P2 in Precision Manufacturing & Metal Fabrication

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Introduction

The Minnesota Technical Assistance Program in partnership with the Minnesota Pollution Control Agency has completed a grant-funded project for pollution prevention assistance for the metal fabrication sector. The project has utilized an informational interview strategy to verify pollution prevention options within the Minnesota metal fabrication industry. Best practices and source reduction opportunities have been shared broadly within the sector through newsletters, published articles, and a webinar. MnTAP then conducted technical assistance assessments to industry sites to recommend and implement identified best practices and pollution prevention options. This work also defined chemicals used across the industry and evaluated specific hazards associated with these chemicals. All hazardous materials were taken into consideration, but the primary focus was on TRI chemicals and Minnesota priority materials: per-and polyfluoroalkyl substances (PFAS) materials, n-propyl bromide (nPB), dichloroethylene (DCE), sources of chloride release, and cutting fluids and oils. Other opportunities such as water conservation and energy efficiency were assessed in alignment with the needs and priorities of industry members.

MnTAP conducted interviews in 2021 and 2022 with companies in the sector. The purpose of these interviews was to characterize a portion of Minnesota's metal fabricators, understand current trends and challenges, and learn about industry best practices and opportunities for pollution prevention. This paper summarizes the results of these interviews and highlights opportunities for pollution prevention technical assistance to share findings with the industry.

Survey and Interview Discussion

Process Overview

MnTAP conducted outreach to companies to request participation in completing a survey and interview. Companies were selected by using Mergent Intellect data to generate lists of manufacturers in Minnesota with NAICS codes starting with 332 – Fabricated Metal Product Manufacturing. MnTAP also used existing contacts and records in internal client management database to connect with companies.

The interview process consisted of two steps: 1.) a standardized electronic survey, and 2.) a follow up interview with the company consisting of nine standard questions and additional customized follow up questions addressing some of the responses on the survey. The survey was modular and asked pertinent follow up questions based on respondents' answers to gain further information on their activities and processes. During the interview portion, the focus was given primarily to learning about waste reduction opportunities and pollution prevention best practices at the company. Successful and innovative initiatives that MnTAP learned were highlighted in MnTAP case studies.

Interviews took place through various media including over the phone, video conference calls, and in person at the company. In-person interviews offered the opportunity for a site tour of the facility and further collection of information.

Survey and Interview Results

The following section consists of charts displaying results from the electronic survey and informational interviews. Charts include responses from all 14 respondents unless otherwise indicated in the caption.

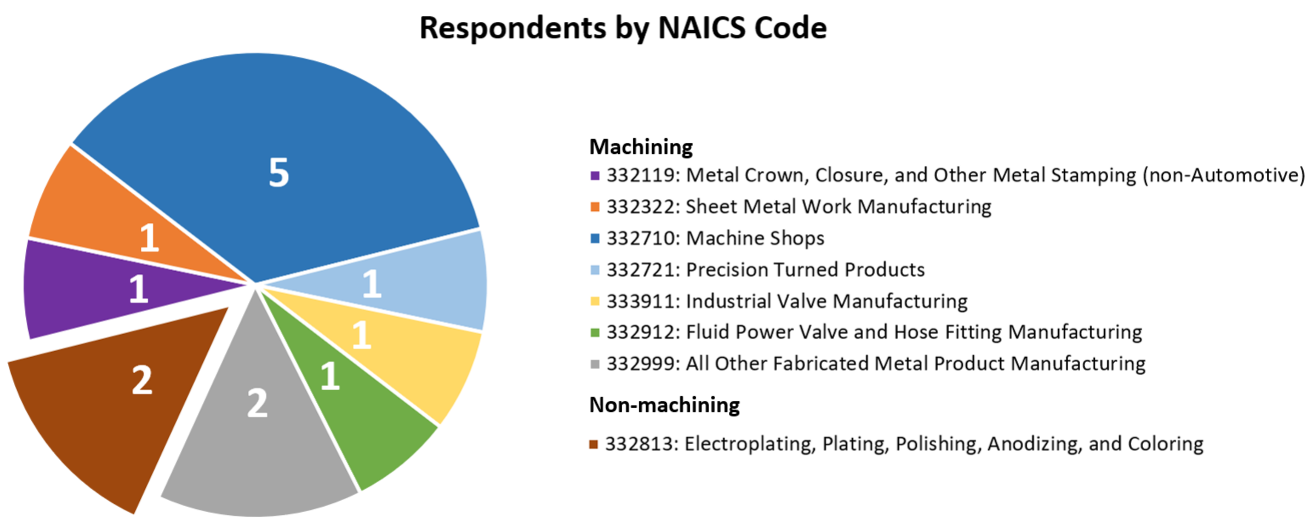

Figure 1: Respondents by NAICS code. Types of companies by manufacturing processes represented in the survey.

Despite the apparent high variety in product, respondents' activities shared similarities in terms of types of equipment, materials, and processes used (except for electroplating). Many of these companies utilized common metal fabrication processes such as cleaning, machining, laser cutting, drilling, welding, and assembling.

The two electroplaters (NAICS code 332813) were unique from the remainder of the respondents in that they did not have any machining processes on site. Both electroplaters indicated that their top priorities were bath optimization (e.g., water conservation and chemistry longevity) and waste treatment. More information related to the plating industry is presented in the Best Practices section below related to dragout reduction. This information was learned during assessment activities.

