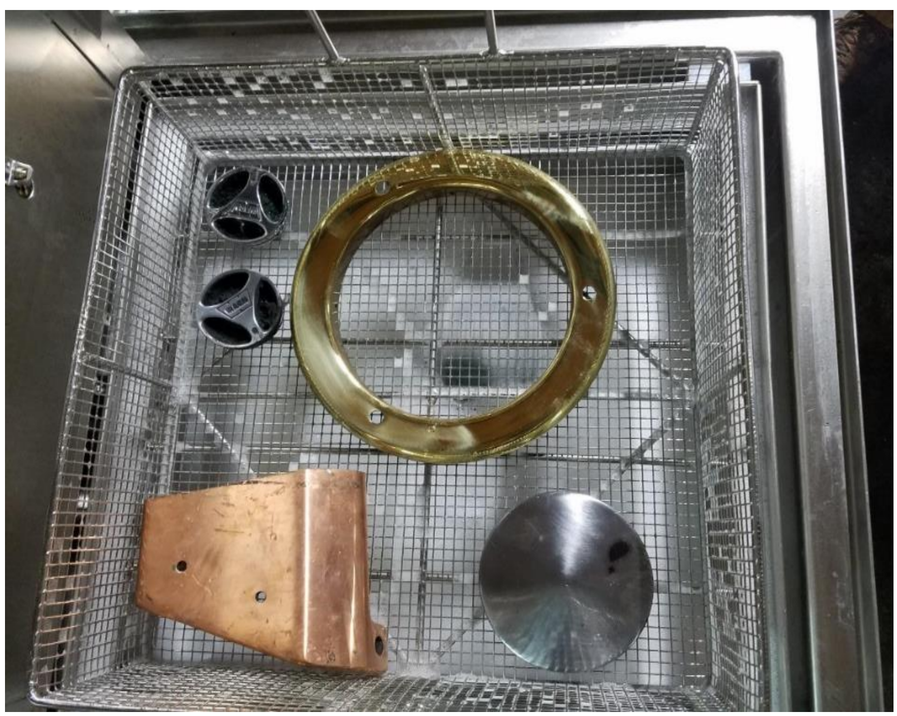

Figure 5-13.
Parts Processed at APC.

A picture of the vapor degreaser, which holds 110 gallons of solvent, is shown in Figure 5-14.

Figure 5-14. Vapor Degreaser at APC.

APC purchases two drums and four pails of solvent every two months. The cost of one drum of solvent is $1,710 and the cost of each pail is $340. The total annual cost for solvent is $28,680.

The vapor degreaser is an old model that was purchased years ago from a company that is no longer in business. It contains a heater and a primary condensing coil. APC added a set of refrigerated coils to the system later. The company is using a heater in the vapor degreaser which uses 8 kW or electricity.

The freeboard chiller that was added later requires 1.5 HP or 1.11855 kW of electricity. The manual for the degreaser does not specify the electric load for the primary condensing coils. Based on simil ar sized degreasers, the electric load for this feature is estimated at 10.5 kW. The total electrical requirement for the system is 19.5 kW. The system is turned on in the morning and turned off at the end of the shift.

Assuming the degreaser operates eight hours per day and five days per week, the equipment operates for 2,080 hours per year. Based on the kW load for the degreaser, the electricity requirement amounts to 40,560 kWh per year. The company does not know the electrical rate they pay. For industrial facilities in Portland, where APC is located, Portland General Electric indicates that the rate ranges between 13 cents on the high end, to 4.6 to 6.3 cents per kWh on the low end, depending on peak energy requirements. Assuming a rate in the mid-range of nine cents per kWh, the energy cost for the vapor degreaser amounts to $3,650 annually.

One operator is responsible for operating the vapor degreaser. The worker spends four hours per week cleaning the oil from parts that come in to the facility. He spends three hours per day operating the degreaser to remove the polishing compound used in the processes. Assuming a five-day work week and 52 weeks per year of operation, the total labor for cleaning amounts to 988 hours annually. Cleaning out the degreaser and changing out the solvent requires two workers 4.5 hours. This is done twice a year and the total number of hours spent in cleaning out the degreaser is 18 hours annually. The total number of labor hours associated with the degreaser is 1,006 annually. At the company labor rate of $22 per hour, the labor cost amounts to $22,132 per year.

