ALTERNATIVES TO VOC EMITTING PETROLEUM BASED LUBRICANTS AND CHLORINATED PARAFFIN LUBRICANTS: MINIMIZING THE HEALTH AND ENVIRONMENTAL CONSEQUENCES

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I. INTRODUCTION AND BACKGROUND

There are thousands of manufacturers in the United States that use lubricants in their metal working processes. Independent machine shops manufacture parts for a variety of different types of metal operations. Many companies have captive machine shops that make parts for their production operations. Examples of the types of processes that use lubricants are stamping, honing, deep drawing, forming, cold heading and tube bending.

About half of the lubricants used in metal working today are petroleum-based lubricants. Some of these lubricants are so-called vanishing oils. Vanishing oils are relatively high vapor pressure lubricants that are designed to evaporate from the part over a period of time. These oils are classified as Volatile Organic Compounds or VOCs that contribute to photochemical smog. Other lower vapor pressure lubricants are diluted with mineral spirits or kerosene to obtain the desired consistency for the operation being performed. In some cases, suppliers of these lubricants dilute them; in other cases, the companies using the lubricants dilute them as they are used. The mineral spirits or kerosene in these lubricants are classified as VOCs and, like the vanishing oils, they contribute to smog.

Some of the petroleum-based lubricants are chlorinated paraffins or contain chlorinated paraffin additives. In general, these are lubricants that are designed to lubricate parts that experience extreme pressures. Lubricants used in deep drawing, tube bending and cold heading, generally contain chlorinated paraffin additives. In some cases, chlorinated paraffin additives are used in lubricants for other types of operations, but they may not be necessary. Lubricants containing chlorinated paraffin additives are generally not further diluted with mineral spirits or kerosene because the applications for which they are useful require very viscous lubricants.

About half the lubricants used in metalworking, instead of being petroleum based, are synthetics. The synthetic lubricants can be vegetable-based methyl esters or polymers of various types. These materials, called synthetic or semi-synthetic lubricants, are often diluted with water rather than VOC solvents to obtain the desired consistency. These lubricants can serve as alternatives to petroleum based lubricants and chlorinated paraffin lubricants. Alternatives to chlorinated paraffin additives may include sulfur-based materials or phosphoric acid esters.

The Institute for Research and Technical Assistance (IRTA) is a nonprofit organization based in Glendale, California. IRTA's aim is to assist companies in adopting low- and non-solvent technologies. IRTA performs test and demonstration projects to find alternatives to ozone depleting, toxic and VOC solvents in a variety of applications including cleaning, dry cleaning, adhesives and coatings. IRTA runs and operates the Pollution Prevention Center (PPC) a loose affiliation of several government entities and a large electric utility. Members include:

- U.S. EPA Region IX
- Cal/EPA's Department of Toxic Substances Control

- California Department of Health Services Hazard Evaluation System & Information Service (HESIS)
- South Coast Air Quality Management District
- Santa Barbara County Air Pollution Control District
- Los Angeles County Sanitation Districts
- City of Los Angeles Bureau of Sanitation
- Orange County Sanitation District
- Southern California Edison

This project was sponsored by U.S. EPA under the Environmental Justice Pollution Prevention program. The aim of the project was to investigate, test and demonstrate alternatives to petroleum based VOC emitting lubricants and lubricants containing chlorinated paraffin additives. VOC emitting lubricants are petroleum based vanishing oils and lubricants that are diluted with VOC solvents. The VOC emissions from these lubricants contribute to smog and they also contain trace quantities of benzene, toluene and xylene. Benzene is an established human carcinogen. Toluene causes central nervous system damage and xylene can cause birth defects. All three substances are listed on Proposition 65 in California. Workers and community members living near the facilities where the lubricants are used are exposed to these toxicants.

Chlorinated paraffins are mixtures of polychlorinated alkanes produced by the reaction of chlorine with specific normal paraffin fractions from petroleum distillation. The carbon chain lengths of commercial products are generally between C10 and C30 and the chlorine content is typically between 40 and 70 percent. Certain of the chlorinated paraffins, the short chain chlorinated paraffins with an average carbon chain length of C12 and an average degree of chlorination of 60 percent, are classified as carcinogens. There is also limited evidence of carcinogenicity for chlorinated paraffins with an average chain length of C23 and an average degree of chlorination of 43 percent. Workers and community members living near facilities using chlorinated paraffins can be exposed to them. The short chain chlorinated paraffins are listed on Proposition 65 in California. In Europe, the short chain chlorinated paraffins have been banned.

Chlorinated paraffins can also cause other problems for manufacturers. They are difficult to clean from the metal substrates. They may require cleaning baths to be changed out more often. If the chlorine content of the spent lubricant is high, the used oil or the water-based cleaning bath used to clean them might have to be disposed of as hazardous waste.

During this project, IRTA worked with manufacturers in the Southern California area to test alternative lubricants. The South Coast Air Quality Management District (SCAQMD) regulates air emissions in the South Coast Basin. SCAQMD Rule 442 “Usage of Solvents” regulates lubricants that contain VOCs. The rule specifies that companies shall not emit more than 833 pounds of VOCs per month from all VOC containing processes subject to the rule. This is a very high limit and most companies using VOC emitting lubricants would be unlikely to emit more than the limit.

The SCAQMD must reduce emissions of VOCs in the Basin substantially over the next several years to achieve attainment with the EPA ozone standards. IRTA estimates VOC emissions from emitting lubricants in the jurisdiction of the SCAQMD at between five and 15 tons per day. If alternative non-emitting lubricants are available, the SCAQMD could further regulate VOC emissions from this category. EPA or other regulatory agencies at the state or local level could eventually restrict the use of chlorinated paraffins, as they have been restricted in Europe. It is important to determine whether the alternative synthetic lubricants on the market today could substitute for the VOC emitting and chlorinated paraffin petroleum based lubricants that are currently used by many manufacturers.

IRTA worked with eight different companies in the course of this project to test, evaluate and demonstrate alternatives to VOC emitting lubricants and lubricants with chlorinated paraffin additives. Five of the companies used VOC emitting lubricants. One of these companies also used a lubricant that had chlorinated paraffin additives. IRTA worked with three additional companies that used non-emitting lubricants that contained chlorinated paraffin additives. The companies that used VOC emitting lubricants included:

- one machine shop
- one metal nameplate manufacturer
- one manufacturer of welding torches
- two aerospace companies

The four companies that used lubricants with chlorinated paraffin additives included:

- one machine shop
- one exhaust system manufacturer
- one deep draw products manufacturer
- one fastener manufacturer

IRTA found alternative non-VOC emitting lubricants and lubricants that did not contain chlorinated paraffin additives that performed well for each of the eight manufacturers. Four of the five companies that used VOC emitting lubricants converted to the alternative non-VOC emitting products. The remaining manufacturer downsized during the project and did not convert to the alternative lubricant that was tested. Two of the companies using lubricants with chlorinated paraffin additives are in the process of converting to the alternative lubricants. The third company using lubricants with chlorinated paraffin additives might consider converting to the alternative lubricant in the future.

Section II of this document summarizes the approach to the testing and the results of the tests for each of the companies participating in the project. In some cases, IRTA tested lubricants that did not work well. IRTA analyzed the costs of using the alternative lubricants that did perform well and compared them with the costs of using the company's original lubricant. Section III summarizes the results of the testing. The appendix contains stand-alone case studies for the four companies that converted to the alternatives in the course of the project.

II. ANALYSIS AND TESTING OF THE ALTERNATIVE LUBRICANTS

This section describes the alternative lubricants that were tested with each manufacturer. It provides information on the processes where the lubricants were tested. In each case, the Material Safety Data Sheets (MSDSs) for the original lubricant are included. The MSDS for each alternative product that performed effectively is also included. The description of the testing at each company includes a cost analysis and comparison of using the original and the alternative lubricants. In some cases, other collateral processes performed by the facility had to be changed to accommodate the use of the alternative lubricant and the costs of these changes are also included in the analysis.

S&H Machine, Inc.

S&H Machine is a small machine shop located in Burbank, California. The company machines parts for the aerospace industry. The parts machined by S&H Machine are made of aluminum and stainless steel. The company has 21 machine stations, which include several CNC lathes and mills. One of the stations is shown in Figure 2-1.

Figure 2-1. Machine Station at S&H Machine

In the past, S&H Machine used a petroleum-based lubricant that contained chlorinated paraffin extreme-pressure additives for machining their parts. Exhibit 2-1 is the MSDS for this lubricant. The company used mineral spirits to clean the parts. When the South

Exhibit 2-1
Original Petroleum Based Lubricant Used at S&H Machine

Coast Air Quality Management District (SCAQMD) regulated the VOC content of cleaners used in batch loaded cold cleaning, S&H Machine purchased eight parts cleaners and began to use a water-based cleaner to clean their parts. At that stage, David Fisher, the owner of the company, began to examine alternative lubricants that would fit better with the water-based cleaners the company now used. After extensively researching the alternative lubricants, David Fisher converted the company's lubricant to a water miscible cutting and grinding lubricant. An MSDS for this lubricant is shown in Exhibit 2-2. S&H Machine used the new lubricant for a few years and then converted to a synthetic vegetable ester lubricant, which is being used today. An MSDS for the vegetable-based lubricant is shown in Exhibit 2-3.