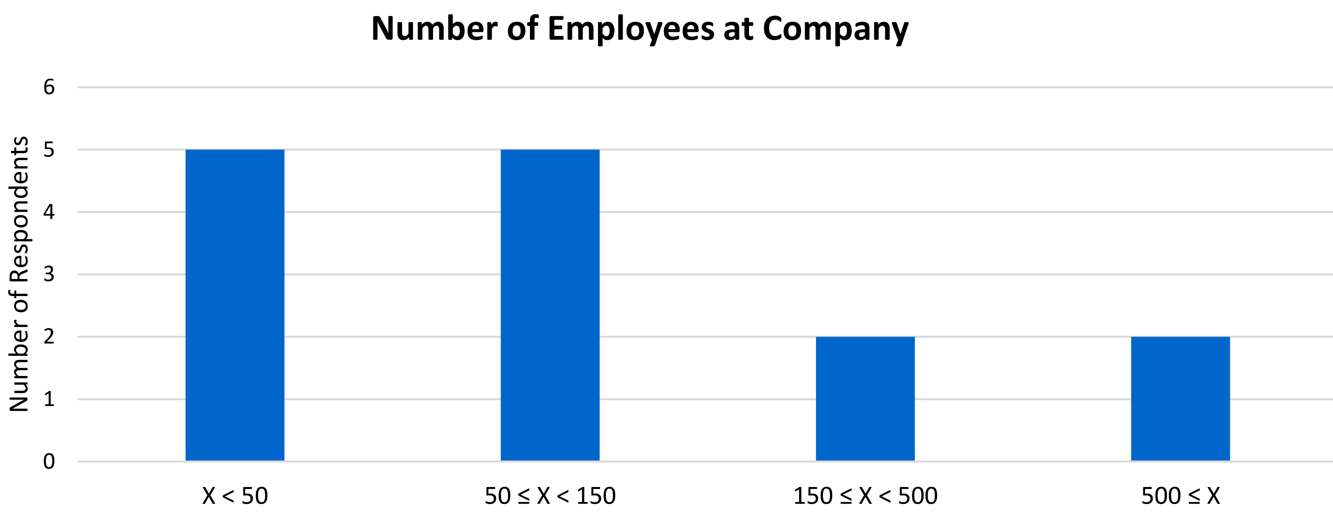

Figure 2: Company Size. There was a balanced representation of small, medium, large, and very large companies interviewed based on the reported number of employees.

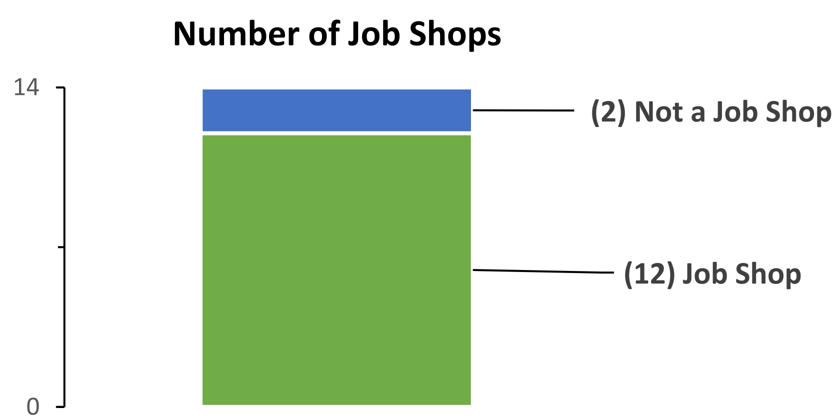

Figure 3: Breakdown of job shops. 12 out of the 14 respondents indicated that they were "job shops," meaning they primarily complete contract work for external customers.

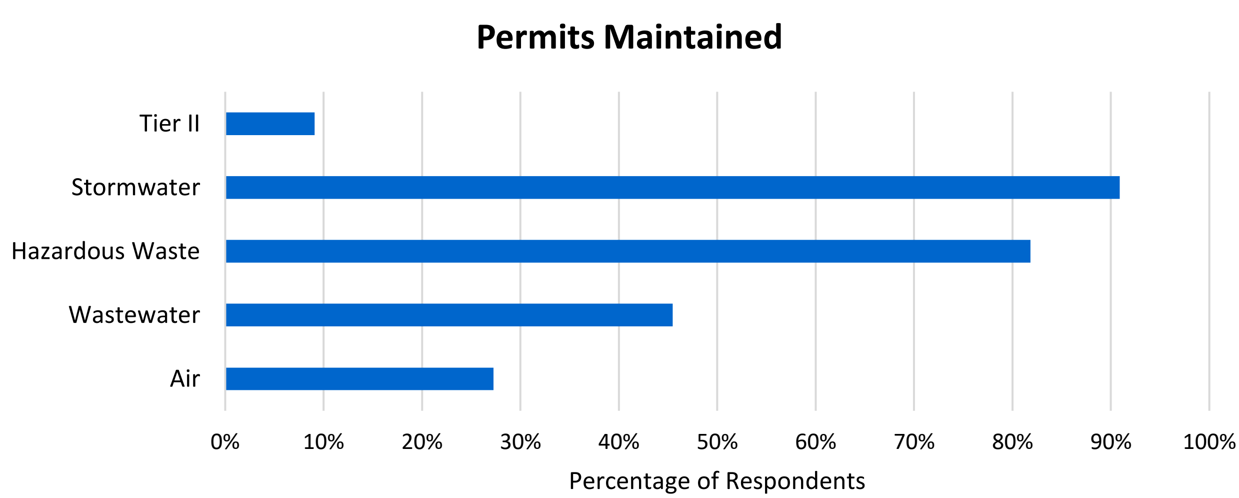

Figure 4: Permits maintained. Figure showing the responses for 11 out of the 14 respondents (3 declined to answer this question). Respondents were asked to indicate which, if any, of the above types of permits were maintained for their facility.

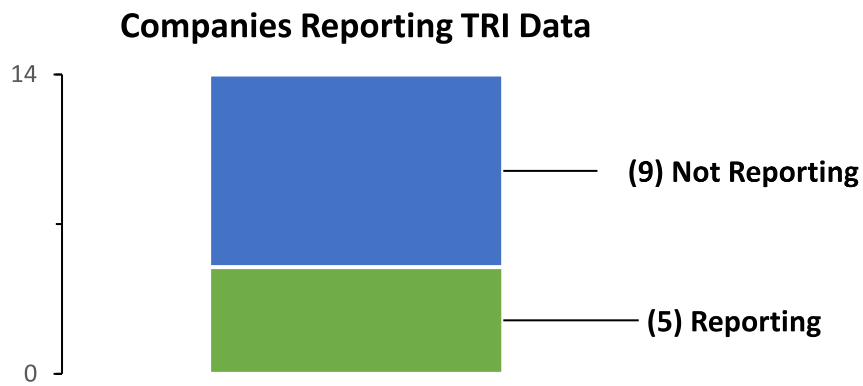

Figure 5: Companies reporting for TRI. 5 out of the 14 companies indicated that they report materials for the Toxics Release Inventory program. Materials that were required to be reported included metals such as lead, zinc, copper, chromium, and two chemicals: nitric acid and diisocyanates.