The workers who operate the degreaser use gloves and goggles when they are operating the vapor degreaser. No respirators are needed since the company has sufficient ventilation to meet the recommended exposure limit. The cost of the PPE that is devoted to the vapor degreaser operation is estimated at $250 per year.

The company changes out the solvent in the degreaser once a year and removes the sludge every six months. This generates a total of two drums of hazardous waste annually. The company pays $150 per drum for disposal for a total yearly cost of $300.

The consultant worked with APC to identify an alternative water cleaning process that could replace the nPB vapor degreaser. Initial testing was performed on several parts with heavy concentrations of the polishing compounds used by the company. A cleaner, called AquaVantage 515NF made by Brulin was selected. It was effective in removing the polishing compounds with ultrasonics at the Brulin test lab.

The parts processed by APC would require an ultrasonic cleaning system for removing the polishing compound. When the cleaner was selected, it was tested in an ultrasonic system. Some of the parts were also tested in a Ramco system which included ultrasonics for removing the polishing compound as well as an immersion/agitation feature. The company would not require a rinse system since they already had rinse tanks in the plating line.

APC was using racks and trays to clean the parts in the vapor degreaser. The dimensions of the trays are 36 inches in length, 24 inches in width and only a few inches high. The racks are smaller in length and width than the trays but are 30 inches high. Figure 5-15 shows a picture of one of the trays. Figure 5-16 shows a picture of a rack.

Figure 5-15. Tray Used at APC

Figure 5-16. Rack Used at APC.

Ideally, the company wanted to continue using the same racks and trays but the decision on what system to purchase depended on the cost to a large extent. If the cost of available systems were considered too high, the company could use smaller fixtures for the parts.

The consultant assisted the facility in getting quotes on three types of systems.

The first option was to use an existing tank. Like many plating companies, APC had two stainless steel tanks not currently in use. One tank was 36 inches wide, 54 inches long and 48 inches deep. The other tank was 24 inches wide, 36 inches long and 31 inches deep. The first tank was larger than the fixtures for the parts and the second tank was smaller. There are suppliers who can install ultrasonics in an existing tank and quotes for doing this with the two tanks were obtained. Ultrasonics are expensive, however, and the larger the tank, the higher the cost of the ultrasonics and this was a limitation of the larger tank. The limitation of the smaller tank is that it would require the fixtures to be cut down or new fixtures to be made.

The second option was to purchase a new ultrasonic system large enough to accommodate the current fixtures, or a smaller unit which would require new fixtures.

The third option was to purchase a system which included both ultrasonics and immersion/agitation in two sizes, one large enough for the fixtures and the other for smaller fixtures.

APC decided the best option would be to purchase a new ultrasonic system without immersion/agitation. The consultant obtained quotes for three sizes of standard ultrasonic systems and the one that would likely be most suitable is a machine made by Omegasonics called the Power Pro 8000. A picture of the system is shown in Figure 5-17. The cost of this system, including a specially designed rubberized fixture for the parts and a set of stainless steel reusable filters, is $28,594. Assuming a life for the system of 10 years and a discount rate of 3%, the annualized cost of the system is $3,235. Assuming a 20 year life for the system and a discount rate of 3%, the annualized cost would amount to $1,922.

Figure 5-17. Omegasonics Power Pro 8000.

This system holds 110 gallons of cleaner. The cost of a drum of the 515 NF amounts to $1,300 or $23.64 per gallon. During the testing, the cleaner was effective at a concentration of 10% in water. The cost of filling the 110 gallon is $260. The system uses a permanent stainless steel filter so the cleaning bath would not require very frequent changeout and it also has oil removal capability. Assuming the system would be changed out four times a year, the annual replacement cost of the cleaner is $1,040. An additional 10% of the cleaner would be needed for makeup over the year which brings the total annual cleaner cost to $1,144.

The company already has rinsing tanks so there is no cost for obtaining deionized water for rinsing. Furthermore, the quality of the water in the Pacific Northwest is good so deionized water would not be needed in any case. There is no cost for filters since the system relies on reusable filters.