In order to make the conversion from the petroleum based lubricant to the water miscible lubricant, S&H Machine had to purchase a mixer for mixing the lubricant and water at a cost of $432, a decanter used to separate tramp oils from the lubricant at a cost of $975 and a sump cleaner for cleaning out the machine sumps at a cost of $4,750. The company also had to purchase 15 oil skimmers used to skim the tramp oil from the surface of the lubricant; at a cost of $280 per skimmer, the total cost of the skimmers was $4,200. One of the skimmers is shown in Figure 2-2. The total capital cost amounted to $10,357. Installation of the new equipment required 15 hours of labor. Assuming a labor rate of $15 per hour, the installation labor cost was $225. The total capital and installation cost amounted to $10,582. When S&H Machine converted to the water miscible ester lubricant, no additional capital equipment was required. Had the company converted from the petroleum-based lubricant directly to the ester lubricant, they would have had the same capital equipment requirements as for the water miscible lubricant. Assuming a cost of capital of 2% and a 10 year life for the equipment, the annualized capital cost is $1,079.

Figure 2-2. Oil Skimmer at S&H Machine

Exhibit 2-2
Interim Water Miscible Lubricant Used at S&H Machine

Exhibit 2-3
Final Vegetable Based Lubricant Used at S&H Machine

S&H Machine used six drums per year of petroleum based lubricant. At a cost of $264 per drum, the total cost of the lubricant was $1,584 annually. The company used less lubricant, about five drums per year, of the water miscible lubricant. The higher cost of the lubricant, at $700 per drum, led to an annual lubricant cost of $3,500. At this stage, S&H Machine is using only three drums per year of the ester lubricant. At a cost of $1,134 per drum, the annual lubricant cost amounts to $3,402.

When S&H Machine used petroleum-based lubricants, the company performed no maintenance. With both the water miscible and the ester lubricant, the company must perform substantial maintenance to achieve peak performance and good part finish quality. S&H's owner estimates that four hours per week is required to pump the coolant out of the machines, refill the machines and decant the removed lubricant. In addition, once a year the water miscible lubricant must be changed out. This requires 10 employees who each spend four hours at this activity. Assuming a labor rate of $15 per hour, the total maintenance labor cost for using the water miscible and ester lubricants is $3,720 per year.

The water miscible and vegetable ester lubricants provide less lubricity than the petroleum-based lubricant. They do, however, serve as better coolants than the petroleum lubricant. As a result, S&H Machine can run the machines faster with the alternative lubricant. In effect, the efficiency of the operation has increased and the company can process more parts. To quantify this increase in efficiency, the machining labor using the petroleum and the alternative lubricant were compared. Eight operators machine parts for eight hours per day. Assuming each operator works 260 days per year and a labor rate of $15, the machining labor amounted to $249,600 annually. With the new lubricant, Mr. Fisher estimates that there has been a 10% increase in efficiency. This translates into a labor cost reduction of $24,960 per year. The machining labor cost is now $224,640.

When S&H Machine used petroleum-based lubricants, the only disposal costs involved disposal of the spent water-based cleaners. The company had eight parts cleaners each with a capacity of 15 gallons. The total of 120 gallons was disposed of three times per year. At a cost of $1 per gallon, the total cost of disposal amounted to $360 per year.

S&H Machine was able to reduce their cleaning requirements when they switched to the water miscible and ester lubricants. Four of the eight water-based parts cleaners were eliminated so disposal costs are half what they were previously. With the two alternative lubricants, however, there is also waste from decanting the lubricants. The cleaning system and decanting waste now amounts to 660 gallons per year. In addition, S&H Machine now changes out the lubricant and disposes of it once a year. Total disposal costs now amount to $1,025.

The labor required for cleaning was reduced when the company changed to the water miscible and ester lubricants. S&H Machine machines 85,549 parts annually. The company estimates that it requires 30 seconds less to clean each part now. Assuming a labor rate of $15 per hour, the cleaning labor cost has been reduced by $10,694 per year. S&H Machine also does not have to purchase detergent for four parts cleaners. Assuming each of the four parts cleaners required five gallons of detergent concentrate (one-third of the capacity), a detergent cost of $10 per gallon and that the parts cleaners are changed out three times per year, the cleaner cost has been reduced by $600 per year. By eliminating four of the parts cleaners, the electricity cost for heating the water-based cleaners has also been reduced. It is estimated that each parts cleaner carries an electricity cost of about $60 per year. Assuming that four parts cleaners have been eliminated, the cost savings are $240 annually. The total savings through eliminating four parts cleaners amounts to $11,534 annually.

When S&H Machine used the petroleum based lubricant and the mineral spirits as a cleaner, the mineral spirits, when it was spent, was poured in the machines and used to continually dilute the lubricant. When the company converted to water-based cleaning, mineral spirits had to be purchased separately to dilute the lubricant. S&H Machine estimates that the company purchased one drum every three months for this purpose. At a price of $148.50 per drum, the total annual cost of the mineral spirits amounted to $594. When S&H Machine converted to the alternative lubricants, the mineral spirits was no longer necessary for dilution.

Table 2-1 shows the cost comparison for S&H Machine for the petroleum based lubricant, the water miscible lubricant and the ester lubricant. The values show that use of the water miscible and the ester lubricant reduces the cost substantially. Use of the ester lubricant, the lubricant currently used, reduced the cost to S&H Machine by 11% and is saving about $30,000 per year. When the company used the petroleum lubricant, the lubricant, maintenance and disposal costs were much lower. This is more than offset by the much higher cleaning cost and the machining labor cost with the petroleum lubricant.

Table 2-1
Annualized Cost Comparison for S&H Machine Lubricants

	Petroleum Lubricant	Water Miscible Lubricant	Ester Lubricant
Annualized Capital Cost	-	$1,079	$1,079
Lubricant Cost	$1,584	$3,500	$3,402
Maintenance Labor Cost	-	$3,720	$3,720
Machining Labor Cost	$249,600	$224,640	$224,640
Disposal Cost	$360	$1,025	$1,025
Cleaning Cost Change	$11,534	-	-
Mineral Spirits Oil Dilution Cost	$594	-	-
Total Cost	$263,672	$233,964	$233,866

S&H Machine is happy with the conversion. As mentioned earlier, the ester lubricant provides more cooling capability than the petroleum-based lubricant. A limitation of the new lubricant, however, is that it does not provide the same lubricity. For the tapping application, in particular, S&H Machine uses one of two machines that still rely on the petroleum based lubricant.

Nelson Nameplate

Nelson Nameplate is a small company with about 250 employees located in Los Angeles, California. The company, which was founded in 1946, manufactures nameplates made of stainless steel, aluminum and brass and membrane switches. An example of the nameplates manufactured by Nelson Nameplate is shown in Figure 2-3. As part of the manufacturing, several operations including stamping, coating, screen printing, lithographic printing and cleaning are required.

Figure 2-3. Nameplates Manufactured at Nelson Nameplate

Nelson Nameplate is a very progressive company concerned about the environment and their workers. Several years ago, the company converted away from 1,1,1-trichloroethane (TCA), an ozone depleting solvent, to a water-based cleaning process. The company has also converted to alternative low-VOC cleanup materials in the screen and lithographic printing processes.

IRTA began working with Nelson on their stamping process as part of a project sponsored by EPA Region IX. The company was using two lubricants in the process used to stamp out the nameplates. The first lubricant was a vanishing oil which the company diluted to 50% concentration with isopropyl alcohol. An MSDS for this lubricant is shown in Exhibit 2-4. The second lubricant was a petroleum-based oil. An MSDS for this lubricant is shown in Exhibit 2-5. One of Nelson's stamping machines is shown in Figure 2-4. The metal is precut in sheets of various sizes

Exhibit 2-4
Original Vanishing Oil Used at Nelson Nameplate

Exhibit 2-5
Original Petroleum Based Lubricant Used at Nelson Nameplate

depending on the particular nameplate and prepared for printing. A single or multiple color print is applied to the metal. The large sheets of nameplates are stamped into smaller nameplates. The nameplates are then cleaned, inspected and packaged for shipping.

Figure 2-4. Stamping Machine at Nelson Nameplate

The lubricant used in the stamping process aids in increasing the accuracy of the cut and eliminating burrs. The lubricant must be compatible with the metals used to make the nameplates and also with the printing inks since they are applied before cleaning. In Nelson's process, the lubricant can remain on the nameplates for up to 72 hours before the nameplates are cleaned. Nelson wanted to examine alternative lubricants for two reasons. First, the company was finding increased rejects. After investigating, Nelson found that the lubricant that remained on the nameplates prior to cleaning was softening the printing inks. To resolve this, Nelson added another manufacturing step to bake and cure the ink a second time after cleaning. The company wanted to convert to an alternative lubricant to eliminate the second baking step. Second, Nelson wanted to adopt another lubricant to reduce their VOC emissions.

IRTA began testing alternative lubricants with Nelson. Two of the alternative lubricants were vegetable based and both softened the ink so they were unacceptable. The third alternative lubricant was a water-soluble lubricant and it was not acceptable because it left more burrs and rough edges on the metal. The fourth alternative lubricant that was tested was a vegetable-based oil that does not soften the ink. Nelson has converted to this lubricant in their stamping process. An MSDS for the lubricant is shown in Exhibit 2-6.