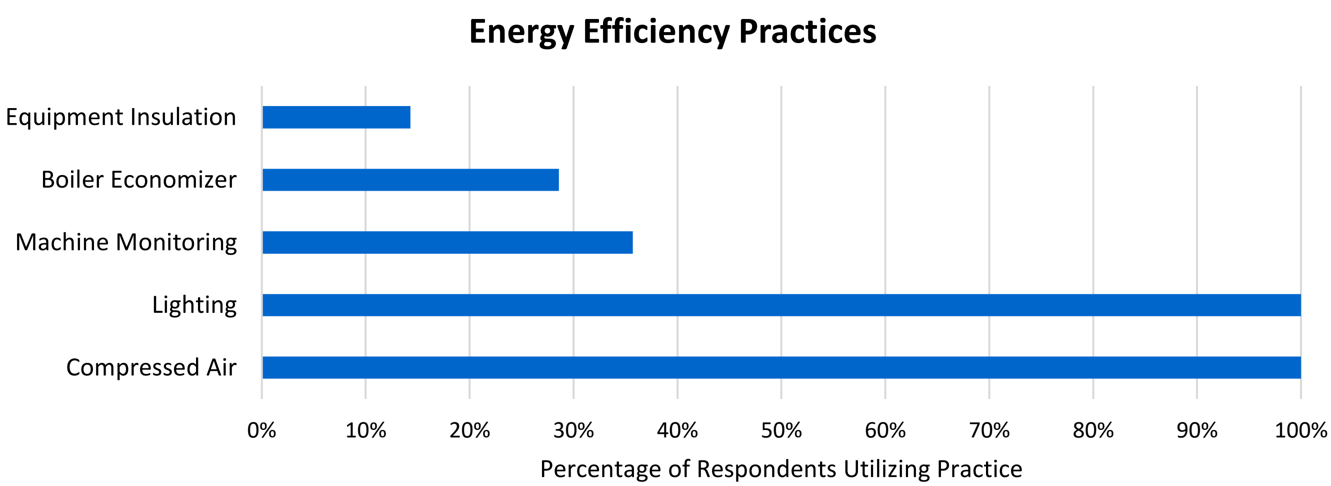

Figure 6: Utilization of energy efficiency best practices. This figure shows the breakdown of survey respondents who indicated they had made upgrades or completed projects related to any of the listed areas to reduce energy usage.

From this data, it appears that the sector has taken advantage of Minnesota energy utility programs for upgraded lighting to LED bulbs and fixtures. A significant majority of businesses also have compressed air systems, which present a significant opportunity for energy efficiency projects. Machine monitoring may be an opportunity for businesses with pieces of equipment that require significant amounts of power as well as boiler economizers for sites that have boiler systems.

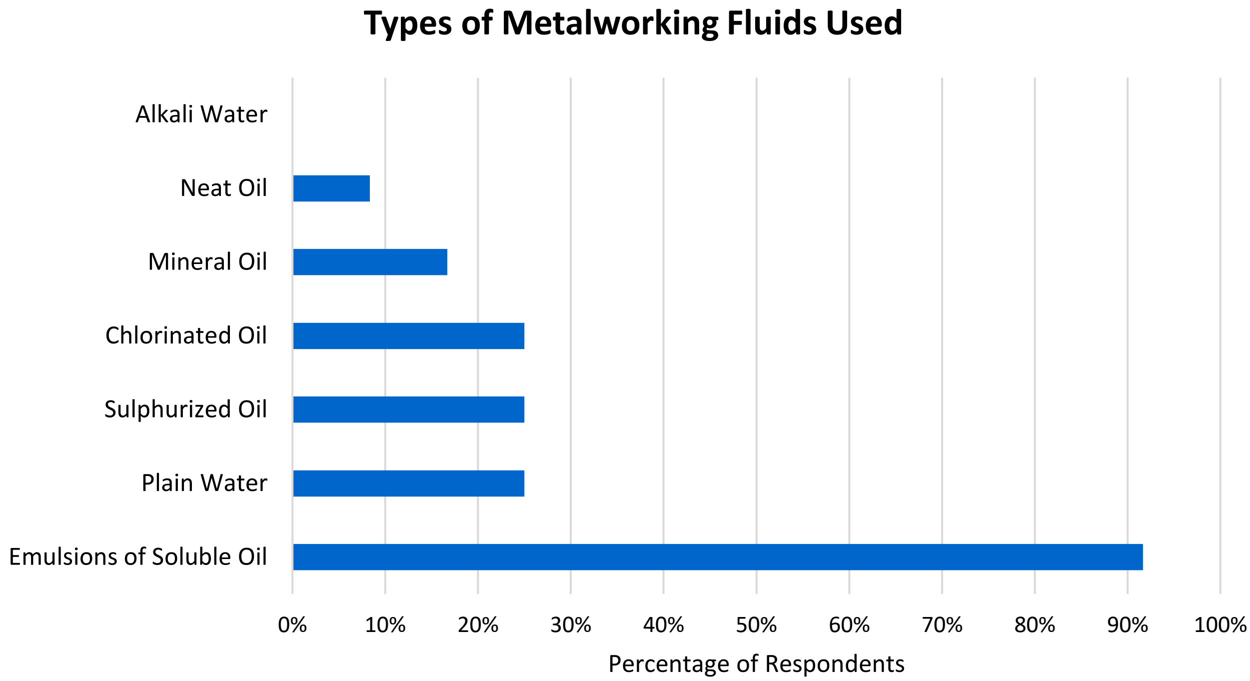

Figure 7: Types of metalworking fluids[1] used for machining. The 12 machine shops were asked to indicate the types of metalworking fluids used for machining. (The two electroplaters did not have machining operations and did not answer this question.) The majority use water-soluble emulsions of oil (also known as semi-synthetic coolants). Metal working fluid (MWF) manufacturers claim that these coolants offer many benefits including the right degree of both lubricity and cooling, as well as the ability to be skimmed (for tramp oil removal) and recycled. Chlorinated paraffins and sulfurized oils are often employed in heavier, “extreme pressure” machining operations due to their ability to react under high temperature and pressure conditions to provide added lubricity and cooling. A follow up discussion with one MWF supplier suggested that machining under these conditions using fluids not containing chlorine or sulfur additives would lead to significantly increased costs from greater machine tool wear and machine time. Hence, there is a significant cost barrier that discourages businesses conducting high pressure machining from changing to chlorine/sulfur-free fluids.