The ultrasonic cleaning unit has six 900-watt heaters for a total of 5.4 kW. Assuming the company turns the heater on at the beginning of each day and assuming it operates five days per week 52 weeks per year, the energy required for the heater amounts to about 11,232 kWh per year. Assuming the worker operates the system for three hours per day for removing the polishing compound and assuming the system operates five days per week and 52 weeks per year, the total hours requiring ultrasonics is 780 hours per year. The peak ultrasonic power in the unit is 8 kW. Although it is unlikely the ultrasonics would operate at peak power level at all times, to be conservative, this value was assumed. On this basis, the electrical requirement for the ultrasonics is 6,240 kWh annually. The total yearly electrical requirement for the heater and ultrasonics amounts to 17,472 kWh. Using nine cents per kWh, the energy cost for the water cleaning system is $1,572 per year.

For the water cleaning system, it was assumed that the labor hours for operating the system are the same as for the vapor degreaser. Since the water cleaner requires replacement twice per year, the same frequency as the changeout for the vapor degreaser, the labor cost is assumed to be the same in this case. Thus, the annual labor cost for operating the system and changing out the cleaner is $22,132 annually.

No PPE is required for use with the water-based cleaning system.

Most plating companies have wastewater treatment systems on-site. APC would likely be able to use their existing wastewater treatment system for disposing of the water-based cleaner. To be conservative, however, the consultant assumed that the spent water cleaner would require off-site disposal. The disposal cost for water waste amounts to about $2.50 per gallon. Assuming the twice per year changeout and a total disposal volume of 440 gallons, the disposal cost for the water waste amounts to $1,100 annually.

The annualized cost comparison for using the vapor degreaser and the water cleaning process summarized in Table 5-4. The annual cost of using the water cleaning process assuming a 10-year life for the equipment is 47% lower than the cost of using the vapor degreasing process. The annual cost of using the water cleaning process assuming a 20 year life for the equipment is 49% lower than the cost of using the vapor degreasing process.

Table 5-4
Annualized Cost Comparison for Vapor Degreaser and Water Cleaning System for APC

Cost Element	Vapor Degreaser	Water Cleaning System (10 Year Life)	Water Cleaning System (20 Year Life)
Equipment	-	$3,235	$1,922
Cleaner	$28,680	$1,144	$1,144
Water	-	-	-
Filters	-	-	-
Energy	$3,650	$1,572	$1,572
Labor	$22,132	$22,132	$22,132
PPE	$250	-	-
Disposal	$300	$1,100	$1,100
Total	**$54,814**	**$29,183**	**$27,870**

5.4 Case Study 4: Anonymous Tube Manufacturer (ATM)

This company, ATM, has been operating in the Seattle area since 1962. The company was originally established to provide tube bending capabilities for companies in the aerospace and industrial sectors. At this stage, the company also provides precision machining and welding services. The company works with the aerospace, space, medical, defense, automotive and tool and die sectors.

Historically, ATM used a vapor degreasing process to remove the bending lubricants from tubes which have an internal diameter of one-eighth inch or larger. The tubes can be as long as five feet and they often have several bends. The lubricant used in the bending process, which is water soluble, remains on the outside and inside of the tubes at the point of bending and must be removed.

Pictures of some of the tubes made by the company are shown in Figures 5-18 through 5-22.

Figure 5-18. Tubes with Multiple Bends at ATM.

Figure 5-20. Circular Coil Tube at ATM.

Figure 5-19. Small Diameter Tube at ATM.

Figure 5-21. Larger Diameter Tubes with Bends at ATM.

Figure 5-22. Large Diameter Tubes at ATM.

For several years, ATM used an old degreaser. In 2018, the company replaced it with a new vapor degreaser with a 42-gallon capacity. The company estimates that they use 82 gallons of nPB annually in the vapor degreaser. They purchase the solvent in drums and the cost of purchasing the solvent is $2,500 per drum. On that basis, the annual cost of purchasing solvent amounts to $3,727.

The company's vapor degreaser includes a heater, a primary refrigeration system and a vapor trap refrigeration unit. The heater has an energy requirement of 9 kW and the refrigeration units have a total energy requirement of 4.5 HP or 3.4 kW. The total electrical requirement of the degreaser is 12.4 kW. The company estimates that the vapor degreaser is used for four to eight hours per week. Assuming the average value of six hours, the degreaser operates 312 hours annually based on 52 weeks of operation each year. The annual energy requirement amounts to 3,869 kWh. The company pays a rate of 9.04 cents per kWh. On this basis, the yearly energy cost is $350.

