Pollution Prevention in Machining and Metal Fabrication

A Manual for Technical Assistance Providers

March 2001

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Chris Wiley, Pacific Northwest Pollution Prevention Resource Center
Paul Van Hollebeke, Vermont Agency of Natural Resources
Greg Lutchko, Vermont Agency of Natural Resources

Project Staff/Contributors

Andy Bray, NEWMOA Project Manager – Researcher/Author
Terri Goldberg, NEWMOA Deputy Director – Managing Editor
Lisa Rector, NEWMOA Project Manager – Editor
Cynthia Barakatt, Communication Consultant – Copy Editor
Beth Anderson, EPA – EPA Project Manager
Beverly Carter, Fineline Communications – Cover Design and Layout

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Northeast Waste Management Officials' Association

The Northeast Waste Management Officials' Association (NEWMOA) is a non-profit, nonpartisan, interstate government association. The membership is composed of state environmental agency directors of the hazardous waste, solid waste, waste site cleanup, and pollution prevention programs in Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont.

NEWMOA's mission is to help states articulate, promote and implement economically sound regional programs for the enhancement of environmental protection. The group fulfills this mission by providing a variety of support services that facilitate communication and cooperation among member states and between the states and EPA, and promote the efficient sharing of state and federal program resources.

NEWMOA was established by the governors of the New England states as an official interstate regional organization, in accordance with Section 1005 of the Resource Conservation and Recovery Act (RCRA). The organization was formally recognized by the U.S. Environmental Protection Agency (EPA) in 1986. It is funded by state membership dues and EPA grants.

NEWMOA established the Northeast States Pollution Prevention Roundtable (NE P2 Roundtable) in 1989 to enhance the capabilities of the member state environmental officials to implement effective source reduction programs. The NE P2 Roundtable's program involves the following components: (1) managing a regional roundtable of state pollution prevention programs; (2) publishing a newsletter; (3) managing a clearinghouse of books, reports, case studies, fact sheets, notices of upcoming meetings and conferences, and a list of P2 experts; (4) organizing training; and (5) conducting research and publishing reports and other documents. The clearinghouse provides pollution prevention information to state and local government officials, the public, industry, and others. Funding for the NE P2 is provided by the NEWMOA member states and the U.S. EPA. For more information on the Roundtable, contact: Terri Goldberg, NEWMOA Deputy Director, 129 Portland Street, 6th Floor, Boston, MA 02114, (617) 367-8558 ext. 302; 617-367-0449 (fax); tgoldberg@newmoa.org (email).

NEWMOA is part of the Pollution Prevention Resource Exchange (P2Rx). P2Rx is a national network of regional P2 information centers located throughout the US. As part of P2Rx, NEWMOA and the other regional centers are able to access a broader pool of information and expertise when responding to the needs of state and local technical assistance providers. The regional P2 information centers that comprise P2Rx allow for the two-way flow of information from the state and local level to the national level. For more information on P2Rx, contact: Andy Bray, NEWMOA Project Manager, 129 Portland Street, 6th Floor, Boston, MA 02114, (617) 367-8558 ext. 306; (617) 367-0449; abray@newmoa.org (email).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
Overview of Metal Fabrication Industry

Background

Everywhere we look, we see fabricated metal products. From paper clips to HVAC housings, from car bodies to spiral stair cases, countless products start out as metal stock that fabricators bend, punch, drill, grind, thread, and cut to produce various shapes. The metal fabrication process varies greatly depending on the material being machined, the rate of production, the desired geometry, and other physical requirements of the part or product.

The metal fabrication[1] industry also varies greatly in the size, type, and distribution of facilities found in different states throughout the United States. For example, metal fabrication facilities in the Northeast are usually small-to-medium sized with older equipment, and the key products they manufacture are bearings, fire arms, aerospace, automotive, machine and perishable tools, electrical components, and wire and cable (U.S. EPA 1995). Table 1.1 lists the number of fabricated metal product and machinery manufacturers in the U.S.