Exhibit 2-6
Final Vegetable Based Lubricant Used at Nelson Nameplate

Nelson used up to one gallon per day of the vanishing oil that was blended with IPA. This analysis assumes that the use of the diluted lubricant amounted to one-half gallon per day. On this basis and assuming 260 days per year, the company used 130 gallons per year of the diluted lubricant. The cost of the vanishing oil was $11.42 per gallon and the company pays $4.93 per gallon for IPA. The annual cost of the vanishing oil lubricant blended with IPA is $1,063. Nelson estimates that the company used between a few ounces and one gallon per day of the second lubricant, the petroleum based oil. Assuming the company uses one-half gallon per day and that there are 260 days per year, use of the second lubricant amounted to 130 gallons per year. The cost of the second lubricant is $21 per gallon. On this basis, the annual cost of the second lubricant amounts to $2,730. The annual cost of the two lubricants is $3,793. Nelson converted to the vegetable ester lubricant about eight months ago and purchased 24 gallons during that time. This translates into an annual usage of 36 gallons per year. The cost of the vegetable ester lubricant is higher than the two original lubricants, at about $35 per gallon. The annual cost of using the new lubricant is $1,260.

With the conversion to the new lubricant, Nelson was able to eliminate the second ink-baking step. The company baked the nameplates in an oven for 20 minutes twice a week. The savings in energy from avoiding the baking is negligible. The labor required for the baking is estimated by Nelson at 40 minutes a week. Assuming a labor rate of $10 per hour, the savings from eliminating the baking step is $347 annually.

Table 2-2 shows the cost comparison for the original and new alternative lubricants. The values show that conversion to the alternative lubricant reduced Nelson's costs by about 70%. Although the cost of the new vegetable lubricant is much higher than the cost of the two original lubricants, use of the new lubricant is much lower. The change resulted in the elimination of VOC emissions.

Table 2-2
Annualized Cost Comparison for Nelson Nameplate Lubricants

	Original Lubricants	Vegetable Ester
Lubricant Cost	$3,793	$1,260
Second Baking Labor Cost	$347	-
Total Cost	$4,140	$1,260

Fortner Engineering and Manufacturing, Inc.

Fortner is a small company with 50 employees located in Glendale, California. The company has been a licensed Federal Aviation Administration (FAA) repair station since 1968. Fortner repairs aircraft components like hydraulic flight controls, actuators and linkages for Boeing, Douglas and a number of airlines.

IRTA worked with Fortner in the past to assist the company in converting to water-based cleaning systems and acetone to replace a vapor degreaser that used 1,1,1-trichloroethane (TCA) and several batch loaded cold cleaners that used a VOC solvent. IRTA began work with Fortner again as part of a project sponsored by EPA Region IX on alternative lubricants. The project focus is on testing and demonstrating alternatives to VOC emitting lubricants and lubricants containing chlorinated paraffin extreme pressure additives. IRTA worked with Fortner to test alternatives to a petroleum based VOC emitting lubricant that the company used for honing operations on several substrates including aluminum, bronze, steel, stainless steel, nickel and chromium. Figure 2-5 shows one of the honing machines at Fortner. Exhibit 2-7 shows the MSDS for Fortner's VOC emitting honing oil.

Figure 2-5 Honing Machine at Fortner

IRTA tested three alternatives with Fortner. One lubricant was a synthetic lubricant. The company found this lubricant to be sticky and it left a residue on the equipment. The parts were more difficult to clean and the lubricant was not easy to work with. The second lubricant, a water-soluble vegetable oil, had an odor the workers didn't like. The third lubricant was a vegetable-based oil that the workers liked. An MSDS for this lubricant is shown in Exhibit 2-8. IRTA arranged for Fortner to conduct scaled up testing for seven months in one machine. The company decided to convert to this lubricant.

Fortner uses between 10 and 15 gallons of lubricant in their three honing machines each year. The price of the petroleum-based lubricant used by the company for many years is currently \$11.90 per gallon. Assuming a usage for this lubricant of 12 gallons per year, the annual cost of using the petroleum-based lubricant was \$143. One of the Fortner employees that used the alternative lubricant indicated that he believes that less of the new vegetable-based lubricant is required. Assuming a usage for the new lubricant of

Exhibit 2-7
Original Petroleum Based Lubricant Used at Fortner Engineering

Exhibit 2-8
Final Vegetable Based Lubricant Used at Fortner Engineering

nine gallons per year and based on its cost of $22.25 per gallon, the cost of purchasing the alternative lubricant is $200 annually.

The employees who tested the lubricant indicated that there are no labor changes in using the new lubricant. They also have experienced no change in the cleaning process in using the alternative. They prefer the new lubricant because it does not have the solvent odor the original lubricant had and because it does a good job on the parts.

Table 2-3 shows the annual cost comparison of the original and new alternative lubricant. Fortner's conversion to the vegetable based lubricant raises the annual cost by 40%. Use of the lubricant at this company is low, however, so the impact of the cost increase is minimal.

Table 2-3
Annualized Cost Comparison for Fortner Lubricants

	Petroleum Lubricant	Vegetable Lubricant
Lubricant Cost	$143	$200
Total Cost	$143	$200

Hydro-Aire

Hydro-Aire is a division of Crane located in Burbank, California. The company manufactures braking systems, pumps and air locking devices and is a subcontractor to Boeing. Hydro-Aire also repairs pumps used in military and commercial aircraft like the C-17 and C-130 transport.

When IRTA began working with Hydro-Aire on a lubricant project sponsored by EPA Region IX, the company was using a petroleum-based lubricant for their honing operations. An MSDS for this lubricant is shown in Exhibit 2-9. The employees did not like the odor of the lubricant and the company subsequently converted to a vegetable ester lubricant offered by the same supplier. The employees disliked the odor of this product as well.

Cleaning the honing oil has always been a problem for Hydro-Aire. The company wanted to find an alternative lubricant that was not petroleum-based, that did not have an objectionable odor and that was more easily cleaned. IRTA tested two different vegetable ester lubricants with the company. Hydro-Aire conducts honing on aluminum and stainless steel parts. The testing of alternative lubricants was performed primarily on aluminum because Hydro-Aire believes that honing of aluminum is more difficult. If the alternative lubricant worked for aluminum parts, it was reasoned that it would likely work for stainless steel parts as well. Figure 2-6 shows one of the machines where the testing was conducted.

Exhibit 2-9
Original Petroleum Based Lubricant Used at Hydro-Aire


Figure 2-6. Honing Machine at Hydro-Aire

Both of the alternative lubricants that were investigated were tested in a two-gallon recirculating reservoir system designed by IRTA. The reservoir could be placed inside the honing machine tray but did not require the entire lubricant tank to be changed out. The first alternative that was tested performed well at 100 percent concentration but cleaning the lubricant was still a major problem. The second alternative lubricant is a vegetable ester lubricant, which is water dilutable; it was selected because it is potentially easier to clean with Hydro-Aire's cleaning process. IRTA experimented to determine the optimal concentration of the lubricant. The first concentration tested was five percent; at this concentration the metal removed from the honed part built up on the honing stone and affected the honing adversely. At 15 percent, the honing was improved but was still not acceptable. At a 24 percent concentration, the build up was reduced and honing was improved but the microfinish of the part was rough. Finally, at about 33 percent concentration, there was virtually no build up and the finish was acceptable.

After the initial testing, IRTA helped Hydro-Aire change out their aluminum-honing machine and the company has been using the alternative lubricant for the last three months. Hydro-Aire has effectively converted to the alternative lubricant for processing the aluminum parts. An MSDS for this lubricant is shown in Exhibit 2-10.

IRTA analyzed and compared the cost of using the original petroleum based lubricant and the new alternative vegetable ester lubricant in the aluminum honing operation. The cost of the petroleum lubricant was $10.18 per gallon and the company used about one-half gallon each month. In addition, the 15 gallon capacity tank was changed out every

Exhibit 2-10
Final Vegetable Based Lubricant Used at Hydro-Aire

six months. The cost of using 36 gallons of lubricant per year amounted to $366. Use of the alternative vegetable ester lubricant is also about one-half gallon per month. This lubricant is used at a concentration of 33 percent and two gallons of water must be added every two weeks to compensate for evaporation. The 15 gallon tank is also changed out twice a year. The price of the alternative lubricant is $15 per gallon. On this basis, the cost of purchasing 16 gallons of the alternative lubricant each year amounts to $240.

The alternative water dilutable lubricant is easier to clean than the original lubricant. With the petroleum lubricant, the parts were soaked in a parts cleaner, then washed in the parts cleaner with a brush. A picture of the parts cleaner is shown in Figure 2-7. The parts were blown off with compressed air. The parts were then soaked in acetone for three minutes and blown off with air again. The parts were then put through an automated precision ultrasonic cleaning system where they went through an alkaline wash step, a deionized water rinse step and a drying step. Figure 2-8 shows the ultrasonic cleaning system. Finally, the parts were blown off again and inspected. In most cases, the parts had to be put through the ultrasonic cleaning system a second time. With the new lubricant, the parts are washed with a brush in the parts cleaner and blown off with compressed air. The parts are then put through the ultrasonic cleaning system only once.