The workers spend an estimated 312 hours per year operating the vapor degreaser. One worker changes out the solvent in the degreaser and it requires about 12 hours annually. The hours spent in operating the degreaser and changing out the solvents totals 324 hours per year. Assuming the company's average hourly rate of $23 per hour, the cost amounts to $7,452 annually. ATM also trains the workers to operate the degreaser and this cost is estimated at $200 per year. On this basis, the total annual labor cost is $7,652.

The workers who operate the degreaser use PPE of various types. They rely on respirators, gloves and face shields at a cost of $600 per year. The jackets worn by workers are also laundered at an annual cost of $600. The total cost for PPE amounts to $1,200 per year.

The company generates about two drums of waste per year from the vapor degreaser. At a cost of $500 per drum, the annual cost of disposal is $1,000.

Some of the tubes at ATM have very small diameters. It is quite straightforward to find a system for cleaning the outside of the tubes. The vapor in the degreaser along with flushing with a wand can penetrate through the inner part of the tube to remove any residual lubricant that might remain from the bending operation. In the case of a water cleaning system, there is no vapor, so making sure the insides of the tubes are clean is very important.

Two different types of water cleaning systems could potentially be used for cleaning the parts in place of the vapor degreaser. The first is an immersion system with ultrasonics which might include both a wash and a rinse tank. In this case, ultrasonics would be necessary to ensure the insides of the tubes are adequately cleaned. One company in Southern California is cleaning similar types of tubing with such a system, so there is evidence that an immersion ultrasonic system is suitable. The second type of system the consultant explored with an equipment supplier was a spray cabinet with a special fixture designed to flush the inside of the tubes. Budgetary quotes on the systems indicated that the immersion ultrasonic system would be more costly, so the less costly spray cabinet was pursued through testing.

The consultant and the equipment supplier conducted testing of tubes supplied by the company with liberal amounts of the applied lubricant. Some of the tubes tested were small in diameter, to see if the spray cabinet system could adequately clean the parts.

During the testing, the water soluble lubricant was easily removed from the outside of the tubes. The supplier did not attempt to remove any lubricant on the inside of the tubes. The tubes were sent back to the company for evaluation. The company cut apart the tubes and found residue of the lubricant remaining inside. The supplier cleaned additional parts that were sent by the company a second time, and rigged the spray cabinet this time to mimic the presence of a special fixture that could be designed to hold and clean the insides of several tubes in one load. The parts were again sent back to ATM for evaluation and the company judged that the parts had been cleaned effectively. Figure 5-23 shows the spray cabinet with a tube that was cleaned in the system during the testing.