Companies may find that a review of their metalworking fluid is worthwhile if their current product was selected five or more years prior or their machining processes have changed. A safety data sheet review of several products representing different types of metalworking fluids found that these oils and coolants often contain materials that are skin irritants. Spent fluids must be managed as hazardous waste or recycled by a vendor rather than disposed of with wastewater effluent. There may be opportunities to switch to a different coolant for a variety of reasons such as: cost, performance, longevity/recyclability, and/or safety/operator comfort.

[1] Note: the terms “metalworking fluid” and “cutting fluid” are used interchangeably in this report as an umbrella term for all fluids applied to workpieces during machining operations to facilitate lubricity and cooling. The term “coolant” may be used to refer to water-soluble metalworking fluids that help to dissipate heat from the workpiece, whereas “cutting oils” refer to neat or mineral oils, which promote lubricity.

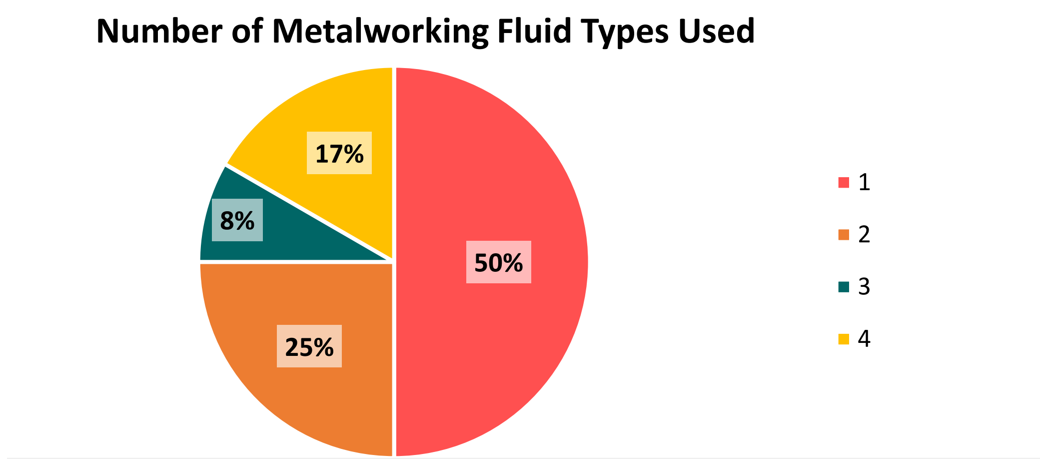

Figure 8: Number of metalworking fluid types present at the facility. Respondents (12 out of 14) indicated how many cutting fluid types they were using. Having several (three or more) types can be a challenge since it requires a greater degree of operator knowledge to manage, store, and utilize in addition to heightening the risk of contamination or use in the wrong machine. On the other hand, companies that machine a wide variety of materials may have opportunities to improve their product quality or equipment performance if their coolants are not optimized to the material being cut.

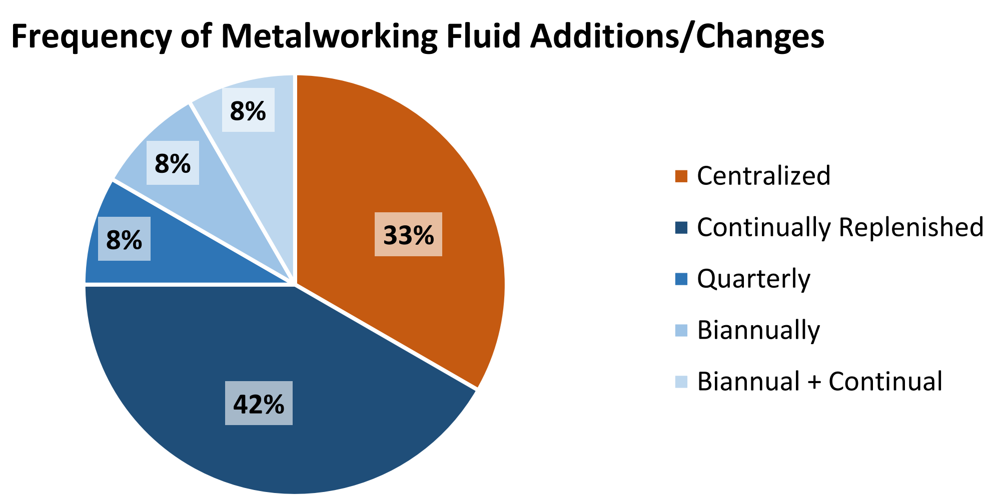

Figure 9: Frequency of metalworking fluid additions/changes. Respondents (12 out of 14) indicated the type and/or frequency of adjustments to cutting fluids done at the facility. "Continually replenished" indicates that the coolant is manually checked and replenished at the machine by operators daily. Sometimes these facilities have an automated blending system that supports automated feeding of coolant to the machine. "Centralized," referring to a centralized system, indicates that coolant is supplied from a central tank and pumped directly to several machines.

It is understood that most shops complete "regular" (daily or weekly) checks of machine coolant level and concentrations and make adjustments accordingly. However, complete turnover or changeout of the fluid occurs either on an as-needed basis or prescribed schedule; both methods generally result in two to four changeouts per year. MWF vendors often provide end-of-life services for managing spent fluids to be hauled for recycling, incorporation into products such as asphalt, or incineration for energy; otherwise waste fluids are disposed of via a hazardous waste hauler.