Figure 2-7. Parts Cleaner at Hydro-Aire

The machinist at Hydro-Aire hones 50 parts in an eight-hour shift or two batches of 25 parts each. The parts are cleaned in batches. The first step--the cleaning in the parts cleaner and acetone--required 50 minutes of employee time during a shift with the petroleum lubricant. The second step--cleaning in the ultrasonic system--required 34 minutes of the employee time during a shift. The total amount of time spent cleaning during a shift was 84 minutes. After conversion to the vegetable ester lubricant, the cleaning time was reduced to half the amount of time or 42 minutes per shift. On this basis, cleaning the petroleum lubricant required 364 hours per year and cleaning with the vegetable ester lubricant required half the amount of time or 182 hours per year. Assuming Hydro-Aire's labor rate of $25 per hour, the cleaning cost of the petroleum lubricant amounted to $9,100 annually and the cleaning cost of the alternative lubricant amounts to $4,550.

Figure 2-8. Ultrasonic Cleaning System at Hydro-Aire

Table 2-4 shows the annualized cost comparison of the petroleum and vegetable ester lubricants for the aluminum honing operation. The cost of the honing operation has been reduced by about half through adoption of the alternative lubricant.

Table 2-4
Annualized Cost Comparison for Hydro-Aire Lubricants in Aluminum Honing Operation

	Petroleum Lubricant	Vegetable Ester Lubricant
Lubricant Cost	$366	$240
Cleaning Cost	$9,100	$4,550
Total Cost	$9,466	$4,790

IRTA also tested the lubricant in the stainless steel machines in a more limited way using the two-gallon recirculating system. The company is considering converting to the alternative lubricant in this honing operation as well. The company has two stainless steel honing machines and operates them each for two shifts. About 50 parts are processed during each shift for a total of 100 parts per day.

In the case of stainless steel, the concentration of the lubricant was optimal at 75 percent concentration. Assuming the two stainless steel honing machines would use twice as much lubricant as the aluminum machine, the cost of purchasing the petroleum lubricant is $732 per year. Because the concentration of the alternative lubricant required for stainless steel honing is higher, at 75 percent, the cost of the 57 gallons of the alternative vegetable ester lubricant would be $855 annually.

Twice as many parts are processed through the stainless steel honing operation as through the aluminum operation. During the testing, the stainless steel parts were again observed to be much easier to clean with the alternative lubricant. Assuming that the stainless steel parts require twice as much cleaning time as the aluminum parts and that adoption of the water dilutable lubricant would reduce the costs by half, the cost of cleaning with the petroleum lubricant is $18,200 annually. The cost of cleaning with the alternative vegetable ester lubricant is half the cost or $9,100 annually.

Table 2-5 shows the annualized cost comparison of the petroleum and vegetable ester lubricants for the stainless steel operation. Again, conversion to the alternative reduces the cost by about half.

Table 2-5
Annualized Cost Comparison for Hydro-Aire Lubricants in Stainless Steel Honing Operation

	Petroleum Lubricant	Vegetable Ester Lubricant
Lubricant Cost	$732	$855
Cleaning Cost	$18,200	$9,100
Total Cost	$18,932	$9,955

Weldcraft

Weldcraft is the world’s leading manufacturer of Tungsten Inert Gas (TIG) welding torches and accessories. The company is located in Burbank, California. Weldcraft was founded in a residential garage as a welding torch repair shop. The aerospace customers wanted to get more life out of their welding torches. The company modified the torches to use a silicone rubber compound, which doesn’t degrade like the old torches and the new torches are widely used today throughout the industry.

IRTA began work with the company as part of an EPA sponsored project on alternative lubricants. In conjunction with management, it was agreed that the work would focus on finding an alternative lubricant for the petroleum based lubricant used in a flooding system in the collet cell equipment. A collet holds the tungsten rod in the welding equipment. The collet cell equipment is a semi-automated machine that drills the collet, slots the length of the collet, redrills the collet and then stamps the part with the part number. Each station of the equipment has a lubricant spout and a steady flow of lubricant that "floods" the parts. The lubricant is collected in a pan and routed to a reservoir where it is recirculated through individual spouts on the machines. A picture of the cutting machine with flood lubrication is shown in Figure 2-9.

Figure 2-9. Flooding Lubrication at Weldcraft

Weldcraft was using a petroleum-based lubricant for the flooding operation. An MSDS for this lubricant is shown in Exhibit 2-11. IRTA decided to test an alternative vegetable ester lubricant in a near dry system. The MSDS for this lubricant is shown in Exhibit 2-12. The near dry approach minimizes the use of the lubricant; the lubricant is applied only at the point of contact with the part. A supply nozzle was positioned at each station. Each nozzle was supplied with lubricant through a centralized dispensing system through a flexible hose. The lubricant was mixed with air in the dispensing system. The near dry applicator was installed in one hour. A picture of a cutting machine with near dry lubrication is shown in Figure 2-10.

The alternative lubricant was tested for eight months at Weldcraft on one collet machine. Each collet machine processes 1,000 parts per day. Assuming the machine operates 260 days per year, each collet machine produces 260,000 parts per year. The alternative

Exhibit 2-11
Original Petroleum Based Lubricant Used at Weldcraft

Exhibit 2-12
Alternative Vegetable Based Lubricant Tested at Weldcraft

lubricant worked well but the drill life was reduced from one each 4,000 parts to one each 3,000 parts. On this basis, 65 drills were used each year with the petroleum lubricant and 87 drills were used each year with the vegetable ester lubricant. Weldcraft uses several different sizes of drills and the average cost of a drill is $5.65. On this basis, the cost of replacing drills with the petroleum lubricant is $367 annually and the cost of replacing drills with the vegetable ester lubricant is $492.

Figure 2-10 Cutting Machine with Near Dry Lubrication at Weldcraft

The flooding system requires half a gallon of the petroleum-based lubricant each week. It uses 26 gallons per year. In addition, the system, which has a capacity of 10 gallons, is cleaned and changed out completely once a year. Thus a total of 36 gallons of petroleum lubricant is used annually. At a cost of $4.68 per gallon, the total lubricant cost amounts to $168 per year. Over the eight-month testing phase, only one gallon of the vegetable ester lubricant was required. On this basis and assuming a cost of $52 per gallon, the annual cost of the vegetable ester lubricant would be $78. No cleaning or changeout of the lubricant is required in the case of the vegetable ester.

When the station is cleaned, the lubricant is discarded as waste. The cost for disposal of the petroleum based lubricant, at 65 cents per gallon, amounts to about $7 per year. The changout requires one hour. Assuming Weldcraft's labor rate of $17 per hour, the changeout labor cost is $17 annually.

Weldcraft has a leanjet cleaning system that is used to clean all the parts that are processed in the factory. The conditions are set to clean the most contaminated parts. Although in principle, the parts using the vegetable ester would be easier to clean because of the near dry conditions, no difference was noted during the testing phase.

Table 2-6 shows the annual cost comparison for Weldcraft's collet equipment. The annual costs of using the petroleum lubricant and the vegetable ester lubricant are comparable.

Table 2-6
Annualized Cost Comparison for Weldcraft's Collet Equipment Operation

	Petroleum Lubricant	Vegetable Ester Lubricant
Drill Replacement Cost	$367	$492
Lubricant Cost	$168	$78
Disposal Cost	$7	-
Changeout Labor Cost	$17	-
Total Cost	$559	$570

During the testing, Weldcraft was downsized and manufacturing engineering and technical support for a change was no longer a priority. The new management, under the circumstances, decided not to make a conversion at this time.

Dynaflex Products

Dynaflex began manufacturing flexible exhaust connectors in 1974 in Los Angeles. Today, the company's major market is chrome stacks that are used in the heavy duty truck market. Dynaflex also manufactures a wide variety of stainless steel bellows type expansion joints used on heavy duty diesel engines for applications involving off road construction equipment, stationary engines and military equipment like the M113 tank.

As part of manufacturing commercial and military exhaust piping, Dynaflex has bending, expanding, flanging, hydraulic forming, convoluting and welding operations. The size of the tubes ranges from one-half inch to 12 inches in diameter. Many of the tubes have multiple bends at tight angles. A picture of some of the tubes processed by Dynaflex is shown in Figure 2-11.

Dynaflex brings in the raw material which is cut to the appropriate length. The tubes are formed in a hydraulic tube bender. A picture of one of the tube bending machines is shown in Figure 2-12. The employees use sticks to apply a heavy honey oil to the inside of the tubes prior to bending. The lubricant is removed with a water cleaning system. In most cases, the tubes are chrome plated or polished and they are packaged and shipped.