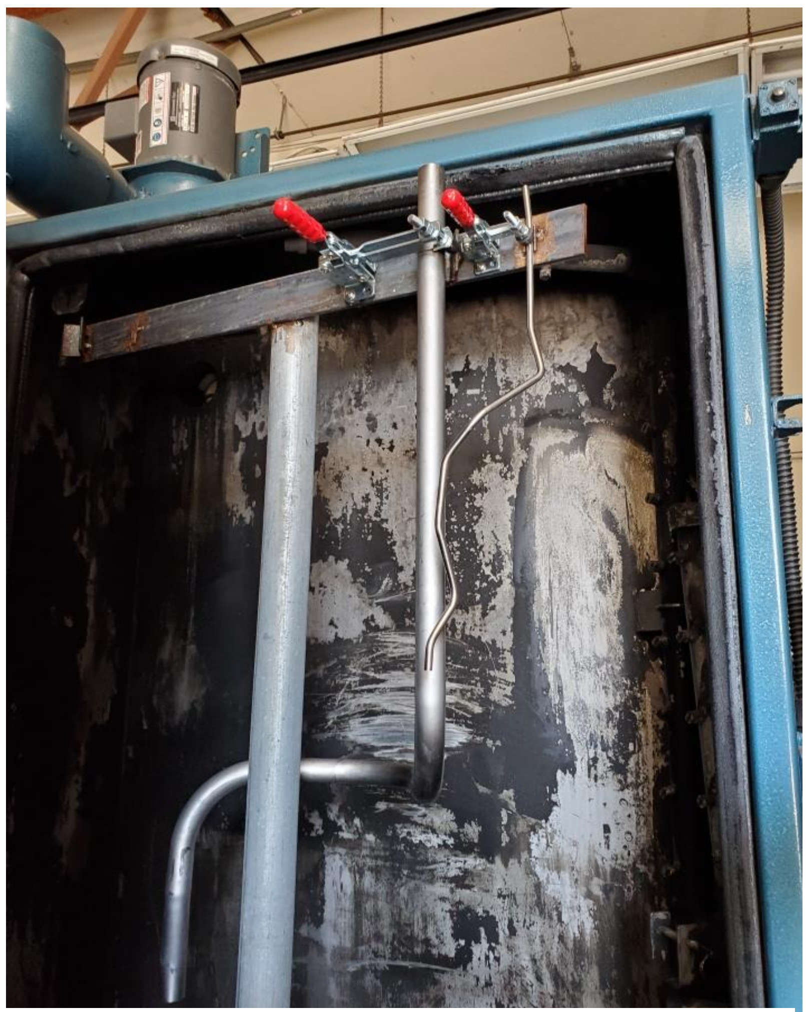

Figure 5-23. Spray Cabinet with Tube Used for Testing for ATM.

The equipment supplier provided a quote for the spray cabinet with the specially designed fixture that would hold the tubes on the turntable upright during the cleaning cycle. The spray cabinet is stainless steel and the system includes an oil skimmer and filtration system. The cost of the system amounts to $73,415. Assuming a life for the equipment of 10 years which is conservative and a discount rate of 3%, the annualized cost for the equipment is $8,606. Assuming a life for the equipment of 20 years which is more realistic and the same discount rate, the annualized cost of the equipment is $4,935.

As mentioned earlier, the approach to the cost analysis the consultant adopted generally includes the cost of the new water-based cleaning equipment but does not include the capital cost of the vapor degreaser. In almost all cases, companies have very old vapor degreasing equipment that has been paid off completely, most often for many years. In this case, however, the vapor degreaser is just over two years old so it is likely that it has not been fully amortized. One approach in this case would be to discount the cost of the equipment for two or three years and just include the balance of the cost remaining. Another approach would be to include the market price of the equipment if it were sold second hand. The consultant decided to use the latter approach and found a similar used vapor degreaser offered by a company called Degreasing Devices. A photo of the advertised unit, specifications, and pricing (accessed online during summer 2021) is shown in Figure 5-24.

BARON BLAKESLEE MLR 280LE **Price – $18,500. USD**

Low Emissions ; 100% freeboard; with primary refrigerant chiller and freeboard chiller; 2 inside sumps – 20″ x 16″ x 16″deep; overall dimensions – 70″ L to R x 42" back to front x 67″ H; 208V, 3 ph., 40 amps; 62 gals solvent capacity; spray wand; meets environmental regulations; 1500 lbs. shipping weight; good & operating condition.

Figure 5-24. Degreasing Devices Used Vapor Degreaser and Associated Information.

As indicated in Figure 5-24, Degreasing Devices offered the used vapor degreaser, which is very similar to the degreaser used at ATC, at a price of $18,500. Assuming ATC might sell its vapor degreaser for $18,500 through Degreasing Devices for this price and assuming Degreasing Devices might charge 20% for handling the sale, the total amount ATC would receive would be $14,800. Amortizing this amount over a 10 year life and assuming a discount rate of 3%, the annual revenue that would be generated over the life of the new spray cabinet would be $1,553. Amortizing the amount over a 20 year life and assuming the same discount rate, the revenue from the sale would be $995. Reducing the annualized cost of purchasing the new system by these amounts would lead to net annualized costs of $7,053 for the 10 year life and $3,940 for the 20 year life.

The spray cabinet tank capacity is 300 gallons. The cleaner used in the testing was Brulin Aquavantage GD3887. The cost of the cleaner is $1,157 for a 55-gallon drum. During cleaning, the cleaner can be used at a 5% concentration in water. Since the company did not convert, it is not possible to know how many hours per week the system would be used. For this analysis, therefore, it was assumed that the system would be used for the same amount of time as the vapor degreaser is used, an average of six hours per week. The tank is large and, since the company currently cleans only about six hours per week, the bath is likely to require changeout infrequently. Assuming the bath is changed out twice per year, the annual cost for changing out the bath is $631. Makeup cleaner would also be required periodically. Assuming this amounts to about one-tenth the cost of changing out the bath, the cleaner makeup cost would be an additional $63 per year. The total annual cleaner cost would be $694.