States with the largest number of metal fabrication plants are New York, Ohio, Pennsylvania, Michigan, Illinois, Texas, and California. Throughout the U.S., fabricators use 175 million gallons of metalworking fluids, valued at $800 million, and accounting for 15 percent of the overall value of sales of industrial oils. Worldwide global annual metalworking fluid consumption is more than 600 million gallons (Glenn, 1998).

There are a variety of processes involved in the manufacture of complex metal parts including: casting, shaping, metal removal, coating, finishing, heat treating, welding, soldering, brazing, and adhesive joining. This Chapter discusses the processes involved in metal shaping and removal and provides in-depth background on the properties and types of metalworking fluids. This Chapter also includes an overview of heat treating, brazing and soldering, adhesive joining, welding, tumbling, buffing, polishing, and honing.

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[1] Metal fabrication, as it is referred to in this manual, is any process that changes the geometry of a metal workpiece by deforming it or removing metal from it. Other processes covered in this manual are metal and surface treating, such as heat treating and case hardening, as well as metal joining processes, such as welding and soldering. Although the manufacturing of metal parts may involve other processes including plating, coating, and casting, these processes will not be covered in this manual because they were covered in earlier manuals in this series, specifically *Pollution Prevention for the Metal Finishing Industry*, *Pollution Prevention for the Metal Coatings Industry*, and, *Pollution Prevention for the Primary Metals Industry*, available online at http://www.newmoa.org/publications/.

Table 1.1. Number of Fabricated Metal Product and Machinery Manufacturers by State[2]

State	NAICS 332	NAICS 333	Total	State	NAICS 332	NAICS 333	Total
Alabama	986	293	1,279	Montana	122	47	169
Alaska	49		49	Nebraska	276	205	481
Arizona	835	316	1,151	Nevada	254	86	340
Arkansas	498	254	752	New	454	206	660
California	8,127	3,112	11,239	New Jersey	1,806	915	2,721
Colorado	798	363	1,161	New Mexico	234	59	293
Connecticut	904	520	1,424	New York	2,771	1,315	4,086
Delaware	102	32	134	North	1,483	757	2,240
Florida	1,998	957	2,955	North Dakota	85	86	171
Georgia	1,114	555	1,669	Ohio	4,332	2,260	6,592
Hawaii	46		46	Oklahoma	969	430	1,399
Idaho	232	129	361	Oregon	929	437	1,366
Illinois	3,782	2202	5,984	Pennsylvania	3,185	1,531	4,716
Indiana	1,897	1,064	2,961	Rhode Island	440	176	616
Iowa	594	443	1,037	South	722	360	1,082
Kansas	1,391	347	1,738	South Dakota	115	93	208
Kentucky	729	370	1,099	Tennessee	1,146	547	1,693
Louisiana	671	226	897	Texas	4,359	1,726	6,085
Maine	241	96	337	Utah	459	164	623
Maryland	510	166	676	Vermont	25		25
Massachusetts	1,762	833	2,595	Virginia	768	348	1,116
Michigan	3,788	2,849	6,637	Washington	1,184	503	1,687
Minnesota	1,536	904	2,440	West Virginia	274	98	372
Mississippi	386	185	571	Wisconsin	1,968	1,258	3,226
Missouri	1,168	579	1,747	Wyoming	82	33	115
United States					62,501	30,665	93,166

Metal Shaping and Removal Processes

Metal Shaping Processes

In metal shaping, stock is formed into its desired geometries through the application of mechanical force. Forming processes are non-chip making processes and may or may not use fluids depending on the severity of the application. Fluids are the primary source of waste in metal shaping processes. Table 1.2 lists some of the characteristics of various forming processes, including the types of stock in use and the shapes that are produced.

Figure withheld due to copyright restrictions.