Figure 2-11. Tubes Processed at Dynaflex


Figure 2-12. Tube Bending Machine at Dynaflex

Dynaflex historically used a lubricant that contains chlorinated paraffin extreme pressure additives. An MSDS for this lubricant is shown in Exhibit 2-13. Dynaflex contacted

Exhibit 2-13
Original Chlorinated Paraffin Lubricant Used at Dynaflex Products

IRTA because of difficulties in cleaning the lubricant from the tubes. The company was using a cleaner that emulsified rather than rejected the lubricant. The chlorinated paraffin additives sink to the bottom of the cleaning tank and also stratify throughout the bath. The cleaning bath must be changed out frequently because the oil cannot be physically removed. Some cleaners reject oil; it floats on the top of the bath and can be physically removed which lengthens the bath life. Because the lubricant containing the chlorinated paraffins is heavier than water, changing the process to a cleaner that rejects the oil so it floats on the surface would not necessarily fix the problem. IRTA encouraged the company to test alternative lubricants that did not contain chlorinated paraffin additives. This would eliminate the potentially dangerous additives and could make the cleaning process more effective and efficient.

IRTA and Dynaflex tested several alternative lubricants that did not contain chlorinated paraffin additives in the tube bending operation. An alternative lubricant must provide sufficient lubricity under the extreme pressures experienced by the tubes in the forming process. One of the lubricants that were tested caused galling on the outside of the tubes. Another one of the alternatives caused the tubes to split in the bending operation and it also damaged the mandril.

IRTA tested one alternative lubricant, based on a phosphoric acid ester that performed well. An MSDS for this lubricant is shown in Exhibit 2-14. The initial testing was conducted on five inch diameter carbon steel tubes with a 90 degree bend. Plant personnel judged that the lubricant performed as well as or better than the lubricant with chlorinated paraffin additives. IRTA provided Dynaflex with a five gallon sample for extended testing. The alternative lubricant had better lubricity and bending results and the operator preferred it over the lubricant with the chlorinated paraffin additives.

The alternative lubricant is less viscous, or thinner than, the lubricant with the chlorinated paraffin additives. This indicates that a different and more efficient application process would be possible with the alternative lubricant. Instead of applying the lubricant to the inside of the tubes with a stick, the operator could spray the lubricant on the inside of the tubes. The lubricant would be applied in a uniform way and there would be reduced lubricant use. According to a lubricant supplier, in other applications where companies have converted from a brushing process to a spray process, there has been a reduction in lubricant use of 30 to 40 percent. The current stick application method used by Dynaflex is similar to a brushing procedure.

IRTA conducted some testing of the alternative lubricant to determine whether or not the cleaning process could be improved if the company converted to the alternative lubricant. The specific gravity of the alternative lubricant is essentially the same as the specific gravity of water. This means that, even if the company converted to a cleaning agent that rejected oil, the lubricant might still sink to the bottom of the cleaning bath or be stratified in the cleaner. IRTA tested the alternative lubricant with the current cleaner and with a different cleaner that rejected oil in a laboratory setting. The results of the testing showed that the current cleaner completely emulsifies the oil. This indicates that it would not be possible to physically separate the lubricant from the cleaner. In contrast,

Exhibit 2-14
Alternative Lubricant Tested at Dynaflex Products

the rejecting cleaner does float oil to the top of the cleaner. This indicates that a skimming process would be capable of removing much of the lubricant from the surface of the cleaner. This, in turn, indicates it is likely that this cleaner would have a longer bath life than the current cleaner before change-out was necessary.

Two assumptions were made in the cost analysis. First, it was assumed that when Dynaflex adopted the alternative lubricant, the company would also implement the new spray application method. Implementation of the new application method would cut the application labor in half. Second, it was assumed that use of the new lubricant and a rejecting cleaner would allow continuous physical removal of the lubricant.

Dynaflex will incur a capital cost to change the lubricant application method from the stick method to the spray method. The company has nine lubricant application stations. Nine spray units will be required at a cost of $250 per unit. The total capital cost would amount to $2,250. Assuming a 10-year useful life of the equipment and a two percent cost of capital, the annualized cost of purchasing the application units is $230.

Dynaflex uses 40 gallons per month of the lubricant containing chlorinated paraffin additives. The cost of the lubricant is $11.16 per gallon. On this basis, the annual cost of purchasing the lubricant is $5,357. The new application method would reduce the use of the new alternative lubricant by 30 percent, to 28 gallons per month. The price of the new lubricant is $19.80 per gallon. Using this price, the annual cost of purchasing the new lubricant would amount to $6,653.

Use of the alternative application method will reduce the labor required for lubricant application. Employees at each of the nine application stations process 100 parts per day. It currently requires three minutes to apply lubricant using the stick method to every 10 parts. Assuming 260 operating days per year, the annual lubricant application labor is 1,170 hours. At a labor rate of $15 per hour for the bending operators, the annual cost of applying the lubricant currently is $17,550. The spray application method is more efficient and it is estimated that labor requirements will be cut by half. On this basis, the application labor using the spray method would amount to $8,775 annually.

Dynaflex currently uses a powder alkaline cleaner in a 500 gallon cleaning bath. The cleaning bath and an equivalent size rinse tank are changed out three times per year. About 250 pounds of the powder detergent are required each time to charge the bath. In addition, three pounds per week of makeup detergent are required. The cost of the detergent is 93 cents per pound. On this basis, the annual cost of purchasing detergent is $843. The alternative oil rejecting cleaner would require fewer change-outs of the bath. It was assumed that the bath would require change-out only twice a year. The cleaner is used at a five percent concentration. Thus, 25 gallons of detergent would be necessary for each change-out. Makeup detergent of four gallons per week would also be necessary to maintain the bath. The total amount of detergent would be 258 gallons per year. The price of the alternative detergent is $8 per gallon. On this basis, the cost of the alternative detergent would be $2,064 annually.

Dynaflex disposes of their wash and rinse baths three times per year. The price of disposal of the 1,000 gallons is $1,580. The annual cost of disposal, assuming disposal three times per year, is $4,740. One of the reasons for the high disposal cost is that the cleaner is classified as hazardous waste because of the high pH of the material. The alternative cleaner has a pH that is lower than the cutoff for hazardous waste. The disposal cost for oily wastewater would amount to no more than about $1 per gallon. The rinse water could be used as the makeup water for the cleaning bath and should not require disposal. If Dynaflex converted to the alternative cleaner, the wash bath would be changed out twice per year. Assuming the disposal cost of $1 per gallon, the total disposal cost would be reduced to $1,000 annually.

Dynaflex employees spend eight hours cleaning out the cleaning tanks for disposal. The labor rate for the employees is $10 per hour. With the current cleaner, three changouts are required annually and the labor cost associated with the changeouts amounts to $240 per year. Conversion to the alternative cleaner would reduce the number of changeouts to two per year. On this basis, the changeout labor cost would be $160 per year.

Dynaflex believes there would be several other benefits from changing the lubricant and the cleaning agent. These benefits could only be quantified after the conversions had been in place for some time. First, based on the testing results, use of the alternative lubricant will reduce the tool wear and increase bending operator throughput. The alternative lubricant is smoother and using the mandrel for bending the tubes should be faster. This would lead to labor and tool life savings. Second, the new lubricant is much easier to clean than the lubricant with chlorinated paraffin additives that is used currently. The alternative cleaner should be able to clean the new lubricant even faster than the current cleaner. The two changes will lead to savings in finish part cycle time, which would increase throughput and reduce production time.

Table 2-7 shows the annualized cost comparison for the current lubricant and cleaner and the alternative lubricant and cleaner. Dynaflex could reduce their costs by 34 percent through the conversions. In addition, the company could realize other savings that cannot be quantified at this time.

Table 2-7
Annualized Cost Comparison for Dynaflex

	Chlorinated Paraffin Lubricant	Alternative Lubricant
Annualized Capital Cost	-	$230
Lubricant Cost	$5,357	$6,653
Lubricant Application Labor Cost	$17,550	$8,775
Detergent Cost	$843	$2,064
Detergent Disposal Cost	$4,740	$1,000
Detergent Labor Changeout Cost	$240	$160
Total Cost	$28,730	$18,882

B&B Specialties, Inc.

B&B Specialties is located in Anaheim, California. The company has a 40,000 square foot manufacturing facility and employs 56 people. B&B Specialties manufactures commercial, military and aerospace fasteners or socket screws and specializes in cold forming and thread rolling. The fasteners are sold through a distribution sales network as standard and custom products.

B&B uses wire in various different stainless steel and stainless steel alloy grades to make the fasteners. Figure 2-13 shows wire feeding to one of the machines. The first step in the process is cold heading, which forms the blank. In this forming process, the wire is fed to the heading equipment. Cold heading involves applying force with a punch to the end of a metal blank contained in a die. In heading, a head is formed on a fastener. The second step is to clean the lubricant from the formed parts. The third step, for one of the stainless steel types, is bead blasting. The fourth step is knurling. The fifth step is roll threading and the sixth and final step is cleaning. A picture of some of the fasteners made by B&B Specialties is shown in Figure 2-14.


Figure 2-13. Wire Feeding to Machine at B&B Specialties

About 30 percent of the substrate used by B&B is A286, a stainless steel that is subsequently heat-treated. When the wire is fed to the heading equipment, it is heated to between 400 and 600 degrees F. The socket of the fastener is blackened or discolored during this process and the blackening is removed in a process prior to heat-treating.

Figure 2-14. Fasteners Made by B&B Specialties

Another 30 percent of the substrate used by B&B is alloy. This is a softer material, which requires less pressure to form. Less heated is generated during the process and the material is not blackened.