During the testing, after cleaning the tubes, the supplier rinsed with a small amount of water. This rinse water could serve as the makeup water for the tank to account for evaporation. In the Pacific Northwest, the quality of the water is very good and tap water could be used for the rinse. Thus, the cost of water is considered negligible.

Filters would be required for the spray cabinet. They would need to be replaced twice a year when the cleaning bath was changed out. The cost of the filters is $8 and since two are required, the total annual cost would amount to $16.

The spray cabinet has four heaters, each using 15 kW in electric load. The total electric load for the heaters is therefore 60 kW. The pump is a 15 horsepower model and the turntable requires one-fourth horsepower. Converting the horsepower to kW, the pump and turntable together require 11.37 kW. The total energy requirement for the equipment is 71.37 kW. In the case of the vapor degreaser, the operator would need to position the tubes in the basket, operate the vapor degreaser during the cleaning cycle and then remove the tubes from the basket. In the case of the spray cabinet using the water cleaner, the operator would have to position the tubes, briefly rinse them with a wand and remove them from the machine after the cleaning cycle.

It is difficult to estimate the operating hours for the spray cabinet but it is likely to be roughly the same as the operating hours for the vapor degreaser. On this basis, assuming the system is operated six hours per week for 52 weeks per year and that the cost of electricity is nine cents per kWh, the energy cost would amount to $2,004 annually.

It is very difficult to know what the labor hours would be for cleaning the tubes in the spray cabinet but assuming labor is likely to be similar to that required to use the vapor degreaser, the cost is estimated at the same amount for the spray cabinet, or $7,652 per year.

No PPE would be required in the case of the spray cabinet using the water-based cleaner.

The company would have to dispose of the contaminated water bath twice per year. The cost of disposal for water waste is about $2 per gallon. The amount of water waste generated is 600 gallons per year. On this basis, the disposal cost would be $1,200 annually.

Table 5-5 presents the annualized cost for using the vapor degreaser and the cost for using the water cleaning system. In this case, the cost from the sale of the used vapor degreaser is given as a reduction in the equipment cost for the water cleaning system. The values show that using the water cleaning system would increase the overall cost by 33% in the case of the 10 year equipment life and by 11% in the case of the 20 year equipment life.

Table 5-5
Annualized Cost Comparison of Vapor Degreaser and Water Cleaning System for ATM

Cost Element	Vapor Degreaser	Water Cleaning System (10 Year Life)	Water Cleaning System (20 Year Life)
Equipment	-	$7,053	$3,940
Cleaner	$3,727	$631	$631
Water	-	-	-
Filters	-	$16	$16
Energy	$350	$2,004	$2,004
Labor	$7,652	$7,652	$7,652
PPE	$1,200	-	-
Disposal	$1,000	$1,200	$1,200
Total	$13,929	$18,556	$15,443

6.0 A RELATED CASE STUDY

The consultant recently completed a project that was sponsored by the Hazard Evaluation System & Information Service (HESIS), an agency that is part of the California Department of Public Health. HESIS is concerned with worker exposure to chemicals that pose a health threat. The agency has the authority to require information from suppliers and distributors to submit information on companies that use a chemical they designate in various types of operation. The first chemical HESIS designated as posing a high risk is nPB.

During the project, the consultant worked with a company in California using nPB in a vapor degreasing operation. The aim of the project was similar to the PPRC project. The consultant assisted the company in identifying and testing a safer alternative for their process. The consultant worked with the company, Company A, and identified and tested a viable safer alternative and assisted the company in obtaining quotes from two equipment suppliers for the alternative process. Company A did not complete the conversion within the timeframe of the project. A short description of the company, its operations and the appropriate safer alternative is presented below.

6.1. Company A

Company A is a job shop that manufactures optical components. As part of the manufacturing process, the components are polished using materials like pitch, an asphalt-like material, and wax. These contaminants are very difficult to clean. For several years, the company has relied on an nPB vapor degreaser to clean the components during assembly. A picture of one of the components with the asphalt polishing compound is shown in Figure 6-1.