There are a number of best practices to consider for coolant to optimize its usage, while achieving peak performance from the machine tools. Managing coolant closely has several benefits including longer coolant lifespan, improved product quality, increased cutting tool life, and reduced coolant waste. Maintaining a clean working environment and regularly replenishing or adjusting of coolant levels in the machine sumps are two examples of best practices to verify with businesses. This is an area that many machine shops can continue to optimize for waste reduction, cost savings, and pollution prevention.

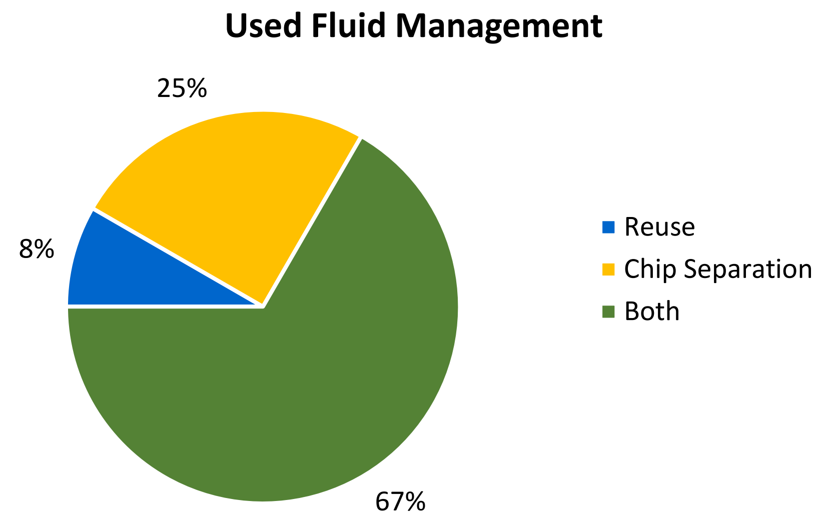

Figure 10: Management for used metalworking fluid. All 12 of the machine shops managed their metalworking fluid either by filtration or coolant reuse. "Chip separation" indicates the practice of allowing coolant to drain from scrap metal fines and turnings. The drained coolant is then returned to the machine sump.

Coolant recycling has been identified as a significant opportunity for pollution prevention by drastically reducing the amount of coolant waste sent out of a facility. A primary method of doing so is to implement a recycling system onsite at the facility. Coolant recycling machines consist of a tank that collects and stores used fluids then processes them through skimming and/or filtering to remove impurities. Many shops will then blend this recycled fluid with virgin product. Running metalworking fluids through such a recycling system can extend the fluid's lifetime by two or three cycles. This reduces costs for both purchasing and disposal, making it an attractive option for shops that are large enough to support the additional equipment and labor required. The overall volume of coolant sent to waste can be reduced significantly, with one facility reporting a one-third reduction in coolant concentrate purchased from implementing a centralized coolant recycling system.

Smaller shops may not have the resources to commit towards a recycling system, but certain MWF vendors offer their own on-site or off-site recycling programs. Most if not all small sized shops try to drain their metal chips to recover fluid and return it to the machine sump.

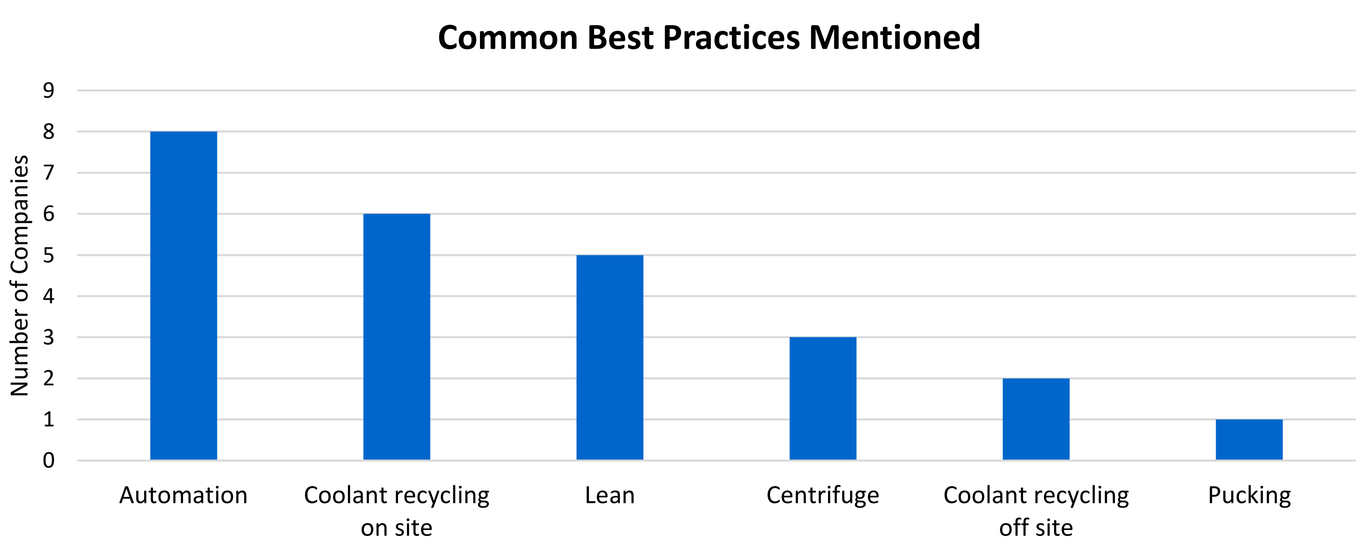

Figure 11: **Best practices mentioned during interviews.** A variety of best practices were mentioned by interviewees. The most common practice mentioned was automation, which is further explained in Figure 12. Metalworking fluids that are recycled on-site are recovered and reused in machining operations. Centrifuges, oil skimmers, and bag filters may all be used as part of a MWF recycling system to separate tramp oils and metal fines from coolant. More often, coolant is "recycled" from chip pans that hold scrap metal turnings; coolant is allowed to drip off chips to the bottom of the pans and is then returned to the machine sump. Centrifuging the scrap metal chips improves the recovery of the coolant further while limiting the amount of coolant in scrap metal sent to metal recyclers. Two facilities indicated that their coolant was recycled off-site through their supplier who was able to process and repurpose it. Pucking, like centrifuging, increases coolant recovery. Additionally, if a facility machines primarily one type of metal, pucking can increase the value of the scrap sent to a facility's recycler. If, however, a facility machines multiple metals, contamination may be a concern, and the value of the recycled metal can decrease. Similarly, facilities that use multiple types of coolant face difficulty in separating the different fluids and may be presented with additional challenges when looking to decrease consumption.