Figure 1.1 *Profiles Attainable with Roll Forming*

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[2] The data for this table are taken from the 1997 U.S. Economic Census Report for the North American Industry Classification System (NAICS) three digit subsector codes 332 and 333. NAICS 332 is the subsector for fabricated metal product manufacturing. This subsector includes industries that transform metal into intermediate or end products. It does not include machinery, computers and electronics, metal furniture, or the treating of metals and metal formed products fabricated elsewhere. NAICS 333 is the three digit classification for machinery manufacturing. This subsector includes industries that create products that apply mechanical force.

Table 1.2 Characteristics of Forming Processes (Goetsch 1991)

Process	Characteristics
Bending & Straightening	• sheet and plate bending • types: straight, flange, contour, and stretch • stressing metal beyond its yield strength, but not beyond its ultimate tensile strength
Roll Forming	• sheet, strip, or coil stock • stock 0.0005 to 3/4" thick by 0.125 to 72" wide • any material that can withstand bending to desired radius • forms any shape that the metal can withstand the bend radius
Spinning	• chipless process of forming axially symmetrical shapes • metal disks, cylindrical workpiece, or preform • stock 1/4" to 26' in diameter, up to 3" in thickness • forms shapes such as cones, hemisphere, tubes, and cylinders
Shearing	• larger sheets cut into smaller lengths • crosshead may be manual, mechanical, hydraulic, or pneumatic • shear types: gapless, gap, alligator, pivot, ironworkers, cut-off machines, bar-billet, computer numeric control (CNC), or rotary
Punching	• performed on sheet metal • ferrous and nonferrous metals • various shapes of punches
Cold Drawing	• pulling the stock through a die of similar shape, but smaller size • metal bar, rod, tube (to about 12"), or wire stock • bars 1-1/4" and smaller having the same cross-sectional shape throughout, including square, and hexagonal • uses grease, dry soap, oil, or other lubricants • similar shape to stock, but smaller
Hot Extruding	• heated billets[3] forced through one or more dies to form uniform cross sections • types: direct, indirect, and hydrostatic • in hydrostatic, entire billet surrounded by fluid • uniform cross sections along continuous lengths
Warm and Cold Extruding	• process is similar to hot extruding • performed on slugs of most steels, nonferrous metals, and superalloys • types: backward, forward, radial, combination, impact, and continuous • for warm extruding, requires more heat resistant lubricants and tools • used for large, hollow extrusions that were formerly formed by tubing (e.g., wheel spindles and axles)
Swaging	• solid or tubular stock, ranging in diameter from 0.5 mm to 150 mm • formed by delivering rapid series of impact blows • applications: tapering, reducing, pointing, external and internal forming, compacting, sizing, and assembling
Hot Forging	• plastic deformation of working metal by pressure or impact blows, or both • types: open-die forging and impression-die forging • stock may range in size from 30-1000 pounds
Specialty Forming	• types: explosive forming, electrohydraulic forming, electromagnetic forming, high-velocity forging, peen[4] forging, and ultrasonic-activated forming

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[3] A billet is a bar of metal.

[4] Peening means to draw, bend, or flatten by or as if by hammering, usually with a hemispherical or wedge-shaped end of the head of a hammer that is opposite the face and is used especially for bending, shaping, or cutting the material struck

Metal Removal Processes

In metal removal processes, stock is given its final geometry through the removal of metal from stock by a number of processes including: broaching, sawing, turning, boring, drilling, reaming, milling, and grinding. Fluids are used in these processes to provide lubricity, cooling, chip removal, corrosion resistance, and to prevent built-up edge (BUE)[5] on the tool bit. The type of fluid used is dependant on a number of factors including substrate compatibility, and the amount of lubricity and cooling required. For more information on fluid characteristics, see the Metal Working Fluid Overview later in this chapter. The two typical wastes from metal removal processes are spent metal working fluids and metal scrap. In the following sections more specific information is presented on the metal removal processes listed above including tool types, chip characteristics, and fluids used.