Another 30 percent of the substrate used by the company is 302SST. This stainless steel material is blackened during the forming process. It is not heat-treated and it requires bead blasting to remove the blackening in the socket. B&B Specialties must send out the stainless steel for bead blasting at an average cost of approximately $50,000 per year. In high production years, the cost might be as high as $100,000. The company is interested in alternative lubricants, primarily to eliminate the need for the outside bead blasting.

B&B Specialties currently uses a thick honey-oil with chlorinated paraffin extreme pressure additives. An MSDS for this lubricant, called Combo Base 1100, is shown in Exhibit 2-15. IRTA worked with the company to test alternative lubricants that contained no chlorinated paraffin additives in the cold heading process. Several lubricants were tested but they failed because of the extreme heat generated in the process.

An MSDS for one of the alternative lubricants, Called Gardolube L6444, is shown in Exhibit 2-16. This lubricant is a polymer with molybdenum sulfide additives. It is best used in a 50 percent dilution with water. When the lubricant was first tested, it failed because the dried lubricant was building up on the die and punch, which damaged the punch and caused quality problems on the fasteners. After investigation, it was determined that the lubricant was clogging in the relief vanes in the tooling rather than

Exhibit 2-15
Original Chlorinated Paraffin Lubricant Used at B&B Specialties

Exhibit 2-16
Alternative Polymer Lubricant Tested at B&B Specialties

draining through them. The relief vanes allow the lubricant to exit the die as the punch pushes the material into the die forming the fastener. When the lubricant is prevented from exiting the die during the forming process, a hydraulic action causes the fastener to be deformed. It is probable that the water in the lubricant was boiling off because of the heat created in the high-pressure process.

IRTA investigated alternative dilution materials. The requirements for the dilution material were that it be close to zero in VOC content and that it boil at a temperature well above the boiling point of water. IRTA purchased antifreeze from an automotive supply store and tested it in a 50 percent combination with the polymer lubricant. Antifreeze is a mixture of ethylene glycol and propylene glycol. Although the VOC content of the antifreeze is unknown, the vapor pressure of both ingredients is low enough to suggest that it would have very low VOC content. The lubricant and antifreeze mixture was tested at B&B Specialties on a stainless steel part (302SST) successfully. IRTA and B&B Specialties wanted to test the lubricant on a part that is very difficult to form. Testing was conducted on a stainless steel fastener with a diameter of 0.375 inches and a length of 1.5 inches. The run consisted of 5,500 parts and the lubricant performed well. The relief vanes did not clog during the run and the fasteners were not blackened. Because the lubricant worked successfully on these parts, it likely would be a suitable alternative for all of B&B's parts.

Approximately three gallons of the alternative lubricant were used to process the 5,500 part run. Typically, a run of this size would require two gallons of the currently used lubricant. The lubrication system, which consists of the pressure regulator, hoses and lubrication valve, has been designed to handle the thick honey oil used today. The alternative polymer lubricant is less viscous. The lubricant application system could easily be modified and optimized to accommodate the use of alternative lubricant. This modification would minimize the use of the polymer lubricant. If the modification were made, the use of the polymer lubricant would be equivalent to the use of the lubricant used currently.

B&B Specialties has a water-based cleaning system that is used to remove the lubricants that are used currently. A picture of the system is shown in Figure 2-15. A major issue that arose during the testing is that the current water cleaning system cannot remove the polymer lubricant from the parts after forming. IRTA has worked with B&B Specialties to test a few alternative water-based cleaners but has not yet found one that can remove the polymer lubricant. IRTA and B&B Specialties plan to continue testing cleaners to find one that is effective.

B&B Specialties uses 55 gallons per month or 660 gallons per year of their current lubricant. The cost of the lubricant is $13.40 per gallon. The cost to B&B Specialties for purchasing the lubricant is $8,844 annually. The cost of the alternative polymer lubricant is very high, at $50.80 per gallon. IRTA investigated the toxicity of ethylene glycol and propylene glycol. Ethylene glycol is on EPA's Hazardous Air Pollutant (HAP) list but propylene glycol is not. The blend that IRTA would propose is 50 percent of the alternative lubricant and 50 percent propylene glycol. The lubricant could be blended with the propylene glycol by the supplier. The price of propylene glycol is about $6.00 per gallon. On this basis, the cost of the lubricant blend would amount to $28.40 per gallon. If B&B Specialties did not make modifications to the equipment, the company would use 1.5 times as much of the new lubricant or 990 gallons per year. The cost of purchasing the alternative lubricant in this scenario would be $28,116 per year. If B&B Specialties did decide to modify the equipment, the company would use the same amount of the alternative lubricant as the currently used lubricant. On this basis, use of the alternative lubricant would amount to 660 gallons per year. At a cost of $28.40 per gallon, the annual lubricant cost would be $18,744.

Figure 2-15. Agilift Cleaning System at B&B Specialties

In one of the scenarios examined above, conversion to the alternative lubricant would require modifications to the lubrication system on all the cold heading equipment. Each piece of equipment would require a three-eighths needle valve to be placed in the line between the pressure pot containing the lubricant and the lubrication valve to allow the machinist to reduce the flow of lubricant. B&B Specialties has 15 cold heading machines. The cost of the needle valve is $17 and each machine will also require two compression fittings at $6.00 each. The cost of the materials for the modification is $435. Installation of the valves will require about one-half hour of labor. Assuming a labor rate of $20 per hour, the labor cost of the installation would be $150. The total cost of the modification is $585. Assuming this modification is spread over 15 years and assuming a cost of capital of four percent, the annualized cost of the equipment modification would be $41.

With the current lubricant, B&B Specialties contracts out the bead blasting of all the 302 stainless steel parts. The cost of this service is, on average, $50,000 per year. With the new lubricant, the testing indicated that there was no blackening of the socket internal diameter. Thus, with the current lubricant, there is an additional $50,000 cost for blasting that would not be needed with the new alternative lubricant.

Two different scenarios were examined for the cost analysis. The first scenario assumes that 1.5 times as much of the alternative lubricant is needed. Under this scenario, B&B Specialties decided not to modify the cold heading machines or the company did modify the machines and the expected reduction in lubricant use was not realized. The second scenario assumes that the reduction in lubricant use is realized. In both scenarios, it was assumed that an alternative cleaning agent, capable of cleaning the alternative polymer lubricant, could be found. It was also assumed that the cost of using the new cleaner would be the same as the cost of using the current cleaner.

Tables 2-8 and 2-9 below summarize the cost comparison under the two scenarios. The figures of Table 2-8 demonstrate that, even if the modifications to the machines do not reduce the use of the alternative lubricant, the cost of using the alternative lubricant is less than half the cost of using the current lubricant. The figures of Table 2-9 show that if the use of the alternative lubricant can be minimized, the cost or using the alternative lubricant is reduced by about 68 percent. Both scenarios assumed that a new cleaner can be found. Even if use of the new cleaner raised the cost of cleaning for B&B Specialties by about $30,000 per year, use of the new alternative lubricant would still be cost effective.

Table 2-8
Annualized Cost Comparison for B&B Specialties
High Alternative Lubricant Use Scenario

	Chlorinated Paraffin Lubricant	Polymer Lubricant
Annualized Machine Modification Cost	-	$41
Lubricant Cost	$8,844	$28,116
Bead Blasting Cost	$50,000	-
Total Cost	$58,844	$28,157

Table 2-9
Annualized Cost Comparison for B&B Specialties
Low Alternative Lubricant Use Scenario

	Chlorinated Paraffin Lubricant	Polymer Lubricant
Annualized Machine Modification Cost	-	$41
Lubricant Cost	$8,844	$18,744
Bead Blasting Cost	$50,000	-
Total Cost	$58,844	$18,785

Metalite Manufacturing Company

Metalite Manufacturing Company, located in Pacoima, California, manufactures metal products for commercial, medical, military, aerospace, food processing and other markets. The company is a versatile job shop specializing in deep drawing metal cans and other stamped parts to particular specifications. The company has several metal working draw, double action mechanical and multiple action hydraulic presses and other tooling. One of the presses is shown in Figure 2-16. Metalite can draw and redraw the metal up to three times in one cycle and has drawn parts 20 inches deep. The substrates that have been processed by Metalite include steel, stainless steel, aluminum and various other types of metals.

Figure 2-16. Press at Metalite

Deep drawing is a very stressful activity. It is a metal forming process where a flat sheet of metal is formed or drawn by a press into a seamless can. As the material is drawn into the die by the punch, it flows into a three dimensional shape. Drawing is considered deep when the product formed is deeper than half its diameter. A picture of a worker processing a part at Metalite is shown in Figure 2-17.

Metalite uses three lubricants that have chlorinated paraffin additives to handle the stress of the draws in the deep drawing process. MSDSs for the three lubricants are shown in Exhibits 2-17, 2-18 and 2-19. Exhibit 2-17, called Paroil 140, is a pure chlorinated

Exhibit 2-17
Original Paroil 140 Chlorinated Paraffin Lubricant Used at Metalite Manufacturing Company

Exhibit 2-18
Original Arrow 337 Chlorinated Paraffin Lubricant Used at Metalite Manufacturing Company

Exhibit 2-19
Original A71 Chlorinated Paraffin Lubricant Used at Metalite Manufacturing Company

paraffin. This lubricant is used for most of the short manufacturing runs of stainless steel, steel and other metals excluding aluminum. Exhibit 2-18 is the MSDS for Arrow 337, a chlorinated paraffin lubricant with emulsifying additives. It is used on stainless steel and other metals. Exhibit 2-19 is a petroleum-based lubricant with chlorinated paraffin additives called A71. This lubricant is used exclusively on large domed parts. Metalite uses another lubricant, a solid paste with no chlorinated paraffin additives, that is used exclusively on aluminum parts.