Figure 6-1. Optical Component with Asphalt Contaminant at Company B.

The consultant had worked with a few other companies who make optical components in the past and those companies had adopted an alternative process that used soy-based cleaners in an ultrasonic cleaning system. These cleaners, when used in ultrasonic tanks, are especially effective in removing pitch and wax. The soy does not evaporate readily, however, and leaves a heavy residue on the parts. A water-based cleaner is usually needed to remove the soy from the parts in a second step.

The consultant arranged for an equipment supplier to conduct on-site testing with a small ultrasonic unit. During the test, the contaminants were removed effectively and the water-based cleaner was able to rinse the residue of the soy from the parts. The consultant assisted Company A in obtaining quotes from two equipment suppliers for the two ultrasonic units that would be needed to clean with the soy and rinse with the water-based cleaner. The costs of the two alternative systems were comparable but one system had a larger bath size than the other and this would require fewer changeouts of the baths when they were contaminated, so the larger system was selected as the best option for the company.

The company is still evaluating the quote for the system and has not yet converted the operation. The consultant used the selected quote for the alternative system together with certain assumptions about the operating costs from experience with other similar conversions to conduct a cost analysis and comparison. The results indicate that the cost of using the vapor degreaser on the one hand and the cost of using the alternative system on the other hand are roughly comparable assuming a life for the cleaning system of 10 years and 20 years. In both cases, there is a slight reduction in the annualized cost in moving to the soy alternative.

7.0 RESULTS AND CONCLUSIONS

nPB is a toxic solvent that has been used for many years in vapor degreasing operations for cleaning parts. The chemical is a carcinogen, it can harm the nervous system and it is a reproductive toxin. The agency plans to regulate the chemical in the Halogenated Solvents Cleaning NESHAP. EPA also is in the process of developing regulations on the chemical under the 2016 amendments to TSCA. Vapor degreasing and many other nPB applications were determined by EPA to pose an unreasonable risk. The agency is currently conducting a risk management process and will eventually propose a regulation.

This project involved working with four companies that relied on nPB vapor degreasing processes for cleaning parts Three of the companies participating in the project are aerospace operations located in the Seattle area. The first of these companies conducts NDT testing for other aerospace facilities. The second company manufactures small diameter tubing for transferring liquids and gases from one place to another in aircraft. The third company manufactures ducting for industrial and aerospace applications. All three of these aerospace companies had to comply with stringent standards and one also needed to comply with REACH. The fourth company participating in the project is located in the Portland area and provides plating and coating services. The consultant worked with all four companies to assist them in converting away from nPB to safer alternatives.

There are many different alternatives to nPB in vapor degreasing. These include the chlorinated solvents, TCE, PERC and MC. Many companies converted away from the chlorinated solvents to nPB when nPB entered the market. They wanted to avoid compliance with other regulations that had been adopted on the chlorinated solvents. Another alternative option is fluorinated solvents, HFEs, HFCs and HFOs. The HFCs and HFEs are very poor cleaners and are almost always combined with DCE which is structurally similar to three other chemicals that are carcinogens. In addition, they must be used in airless/airtight equipment to prevent high emissions and this equipment is extremely expensive. The HFCs and HFEs contribute to global warming and they may eventually be regulated for that reason. The HFO is slightly more aggressive and can be used alone and in open-top equipment, but one toxicologist who has evaluated its toxicity, indicates it is cardiotoxic. A third option is to use various solvents with flashpoints either in a vapor degreasing or a cold cleaning operation. For vapor degreasing, they must be used in airless/airtight equipment which, again, is very expensive. In cold cleaning, they may not be as effective in cleaning. Furthermore, some of the solvents with flash points have toxicity issues. A fourth option is to use soy-based cleaners and these are appropriate for certain types of operations. A fifth operation is to use water-based cleaners and these are the best alternative for nearly all operations where nPB is currently used in vapor degreasing. The fifth and last option is to use non-chemical methods and these are suitable on a case-by-case basis.

Table 7-1 briefly summarizes these options. Many companies have switched from one option to another several times as the chemical they are using is increasingly regulated or is determined to be toxic. This shell game behavior is very expensive and time consuming and wiser companies generally make a conversion to a permanent alternative. These include the soy cleaners, water-based cleaners and non-chemical methods shown in Table 7-1. More detail on the specific alternatives is provided in Table 2-1.