Broaching and Sawing

Broaching

Broaching is a metal removal process that is performed on flat, round, or contoured substrates. The multitoothed cutting tools used in broaching have teeth that are generally higher than the preceding tooth, each removing more material as it passes over the substrate. The tool material generally used is high-speed steel (HSS); however, tungsten carbide tools bits may be used in high-speed broaching applications or broaching of gray cast iron. A variety of metalworking fluids may be used in broaching, depending on the machining conditions (i.e., speed of cutting, type of material being broached, and design of machine). Broaching may also be performed dry, as fluids are usually not required for planing, shaping, and slotting operations because of the intermittent contact of the blade with the workpiece, and the chips formed generally fall away without the use of fluids.

Power Hacksawing

Power hacksawing is performed using a relatively short, straight blade that is drawn back and forth over the workpiece. Power hacksaws are used extensively as chop saws and in facilities where production requirements are not high. These saws may be used on all sizes of stock and practically all materials.

Bandsawing

Bandsawing uses a continuous band with small teeth that perform one-directional cutting. A variety of fluids may be used in bandsawing, depending largely on the metal being cut. Metalworking fluids are applied to the cutting area and are carried across the cross section of material being cut. Fluid may be applied through the blade guides, or through nozzles, spray mists, pressurized mists, and curtain applicators. Bandsawing is more precise than the other methods and complex cuts are easily achieved. Compared to other sawing methods, bandsawing is more energy-

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[5] Built-up edge, or BUE, is the condition of chip material adhering or becoming joined to the tool bit.

and materials-efficient and creates a smaller kerf.[6] The chips that are formed from bandsawing are usually full and uniform.

Figure 1.2 *Broach Tool*

Figure withheld due to copyright restrictions.

Circular Sawing

Circular sawing may be used on billets, forgings, extrusions, bars, tubes, and similar stock, generally five inches in diameter or less. The use of metalworking fluids is recommended for all metals except brass and cast iron. However, fluids are not generally used when using carbide-tipped blades. Fluids are used in circular sawing more to facilitate flow of the chips than for cooling action, and soluble oils and synthetics are used at a relatively rich mix. Circular sawing creates a wider kerf. Chips generally act as heat sinks allowing workpieces to stay cool, thereby reducing the need for fluid cooling.

Turning and Boring

Turning

In turning operations, a workpiece is rotated about its longitudinal axis on a machine tool called a lathe. Material is removed by tools mounted on the lathe to create the desired shape. Turning is performed on surfaces that are concentric with the longitudinal axis of the workpiece. Turning may be performed with or without the use of fluids; however, dry turning is generally only performed on cast iron or short-run applications. A variety of fluids are used in turning operations, depending largely on the material feed rate, tool speed, and workpiece substrate.

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[6] Kerf is a slit or notch made by a saw or cutting torch, or the width of a cut made by a saw or cutting torch.

Boring

In this precision metal removal process, internal cylindrical holes are generated using a single-point or multiple-edge cutting tool. Boring may be performed by rotating the tool or the workpiece. Boring may produce long, stringy chips depending on the substrate being bored. A variety of fluids are used in boring operations, depending largely on the material feed rate, tool speed, and workpiece substrate.

Drilling and Reaming

Twist Drills

Drilling is the production or enlarging of holes in a workpiece by the relative motion of a cutting tool. Water-based emulsified oil is the most common metalworking fluid used in these operations. These metalworking fluids minimize friction between the drill and workpiece and reduce friction between the sliding chip and the drill. Because of the limited space involved in drilling, for chips to leave the cutting zone, it is desirable to have small chips form. Coiling of chip material may pack drill flutes, interfering with chip ejection and fluid flow. Hence, more ductile metal may require more complex tool designs and geometries.