Figure 2-17. Worker Processing Part at Metalite

IRTA worked with Metalite to test a number of alternative lubricants that did not contain chlorinated paraffin additives. The alternatives were tested on stainless steel, which accounts for about 70 percent of Metalite's production. Paroil 140 and Arrow 337 are both used on stainless steel. The alternatives were poured into a pressure spray applicator and sprayed on both sides of a flat stainless steel blank before the first draw. This is the method Metalite uses to apply their chlorinated paraffin based lubricants.

Some of the lubricants that were tested failed immediately and some were able to process a number of parts before unacceptable galling or scratching occurred. Other lubricants did not gall but the metal thickness was not acceptable; these alternatives were not tested further. One lubricant, called Arrow 20458, was successful for three draws of a stainless steel can. After the first draw, the dimensions of the can are 8 inches in diameter and 4 inches in depth. The second draw forms the can into a product with a 5.5 inch diameter and a 6 inch depth. Finally, the third draw results in a can with a 4.375 inch diameter and a 7.125 inch depth. This three-stage draw represents the most challenging test of a lubricant. The successful test indicates that the lubricant would likely work effectively for all of Metallite's production that requires lubricants with chlorinated paraffin additives.

An MSDS for the Arrow 20458 lubricant is shown in Exhibit 2-20. Chem Arrow Corporation, the manufacturer of the lubricant, indicates the lubricant is very new and is presently considered an "exotic" material. It is currently produced in very small quantities.

During the testing, some of the parts that were made with the alternative lubricant were cleaned using the water-based cleaning process Metalite has currently. The cleaning effectiveness was about the same as it is for the current lubricants.

Metalite purchases 525 gallons of the Paroil 140, 1,100 gallons of the Arrow 337 and 110 gallons of the A71 each year. Metalite also purchases 660 gallons of the non-chlorinated paraffin lubricant called Safety Draw 700 that is used on aluminum. The cost of the Paroil 140 is $8.97 per gallon; the cost of the Arrow 337 is $14.60 per gallon; the cost of the A71 is $16.94 per gallon and the cost of the Safety Draw 700 is $14.17 per gallon. On this basis, the cost of using the Paroil 140 is $4,709 per year, the cost of using the Arrow 337 is $16,060 per year, the cost of using the A71 is $1,863 per year and the cost of using the Safety Draw 700 is $9,352 per year.

During the testing of the alternative Arrow 20458 lubricant, the operators indicated that use of the lubricant was about the same as the use of the chlorinated paraffin lubricants. The cost of this lubricant is $24.56 per gallon. Assuming that the new alternative lubricant can replace the Paroil 140, the Arrow 337 and the A71, the annual cost of using the alternative lubricant would be $42,612. Metalite would still use the Safety Draw 700 for the aluminum parts at a cost of $9,352 per year.

Table 2-10 shows the cost comparison of the current and new alternative lubricants. The cost of using the alternative non-chlorinated paraffin lubricant is 62 percent higher than the cost of using the chlorinated paraffin lubricants that are used currently.

Table 2-10
Annualized Cost Comparison for Metalite

	Current Lubricants	Alternative Lubricant
Cost of Paroil 140	$4,709	-
Cost of Arrow 337	$16,060	-
Cost of A71	$1,863	-
Cost of Safety Draw 700	$9,352	$9,352
Cost of Arrow 20458	-	$42,612
Total Cost	$31,984	$51,964

IRTA also examined a different cost scenario for Metalite. As mentioned above, the Arrow 20458 lubricant was only recently developed and it is manufactured in very small quantities. The price of the lubricant, at $24.56 per gallon, is accordingly high. When products are first marketed, their price is often high until substantial quantities of the product are manufactured. The price, after larger quantities are produced, can be 70 to 80 percent lower than the initial market price. For the second scenario, IRTA assumed that

Exhibit 2-20
Alternative "Exotic" Lubricant Tested at Metalite Manufacturing Company

the price of the new alternative lubricant would be cut in half when production volume increases. Table 2-11 shows the cost comparison based on this assumption. The total lubricant cost to Metalite currently and with the new lubricant is comparable.

Table 2-11
Annualized Cost Comparison for Metalite
Assuming Larger Production Volume for Alternative Lubricant

	Current Lubricants	Alternative Lubricant
Cost of Paroil 140	$4,709	-
Cost of Arrow 337	$16,060	-
Cost of A71	$1,863	-
Cost of Safety Draw 700	$9,352	$9,352
Cost of Arrow 20458	-	$21,306
Total Cost	$31,984	$30,658

III. RESULTS AND CONCLUSIONS

This project involved working with eight manufacturers in Southern California that use lubricants in their production process. The companies that participated in the project represented a range of different manufacturing operations that use lubricants. Five of the eight companies used lubricants that were vanishing oils or contained dilution solvents. These lubricants are classified as VOC emitting lubricants. Four of the eight companies used lubricants containing chlorinated paraffin additives, which are generally used in extreme pressure processes. Some of the short chain chlorinated paraffins are considered to be carcinogens.

IRTA undertook this project to determine if there are acceptable alternatives to VOC emitting lubricants and lubricants with chlorinated paraffin additives. The results of the project indicate that alternatives to these lubricants are available. This suggests that in California where smog is a problem, regulations that restrict emissions of VOC emitting lubricants could be implemented. IRTA estimates that VOC emissions in the South Coast Basin could be reduced by five to 15 tons per day if the lubricants were regulated. The results of the project also indicate that there are suitable alternatives to lubricants containing chlorinated paraffin additives. This finding suggests that the chlorinated paraffins could be phased out.

S&H Machine, a small typical machine shop, used a VOC emitting petroleum-based lubricant with chlorinated paraffin additives. The company converted to a water miscible synthetic lubricant and reduced their annual costs by about 11 percent. S&H Machine later converted to a vegetable ester lubricant that had roughly the same annual costs as the water miscible lubricant.

Fortner Engineering, a small company that repairs aircraft components, used a VOC emitting petroleum based lubricant in their honing operations. The company converted to a vegetable-based lubricant and increased their annual costs by about 40 percent. The cost of Fortner's lubricant use is small, however, so the absolute cost increase is minimal.

Hydro-Aire, a manufacturer of aircraft braking systems, used a VOC emitting petroleum-based lubricant in their honing operations. The company converted to a vegetable based lubricant for their aluminum substrates and is in the process of converting to the alternative lubricant for their stainless steel substrates. In both cases, the company cut their annual costs approximately in half because use of the new lubricants reduces their cleaning costs.

Weldcraft, a manufacturer of welding torches, used a VOC emitting petroleum-based lubricant in a flooding operation. IRTA successfully tested an alternative vegetable-based lubricant in a near dry operation with the company. The annual cost of using the two lubricants was approximately the same. Weldcraft did not convert to the alternative lubricant because the company downsized soon after the testing.

Dynaflex Products, a manufacturer of flexible exhaust connectors, used a petroleum-based lubricant with chlorinated paraffin additives in their tube bending operations. The company is in the process of converting to an alternative lubricant that does not contain chlorinated paraffin additives. Dynaflex is also changing their application method to apply the lubricant more efficiently. Finally, the company is changing their cleaning process, which should be easier with the alternative lubricant. The annual cost of using the alternative lubricant would be lower by 34 percent.

B&B Specialties, a fastener manufacturer, uses a chlorinated paraffin petroleum based lubricant in their cold heading operations. IRTA tested an alternative polymer lubricant with the company that performed well. IRTA and B&B Specialties are still testing alternative cleaning agents to identify one that will clean the polymer lubricant effectively. If a cleaning agent can be found, B&B Specialties could reduce their annual costs by about half by adopting the alternative lubricant. If the company also modified their machines to use the new lubricant optimally, the costs could be reduced further, by 68 percent.

Metalite Manufacturing Company, a manufacturer of many metal products, uses chlorinated paraffin petroleum based lubricants in deep drawing operations. IRTA identified and successfully tested an alternative lubricant that does not contain chlorinated paraffin additives. The alternative lubricant is an "exotic" material that is not used yet in the market. The cost of using the alternative lubricant is 62 percent higher than the cost of using the chlorinated paraffin lubricants. If the price of the lubricant declines as expected when products are more widely commercialized, the cost of using the alternative lubricant would be comparable to the cost of using the chlorinated paraffin lubricants.

Four of the five the companies that used VOC emitting petroleum based lubricants converted to the alternative non-emitting lubricants in the course of the project. The fifth manufacturer downsized and did not make the conversion. One of the four companies using lubricants with chlorinated paraffin additives also used VOC emitting lubricants. This company converted to an alternative that did not contain chlorinated paraffin additives. Two of the other companies using chlorinated paraffin lubricants in extreme pressure applications are in the process of converting to alternatives with no chlorinated paraffin additives. The fourth company, also using chlorinated paraffin lubricants in an extreme pressure application, conducted a successful test of an alternative and may decide to convert their process in the future.