All facilities that had implemented lean practices also mentioned recycling coolant on site. Lean practices and process mapping are useful strategies for facilities that manufacture standard products but may be more challenging to implement in low volume/high mix environments.

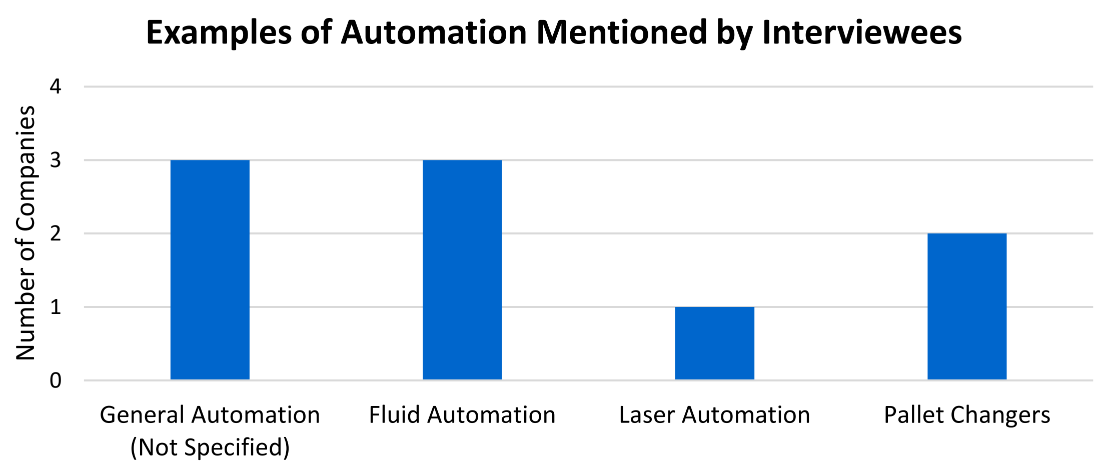

Figure 12: **Examples of Automation Mentioned by Interviewees.** In total, 8 companies explicitly indicated that they had some form of automation present at their facility. Three companies mentioned having "automation" at their facility without further elaboration. One company had both fluid automation and automatic pallet changers.

Fluid automation refers to the automatic dosing of cutting fluids to machines. The laser automation example refers to the "automated" capabilities of laser cutting. Pallet changers refer to machines capable of loading and unloading pre-stocked pallets of material for continuous autonomous operation.

It is likely that more facilities than those represented in the chart have some form of automated machinery, but not all interviewees may have thought it as being notable or significant enough to mention. However, automation is certainly a key improvement that is widely recognized in the industry as providing a major productivity and quality advantage.

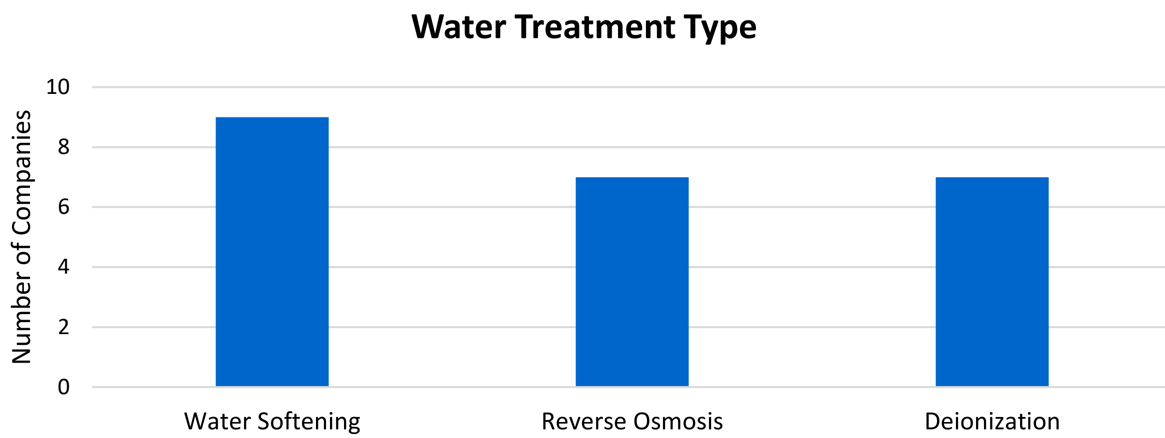

Figure 13: Water treatment types used. Companies indicated what type of treatment was used for water in their facility. Water treatment is a common process that may be used for achieving a higher purity water for applications in either coolant (diluting purchased coolant concentrate) or parts cleaning. Five companies indicated that they utilized all three treatment types. With the high prevalence of water softeners at metal fabricators (9 out of 14 respondents), water softening optimization may be an area of opportunity to reduce chloride releases.