Counterboring, Spotfacing, and Countersinking

Enlarging a hole for a limited depth is called counterboring. If the cut is shallow so that it leaves only finished face around the original hole, it is called spotfacing. The cutting of an angular opening into the end of a hole is known as countersinking. A counterbore toolbit usually has straight or helical flutes for the passage of chips or fluids. Speeds and feeds used in counterboring and spotfacing are generally less than those used in drilling. A variety of fluids are used in counterboring, spotfacing, and countersinking operations, depending largely on the material feed rate, tool speed, and workpiece substrate.

Reaming

This process is used for enlarging, smoothing, and/or accurately sizing existing holes by means of a multi-edge fluted cutting tool. Tools used may be bore, carbide, or coolant-fed reamers. Like counterboring, spotfacing, and countersinking, there are a variety of fluids that may be used in reaming depending on feeds, speeds, and substrate.

Milling and Grinding

Milling

Milling involves the removal of metal in small, individual chips made by each milling cutter. In face milling, chip thickness varies from a minimum at the entrance and exit, to a maximum along the horizontal diameter.

Grinding

Grinding is performed through basically the same functions as cutting operations. Fluid is applied to lubricate the chip/grit and grit/workpiece interface, reducing the power required to remove a volume of material and thereby reducing the heat generated. In metal cutting, the energy required to form a chip is about twice that required to overcome friction between the tool/workpiece and chip/workpiece interface. In grinding, the force necessary to overcome friction is approximately the same as that required for chip formation, therefore lubrication is critical from a standpoint of power, wheel life, surface finish, heat development, and possible surface damage.

Nontraditional Machining

The category of nontraditional machining covers a broad range of technologies, including some that are used on a large scale, and others that are only used in unique or proprietary applications. These machining methods generally have higher energy requirements and slower throughputs than traditional machining, but have been developed for applications where traditional machining methods were impractical, incapable, or uneconomical. An added benefit of these techniques is that there is little to no localized damage such as cracks, residual stresses, recrystallization, or plastic deformation (Goetsch 1991). Although nontraditional machining methods are not widely used, some have inherent P2 benefits. Nontraditional machining methods are typically divided into the following categories: mechanical, electrical, thermal, and chemical processes. Table 1.3 lists the categories and specific types of nontraditional machining.

Figure 1.3 *Schematic of Electrochemical Machining (ECM)*

Figure withheld due to copyright restrictions.

Table 1.3 Nontraditional Machining Processes

Category	**Processes**
Mechanical	• Ultrasonic Machining (USM)
	• Rotary Ultrasonic Machining (RUM)
	• Ultrasonically Assisted Machining (UAM)
Electrical	• Electrochemical Discharge Grinding (ECDG)
	• Electrochemical Grinding (ECG)
	• Electrochemical Honing (ECH)
	• Hone-Forming (HF)
	• Electrochemical Machining (ECM)
	• Electrochemical Turning (ECT)
	• Shaped Tube Electrolytic Machining (Stem$^{\text{TM}}$)
	• Electro-Stream$^{\text{TM}}$ (ES)
Thermal	• Electron Beam Machining (EBM)
	• Electrical Discharge Machining (EDM)
	• Electrical Discharge Wire Cutting (EDWC)
	• Electrical Discharge Grinding (EDG)
	• Laser Beam Machining (LBM)
Chemical	• Chemical Milling
	• Photochemical Machining

Electrical discharge machining and laser beam machining are discussed further in Chapter 5, Innovative Pollution Prevention Technologies.

Metalworking Fluid Overview

Metalworking fluids perform numerous functions in metal fabrication processes. Fluids can:

- provide cooling for the workpiece and tool
- remove chips from the cutting zone
- provide lubrication between the tool and the workpiece
- prevent corrosion of the workpiece and tool, and
- prevent built-up edge (BUE)

This Section will cover tool and workpiece cooling, chip removal, lubrication, the classifications used for fluids, and the types of fluid components.