Appendix
Case Studies for Companies That Adopted Alternative Lubricants

BURBANK MACHINE SHOP CONVERTS TO NON-VOC LUBRICANT
Adopts Vegetable Ester Oil

S&H Machine is a small machine shop with 13 employees located in Burbank. The company is a job shop that machines parts made of aluminum, stainless steel and carbon steel. Many of the parts are complex with blind holes and threads. S&H Machine's primary customers are aerospace subcontractors.

Like other machine shops, S&H Machine used mineral spirits for cleaning the oil from the parts. The company has 21 stations where operators machine parts. After the parts were machined, the workers cleaned them in coffee cans that contained mineral spirits. When the mineral spirits was spent, it was simply poured in the machines to dilute the petroleum-based oil to the proper consistency.

When the South Coast Air Quality Management District (SCAQMD) amended Rule 1122 "Solvent Degreasers" to require lower VOC content cleaners, IRTA worked with S&H Machine to identify and test water-based cleaners. The company purchased eight parts cleaners and began cleaning the machined parts with a water-based cleaner instead of the mineral spirits.

David Fisher, Manager and Vice President of S&H Machine, wanted to simplify his operations after the company converted to water-based cleaners. "Cleaning our petroleum based oil with mineral spirits was so much easier than cleaning with water-based cleaners," he said. "I began testing other kinds of oils."

S&H Machine first converted to a semi-synthetic lubricant that was miscible with water instead of solvent and used it for a few years. The lubricant worked well but maintenance and disposal costs were higher than for the petroleum lubricant. Mr. Fisher continued examining other lubricants and recently converted to a vegetable ester based lubricant. "We like the vegetable oil the best," he says. "It does cost more than the original oil, but it does a very good job on the parts and we reduced our costs overall. I got rid of four of the parts cleaners and simplified the cleaning process and also increased the efficiency of the machining."

Annualized Cost Comparison for S&H Machine Lubricants

	Petroleum Lubricant	Water-Miscible Lubricant	Ester Lubricant
Annualized Capital Cost	-	$1,079	$1,079
Lubricant Cost	$1,584	$3,500	$3,402
Maintenance Labor Cost	-	$3,720	$3,720
Machining Labor Cost	$249,600	$224,640	$224,640
Disposal Cost	$360	$1,025	$1,025
Cleaning Cost Change	$11,534	-	-
Mineral Spirits Oil Dilution Cost	$594	-	-
Total Cost	$263,672	$233,964	$233,866

NAMEPLATE COMPANY CONVERTS TO NON-EMITTING LUBRICANT
New Vegetable Oil Reduces Costs

Nelson Nameplate, a company with 250 employees, has been operating in Los Angeles since 1946. The company makes metal nameplates of all kinds and also manufactures membrane switches. Nelson conducts a range of different processes like cleaning, screen and lithographic printing and stamping.

IRTA began working with Nelson on a project sponsored by EPA Region IX that focused on lubricants. The project involved identifying, testing and demonstrating alternatives to emitting lubricants and lubricants that contained chlorinated paraffin extreme pressure additives. In their stamping process, Nelson was using two lubricants, one a vanishing oil that was diluted with isopropyl alcohol and another that was a petroleum based lubricant. There are VOC emissions from both of these lubricants.

Nelson was interested in testing alternative lubricants because they wanted to eliminate the lubricant VOC emissions. Another reason Nelson wanted to find an alternative was that the lubricants the company was using softened the ink on the nameplates requiring a second baking step to cure the ink again. IRTA tested three lubricants that were not acceptable to Nelson. Two of them softened the ink like the company's original lubricants and one, a water-soluble lubricant, left more burrs and rough edges on the metal. The fourth lubricant that was tested was a vegetable ester oil that did not soften the ink. The company decided to adopt this lubricant and has been using it for about eight months.

According to Sam Wong, who is responsible for environmental issues at Nelson, "the lubricant from the stamping process can remain on the parts for up to 72 hours. We needed a lubricant that wouldn't soften the ink during that time." He adds, "the employees like the new lubricant; it seems to perform well for our purposes."

Nelson is a very progressive company and has worked to implement alternatives in their cleaning, screen printing and lithographic printing operations. Tom Cassutt, owner and President of Nelson, is committed to reducing VOC emissions. "The new lubricant works well and we were able to eliminate VOC emissions from the stamping process," he says. "I'm always looking for ways to make the processes safer for the employees especially when we can save money doing it."

Annualized Cost Comparison for Nelson Nameplate Lubricants

	Original Lubricants	Vegetable Ester
Lubricant Cost	$3,793	$1,260
Second Baking Labor Cost	$347	-
Total Cost	$4,140	$1,260

SMALL GLENDALE AEROSPACE SUBCONTRACTOR CONVERTS TO SAFER LUBRICANT

Fortner Engineering and Manufacturing, Inc. has 50 employees and is located in Glendale, California. The company repairs aircraft components like actuators, linkages and flight controls for various airlines, Boeing and Douglas. Fortner is a licensed Federal Aviation Administration repair station.

Fortner is a progressive company and converted all of their solvent cleaning operations to water-based cleaners and acetone some years ago; the regulations do not require the conversion until January 1, 2005. More recently, IRTA began working with Fortner as part of an EPA Region IX sponsored project to test and demonstrate alternative safer lubricants.

Fortner performs a variety of machining operations as part of their activities. The company has three honing machines that are used for honing parts made of various substrates including aluminum, bronze, steel, stainless steel, nickel and chromium. When IRTA began working with Fortner, the company used a VOC emitting petroleum based honing oil that is widely used by aerospace subcontractors.

IRTA tested three alternative non-VOC emitting lubricants with Fortner. The company did not like two of the lubricants but has adopted the third lubricant. It is a vegetable based oil and testing indicated that less lubricant is required to do the same operations as the petroleum-based lubricant Fortner has used for many years.

“We want to be ahead of the game in using safer alternatives before the regulations go in place,” says Jim Fortner, Vice President and owner of Fortner. “We converted our cleaning operations before we were required to and we want to do the same with the lubricants.”

The two employees who do the honing like the vegetable based lubricant better than the original lubricant. One employee commented that he doesn’t go home smelling like solvent anymore.

The cost of the alternative lubricant is higher than the cost of the original lubricant. Even though less of the new lubricant is required, the total cost of using the new lubricant is higher. Jim Fortner comments, “The cost of the vegetable oil is higher but the company policy is to use safer materials whenever possible. It’s better for the employees and for the environment.”

Annualized Cost Comparison for Fortner Lubricants

	Petroleum Lubricant	Vegetable Lubricant
Lubricant Cost	$143	$200
Total Cost	$143	$200

AEROSPACE SUBCONTRACTOR CONVERTS TO VEGETABLE ESTER LUBRICANT IN HONING OPERATION

Hydro-Aire is an aerospace subcontractor with 572 employees located in Burbank, California. The company manufactures braking systems, pumps and air locking devices and serves as a Boeing contractor. Hydro-Aire also repairs pumps that are used in military and commercial aircraft like the C-130 transport and the C-17.

IRTA began work with Hydro-Aire on an alternative lubricant project sponsored by EPA Region IX. The company was using a petroleum-based lubricant in their aluminum and stainless steel honing operations. Similar petroleum lubricants are used by a number of other aerospace subcontractors in their honing operations.

Hydro-Aire was motivated to examine alternative lubricants primarily because the petroleum-based lubricant was very difficult and time consuming to clean after the honing operation. The employees also disliked the odor of the lubricant. The company converted to a vegetable-based lubricant offered by the same supplier, but the odor and cleaning problems persisted.

IRTA and Hydro-Aire tested two alternative lubricants in the aluminum honing operation in a small recirculating reservoir device designed by IRTA. The reservoir allowed alternative lubricants to be tested without changing out the larger honing machine reservoir. The first alternative lubricant that was tested did not clean easily. The second alternative lubricant, a water dilutable vegetable ester, worked well in the honing operation and also cleaned much more easily than the petroleum lubricant. Hydro-Aire changed out the aluminum honing machine and used the alternative lubricant for several months.

“We decided to convert our aluminum honing operation because the new lubricant didn’t have an odor and it was much easier to clean,” says Tommy Jennings, Environmental Manager at Hydro-Aire. “The new lubricant is safer and it does not require solvent for dilution.”

IRTA and Hydro-Aire also tested the alternative lubricant in the stainless steel honing operation in a more limited way. Hydro-Aire is considering converting to the alternative lubricant in that operation as well.

Even though it has a higher cost than the petroleum lubricant, smaller quantities of the alternative vegetable ester lubricant are required because it can be diluted with water. According to Mr. Jennings, “we cut our costs in half in the aluminum honing operation primarily because of the reduced labor in the cleaning with the new lubricant. We think we can cut our costs significantly if we convert the stainless steel operation as well. It’s a win-win situation.”

Annualized Cost Comparison for Hydro-Aire Lubricants in Aluminum Honing Operation

	Petroleum Lubricant	Vegetable Ester Lubricant
Lubricant Cost	$366	$240
Cleaning Cost	$9,100	$4,550
Total Cost	$9,446	$4,790