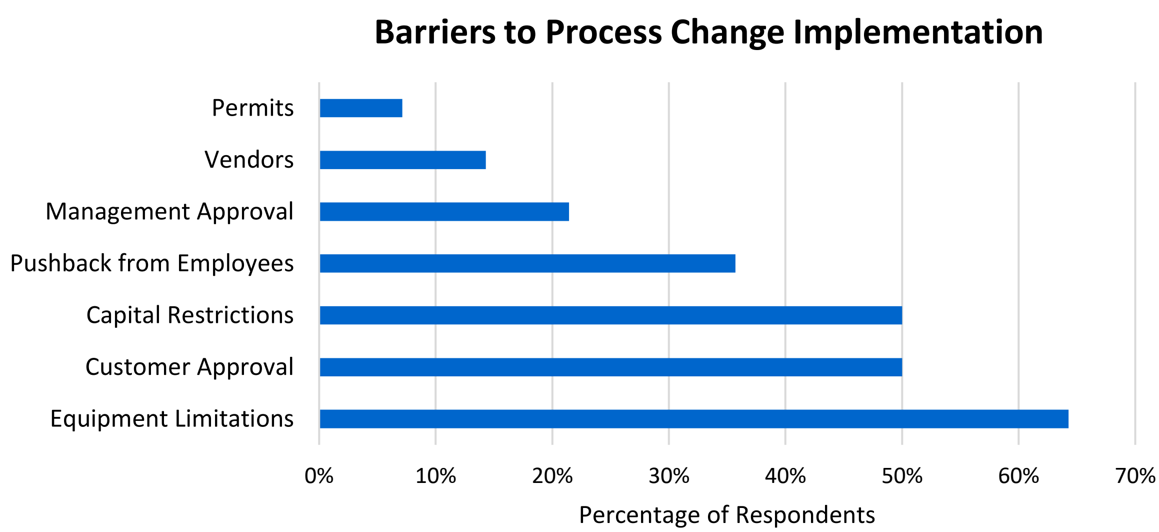

Figure 14: Barriers to process change implementation. All the respondents indicated a variety of challenges to implementing process changes. Equipment limitations, the most common, could indicate several different challenges. For example, a machine may be set up with a focus on throughput but sacrifice tooling longevity or expend additional coolant. Another example of a limitation could be a facility that desires to run "lights out", but the equipment does not support automated parts loading, requiring an operator to manually set up each workpiece. Capital restrictions surrounding the purchase of certain equipment and/or systems were closely related to the limits of the machines currently in use. Customer approval is a key consideration for certain job shops where process changes require advance customer authorization. This common practice may disincentivize shops from improving workflows or reducing wastes.

During the technical assistance phase of this project, these challenges had to be considered and addressed to have success with the implementation of suggestions. Participating companies were provided with clearly indicated economic benefits to help justify the expense of an operational change or a capital project. Where possible, low or no-cost recommendations that would not affect customer quality (and hence would not require customer authorization) were prioritized. Another important component of successful initiatives was soliciting input from various perspectives, including operators and maintenance.

Best Practices, P2 Opportunities, and Other Challenges

Based on information gathered from the interviews, several opportunities and challenges for pollution prevention were apparent in the metal fabrication industry. These key takeaways are summarized in the following sections.

Areas with Pollution Prevention Opportunities

Areas prevalent among companies interviewed that may present pollution prevention opportunities for many businesses in the sector were:

- Optimizing metalworking fluid use to minimize waste
- Assessing metalworking fluids for hazardous ingredients
- Reducing dragout
- Conserving water
- Optimizing water softeners for chloride reduction
- Decreasing solid waste generation
- Reducing greenhouse gasses (GHG) through energy efficiency

Further discussion for each area continues below.

Optimizing Metalworking Fluid Use

Cutting fluids are a common opportunity for optimization for companies with machining operations. Common best practices include proper coolant selection, daily concentration monitoring and adjustment, fluid reclaim and reuse either on site or through the supplier or a third party, and automated dosing. These best practices reduce coolant waste and improve cutting tool life. They also increase the likelihood of product meeting quality specifications. Centrifuging and pucking metal chips are two activities that increase the volume of coolant recovered.

Assessing Products for Hazardous Ingredients

Reviewing materials utilized in the industry to determine the safety risks and hazards of materials may reveal opportunities for switching to safer alternatives. Products such as cutting fluids, cleaners, and degreasers should be considered. Chemicals used in electroplating baths and fume suppressants are an additional area to review with finishing shops.

Reducing Dragout

Dragout reduction techniques are applicable at electroplating, plating, polishing, anodizing, and coloring facilities. These facilities tend to use high amounts of water and chemicals as part of their finishing operations. The key finding from this survey regarding this practice is that while many businesses are aware of this strategy and its benefits (and may even practice it to some degree), there is often room for improvement. Common methods to improve dragout include increasing the draintime of parts as they are removed from baths, utilizing spray rinses near the surface of tanks to wash the bath chemistry off parts and racks back into the tank, and recycling rinse water back into the baths as makeup water.

The importance of dragout is in the conservation of resources that these businesses would consider critical to their success. These resources include water, chemicals, and energy spent on tank heating. Water costs are further compounded by any incoming and outgoing treatment costs, such as softening or reverse osmosis and wastewater pretreatment procedures. Additional costs may also be incurred from generation of hazardous waste from tank or wastewater sludges. Dragout reduction linearly reduces all these costs, which results in considerable cost savings for businesses.

Many shops – particularly those with manual operations – were observed to have drain times of only five seconds or less. Extending these drain times to 15-30 seconds can capture an additional 30% or more in water, chemical, and energy costs. Before implementation, the bottlenecks of the process must be considered. If usage of a particular tank is slowing down production, businesses will want to take that into account. However, in MnTAP's observations, many finishing shops had sufficient downtime between steps in the process to accommodate additional drain time without impacting the production schedule. Dragout reduction can have a considerable value that is often overlooked; when fully optimized, dragout reduction techniques can result in thousands or even tens of thousands of dollars saved annually. It is also worth noting that this is not an all-or-nothing action. Increasing drain time by even a few seconds is better than nothing, and there is a lot of room for customization to fit each facility's unique situation while still achieving savings.

Conserving Water

Another P2 area for electroplating, plating, polishing, anodizing, and coloring facilities is water conservation. Due to the large number of tanks and baths that are used in these facilities, water is a high demand resource that undergoes considerable pre- and post-processing (e.g. softening, RO, pH adjustment, wastewater pretreatment). Chemicals used to formulate bath chemistries are also an embedded cost that is tied in with water usage. Thus, there is considerable economic incentive for shops to conserve water where possible.

A common opportunity for water savings is conductivity control. Conductivity is a useful proxy for measuring the amount of contamination present within a tank and is of particular benefit when used to control the cleanliness of rinse tank water. Neglecting conductivity control forces businesses to flow water through rinse tanks constantly to achieve proper product quality; however, there is a strong likelihood that water in these rinse tanks is cleaner than necessary, resulting in a high amount of water wasted.