Tool and Workpiece Cooling

Metalworking fluids provide cooling action to the workpiece and the tool. This prevents thermal damage to the workpiece, minimizes thermal stressing and brittle hardening of the tool bit, and prevents BUE. Fluids help to reduce these problems by absorbing heat through convection and by reducing the frictional forces, thereby reducing the force and energy requirements and heat generation (Kalpakjian 1992). In place of fluids for cooling, some operations may use pressurized air, a combination of pressurized air and fluid, or other means. For more information on machining without using fluids, see Chapter 5, Dry Machining.

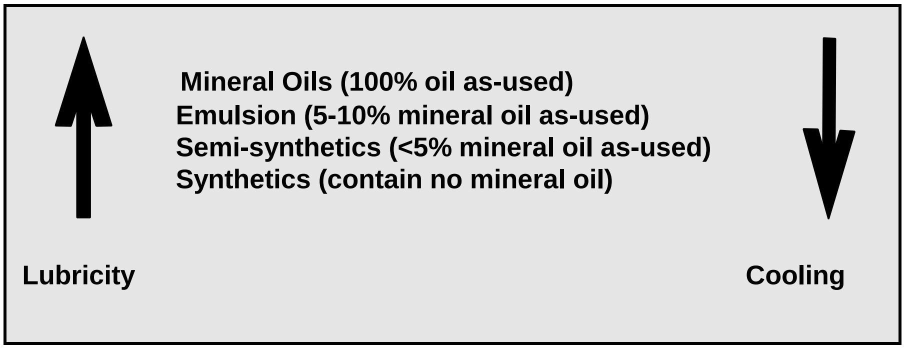
Chip Removal

Chips that are formed during chip-making processes can have a tendency to build up in the cutting area and cause undue stress on the machine tool. Fluids are used to flush chips out of the work zone. The amount of fluid necessary to perform this function is dependant on the chip formation characteristics of the given application. Some processes may be modified to use alternative means of chip removal, such as compressed air or compressed air combined with fluid mist application, which are equally successful at removing chips from the work zone without the use of excessive amounts of fluids and the subsequent waste generation. In other cases, retooling may be performed to modify chip formation and ejection to prevent chips from building up on the tool or in the work zone. Additionally, some substrates may be surface treated to modify the chip making characteristics, allowing the chips to break away and exit the cutting area. For more information on alternatives to fluid for chip removal, see Chapter 5, Dry Machining.

Lubrication

The amount of lubrication provided by the fluid largely depends on the type of fluid and fluid additives used. Straight oils provide fair lubricity, but when compounded with active chemical agents such as chlorine, sulphur, or phosphate, they provide a great deal more lubrication. The additives react with the surface of the workpiece, causing the bonds between metallic fibers to weaken, making it easier for the chip to be formed and removed (Peterson 1995).

Figure 1.4 *Lubricity Versus Cooling Capacity of Lubricants (Peterson 1995*)



Fluid Classification

Metalworking fluids have been characterized and classified into many different groups, and the classifications vary depending on the source of information. In Table 1.4 fluids are characterized by base fluid type and additives.

A class of lubricants not covered in the table is paste and solid lubricants. They are sometimes used on grinding wheels, sanding disks or belts, and band or circular saws. Types of solid and paste lubricants are: sulphur, solid waxes, grease sticks, molybdenum disulfide, tripoli, graphite, mica, talc, glass, pastes, and soaps (MA TURI 1996).

Fluid Components

Metalworking fluids have evolved from straight mineral oils, which were widely used at the turn of the century, to extremely complex chemistries today. In addition to base oils, fluids may contain additives, such as emulsifiers, corrosion inhibitors, emulsion stabilizers, anitfoaming agents, buffers, extreme pressure additives, biocides, and antimisting agents. The amount of information available from the formulators varies, but often is no more than the formulator is required to list on the Material Safety Data Sheet (MSDS), plus the fluid’s compatibility with various substrates, and examples of processes for which it is well suited.