Table 7- 1
Summary of Characteristics of Potential Alternatives to nPB in Vapor Degreasing

Potential Alternatives	Issues	Rating
Chlorinated solvents, fluorinated solvents, other solvents	Toxicity, global warming, expensive solvents, expensive equipment, less effective cleaning	Probably not a permanent solution
Soy-based cleaners, water-based cleaners, non-chemical methods	Good health and environmental characteristics, lower cost	Likely to be a permanent solution

The consultant worked with four participating companies to identify, test and demonstrate suitable alternatives and to assist those companies in purchasing alternative equipment and implementing it. The best alternative in the case of these companies was to convert to a water-based cleaner. Two of the companies converted to and adopted the water-based alternatives. The consultant completed all the testing and cost analysis on alternatives for the two other companies, but they did not convert in the timeframe of the project.

In all four cases, the companies provided information on the costs of using the vapor degreasing process. The consultant assisted the companies in obtaining quotes on the best type of equipment for each process where it was needed. The consultant evaluated the cost of using the alternative for the companies that ended up converting using actual data. In the case of the two companies that did not end up converting, the consultant made estimates for the operating costs of using the alternative process based on the consultant's experience in working with other companies with similar operations.

Table 7-2 briefly summarizes the costs for the four companies. As discussed earlier, two of the companies, the plating company and the tube manufacturer, opted to remain anonymous. The values show that the two companies that made the conversion reduced their costs significantly by converting to the water-based cleaning system.

MAPSCO reduced their cost by converting to a water-based cleaner and using a second-hand cleaning system. Exotic was able to use one of their existing water cleaning systems to clean the parts that previously were cleaned in the vapor degreaser. The values also show that the plating company could reduce their costs by about half through a conversion and that the tube manufacturer would increase their costs by adopting the alternative water-based cleaner.

Table 7- 2
Summary of Annualized Costs for Participating Companies

Company	Vapor Degreasing Process	Water-Based Cleaning Process (10 Year System Life)	Water-Based Cleaning Process (20 Year System Life)
MAPSCO	$67,415	$49,768	$46,417
Exotic Metals Forming Company	$188,615	$35,741	$34,991
APC (plating company)	$54,814	$29,183	$27,870
ATM (tube manufacturer)	$13,929	$18,556	$15,443

One participating company, Exotic, needed to change another process in their operation that would affect the cleaning. This process involved using an nPB anti-spatter formulation in a laser cutting operation. The residue left on the parts could not be cleaned well in the alternative water-based cleaning system and the anti-spatter could leave a residue of nPB in the water cleaner when it required changeout, making disposal or treatment more expensive.

The consultant worked with Exotic to test commercially available water-based anti-spatter alternatives but none of them worked effectively for various reasons. The consultant asked the water-based cleaner supplier to see if they could develop a water-based product. The supplier formulated a product that performs extremely well and is easily cleaned in the water cleaning system. Table 7-3 shows the cost comparison for using the nPB anti-spatter and the water-based anti-spatter. The values indicate a significant cost reduction of 71% from use of the alternative.

Table 7-3
Annualized Cost Comparison for nPB and Water-Based Anti-Spatter for Exotic Metals Forming

Cost Element	nPB Anti-Spatter	Water-Based Anti-Spatter
Total	$95,885	$28,052

The consultant also worked on another project sponsored by HESIS that involved a company using nPB in vapor degreasing in California in a precision cleaning operation. The company manufactures optical components and the consultant worked with the company to test alternatives and obtain quotes from equipment suppliers. The company did not convert to the alternative in the timeframe of the project but testing indicated that the best alternative for this company is a soy-based cleaner which cleaned their parts effectively. The consultant conducted a cost comparison and it illustrates that the company would reduce its costs by adopting the soy alternative process.

The collective results of this project demonstrate that there are safer alternatives available that can replace nPB in vapor degreasing. In the PPRC project and the HESIS project, the companies participating employed a diverse set of operations ranging from precision cleaning to aerospace servicing and manufacturing to job shop plating. Another point that is important to note is that companies using chlorinated solvents like TCE, PERC and MC or fluorinated solvents can also convert their operation in the same way these participating companies did. The safer alternatives are suitable for all companies with similar operations that are using any solvent in a vapor degreasing operation.