Due to the linear relationship between reducing dragout and conserving water, recycling rinse water back into plating baths to replace water lost to evaporation saves chemicals and water. To that end, evaporation is also a common source of loss for these operations as many of the tanks are heated and uncovered. Useful strategies to reduce evaporation include covering tanks when not in use and reducing total heating time for tanks by turning the heat off or down over nights and weekends.

Optimizing Water Softeners

Facilities treat incoming water to remove impurities prior to use in various operations such as parts cleaning or coolant formulation. Water softening was a commonly reported procedure that appears to be prevalent in the metal fabrication industry. Chloride discharge to wastewater is often reduced if water softeners are optimized. In some cases, water conservation may also be achieved from this best practice, which MnTAP has found in previous work, including a water softener optimization flow chart[2] and an intern project.[3]

Decreasing Solid Waste Generation

Solid waste opportunities primarily relate to two categories: materials used for packaging and transportation of product and metal waste from cut products.

Solid wastes from packaging and transportation include cardboard, plastics, pallets, dunnage, and various containers made from these materials. These wastes may enter the facility as packaging from shipments of raw materials, or they may be generated onsite through use as containers for transporting product through the facility. Some facilities have built their own containers out of metal to replace less-sturdy counterparts made out of wood or cardboard, achieving waste reduction.

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[2] http://www.mntap.umn.edu/wp-content/uploads/simple-file-list/Resources/Tools-and-Calculators/Chloride-Softener-Decision-Flowchart.pdf

[3] http://www.mntap.umn.edu/wp-content/uploads/simple-file-list/Intern/2020-2029/2021/Executive-Summary/MnTAP-Chloride-Executive-Summary.pdf

Optimizing jobs for products cut out of bar stock or sheet metal is one best practice for maximizing usage of raw materials. Careful product inspection, coolant management, and proper machine tool operation are also essential to minimize defects and prevent waste from off-spec product.

Metal scrap can be sold to recyclers. While this is not a P2 practice, it is the next desirable outcome for unavoidable scrap. The economic benefit of recapturing value out of metal waste is the primary reason that virtually all machine shops recycle scrap. Centrifuging or "pucking" (compacting) metal scrap helps to separate metalworking fluids out of outgoing metal waste, which decreases the fluid content in outgoing metal scrap and may allow the facility to recover more fluid. This practice may also help to limit potential releases of cutting fluid in the scrap handled by metal recyclers.

Reducing GHG through Energy Efficiency

Energy efficiency opportunities are dependent on the types of machining operations carried out at the facility. One common opportunity is optimizing compressed air systems, which are prevalent among metal fabricators. Facilities depend on air-powered hand tools and other compressed air-powered equipment for grinding, cutting, and shaping operations. Compressed air system maintenance relates to proper sizing of compressors, using VFDs, setting the right system pressure, and maintaining a leak detection program. Automatic shutdown controls may help reduce energy draw of idle machines. For sheet metal cutting, fiber lasers offer significant energy and speed advantages over conventional CO_2 lasers.

Challenges to Implementing P2

As part of the informational interview, businesses shared numerous challenges regarding implementation of best practices and P2 initiatives. Further insights into implementation challenges were identified through the technical assistance process. Some of these challenges were discussed during onsite visits; others were discovered during follow-up calls to document implementation. The challenges observed are generalized into common trends that are examined in the following list.

1. Initiatives may be deemed infeasible due to **unsatisfactory results** during trialing of a new product or process. In other cases, a long payback for a change did not justify investment in new equipment. Examples included attempting to implement a coolant recycling program and utilizing a centrifuge for coolant separation.
2. Best practices may not be attempted or may be discontinued due to **lack of knowledge of the potential savings** that could be delivered. Several businesses were interviewed that did not see the economic benefit of a practice such as dragout reduction or water conservation. Projects that focused on a review of the current costs and then collected data necessary to estimate the savings potential of these best practices resulted in a very positive response from the business. Conversely, businesses that had not taken the time to measure the pre- and post-state of an implementation and did not determine its impact were less likely to continue maintenance activities and thus failed to sustain the change.
3. Low volume/high mix job shops may struggle with **lean-related wastes** such as raw material loss (metal scrap), process wait times, transportation, and inventory. This presents a significant challenge for many companies in the sector. Many companies have conducted value stream mapping and other lean exercises, which suggests that such tools can be an effective method of addressing lean wastes.
4. **Human capital** is currently one of the highest demanded and lowest supplied resources currently available to companies. This has led to challenges related to employee training, turnover, and adherence to procedures. New processes and equipment may not always have the required personnel to operate or maintain, or information about a change may not have been included in training, causing it to be discontinued. This is one barrier that can discourage a company from seeking implementation of waste reduction initiatives.
5. **Capital cost** of equipment can be a significant hurdle for companies, especially smaller businesses. This is apparent in the challenge to automate different processes that can facilitate waste reduction and/or save time. Automation is one potential solution that companies are exploring in response to low worker availability as a way to save employees' time and reduce waste.

6. **Organizational structure and culture** are important factors for the success of waste reduction programs. Aspects within a company's culture that can help sustain a best practice include broad awareness of the initiative, early engagement and input from employees, clear benefits and incentives, and alignment of goals and vision between a company's management and its workers. Documentation and standardization of procedures, targets, and operating parameters are also recommended components for ensuring successful execution and longevity of programs.

As a P2 provider, it is important to consider these factors when determining recommendations. While these challenges should not prevent addressing observed opportunities, they should be discussed and considered when communicating with businesses; P2 opportunities can often be addressed in more than one way. When considering an opportunity, a best practice is to discuss strategies for addressing potential obstacles with the business. Providing strategies such as step-wise implementation, low-capital solutions, and short-term pilots can allow businesses to observe savings with low-barriers of entry. Ultimately, the goal for any P2 provider is to develop effective solutions that are implemented and provide savings. Navigating the path to success for a business will be different for each opportunity, but when traveled together, these efforts can result in significant and impactful outcomes.