Metalworking fluids may contain inactive or active chemical additives that provide increased lubricity. Inactive extreme-pressure (EP) additives, such as chlorine, sulfur or phosphorus, are added to mineral or compounded oils for machining applications where forces are high. These same chemicals may also be added in concentrations high enough that they become active, and chemically interact with the substrate material to further decrease the mechanical energy needs and frictional forces between the tool and the workpiece.

Biocides are used in water-based metalworking fluids to control the growth of bacteria, algae, and fungi. Classes of compounds used are phenolics and nonphenolics, formaldehyde release agents, aliphatic derivatives, organosulphur-nitrogen compounds, and some mixtures of these (Shennan 1983).

Table 1.4 Metalworking Fluid Types, Characteristics, and Uses (MA TURI 1996)

	Type	Characteristics and Uses
Cutting Fluids	Straight Mineral Oils	• used in light duty operations that require low levels of cooling and lubrication • if kept clean, can be reused indefinitely • lower in cost than compounded oils
	Animal and Vegetable Fatty Oils	• most common types are lard and rapeseed oil • sunflower oils and soybean oils also used • high anti-friction properties but lower oxidation points
	Compounded Cutting Oils	• made by blending mineral oils with polar additives and/or chemically active additives
	Fatty-mineral Oils	• straight mineral oils blended with up to 40 percent fatty oil
Emulsifiable Oils	Emulsifiable Mineral Oil	• suspension of mineral oil made by blending the oil with an emulsifying agent • emulsifiers break the oil into minute particles and keep the particles dispersed in water for a long period of time
	Extreme-pressure Emulsifiable Oils	• sometimes referred to as heavy-duty soluble oils • contain sulfur, chlorine, or phosphorus; may also contain some fatty oils to increase lubricity
Synthetic Fluids	True Solution Fluids	• chemical solutions containing rust inhibitors, sequestering agents, amines, phosphates, borates, glycols or ethylene oxide condensates • have a tendency to leave a residue of hard or crystalline deposits that are formed when water evaporates
	Surface-active Chemical Fluids	• fine colloidal solutions of organic or inorganic materials dissolved in water • wetting agents are usually added to provide moderate lubricity • have low surface tensions, usually contain rust inhibitors • when dried on a workpiece usually leave a powdered residue
	EP Surface-active Chemical Fluids	• similar to surface-active fluids but contain extreme pressure (EP) additives, such as chlorine, sulfur, and phosphate, to give the fluid EP lubrication qualities

Heat Treating

Parts are heat treated for a variety of reasons. Table 1.5 lists the types of heat treating processes and the characteristics they promote.

Table 1.5 Heat Treating Processes

Category	Characteristics
Solution Treating and Aging	• produces a homogeneous solid solution • quenches rapidly to room temperature • ages to produce fine precipitates in solid solution
Tempering	• provides toughness and ductility, protecting the part from cracking • relieves quenching stresses • provides impact resistance, improved elongation, and area reduction
Annealing	• reduces hardness or brittleness • relieves stresses • improves machinability or facilitates cold working • produces desired microstructure or properties • removes gases • alters the electrical or magnetic properties
Normalizing	• enhances the mechanical properties • still-air to ambient temperature

(U.S. EPA 1992a, Heine 1998)

Heat treating may take place at various stages throughout the fabrication process, depending on the preceding and subsequent processing of the parts, and the desired characteristics of the substrate at that stage in the metal fabrication process. Below are a few examples of process flows that employ heat treating at various production stages. Typical wastes generated from heat treating processes are spent media, contaminant metalworking fluids, metal fines, and salts.

Parts are heat treated using a number of different methods to supply the heat. Furnace types include:

- salt-bath
- vacuum
- fluidized-bed
- induction
- laser
- electron beam

In salt-bath heat treating, parts are heated by immersion in molten baths of nitrates, chlorides, carbonates, cyanides, or hydroxides. Salt-bath furnaces are used to either heat or cool parts, and are within a temperature range of 300^{o}F to 2400^{o}F. There are two basic types of salt-bath furnaces, ceramic or metal pot furnaces. Ceramic lined furnaces are primarily used for neutral chloride applications (Goetsch 1991).

Figure 1.5 *Process Flow Diagram for the Manufacturing of Steel, Aluminum, or Titanium Parts (U.S. EPA 1995b)*

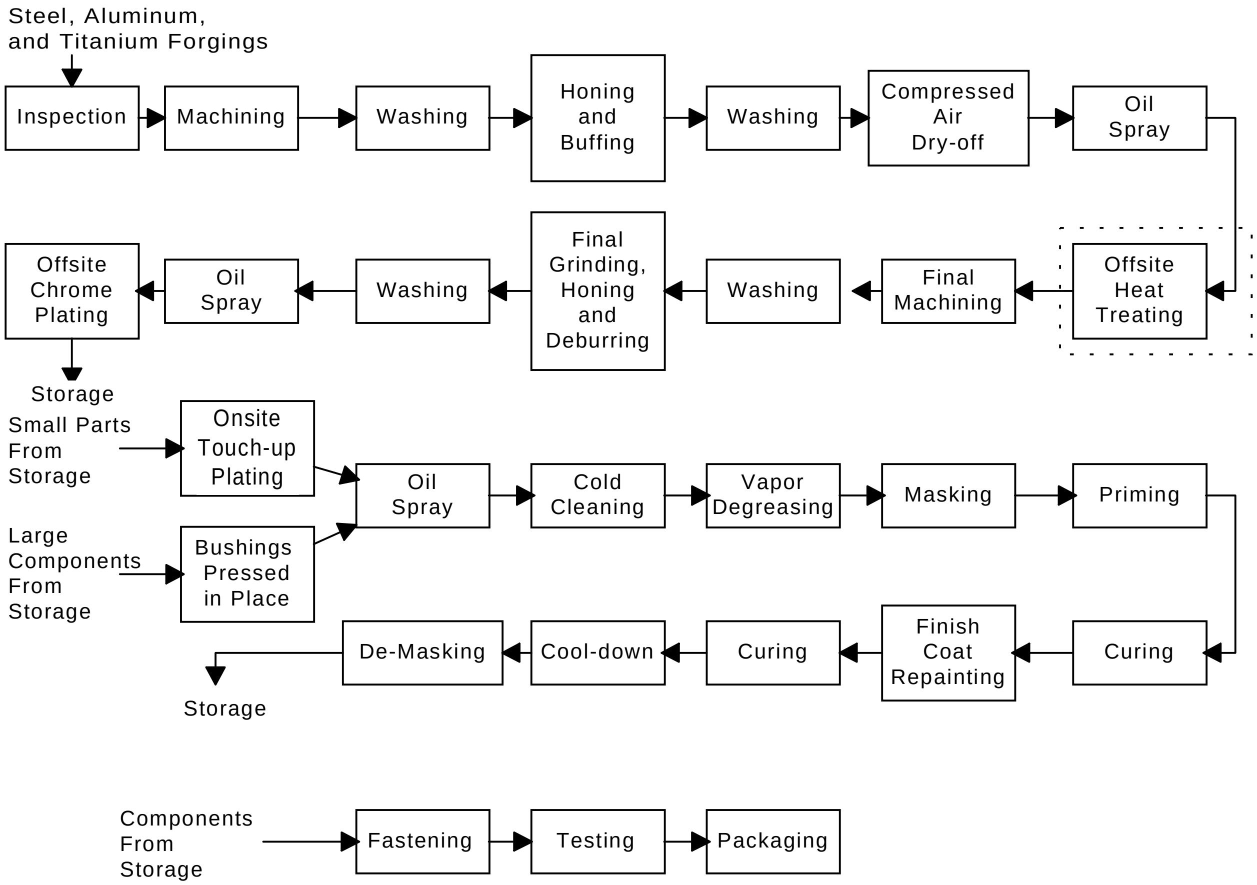
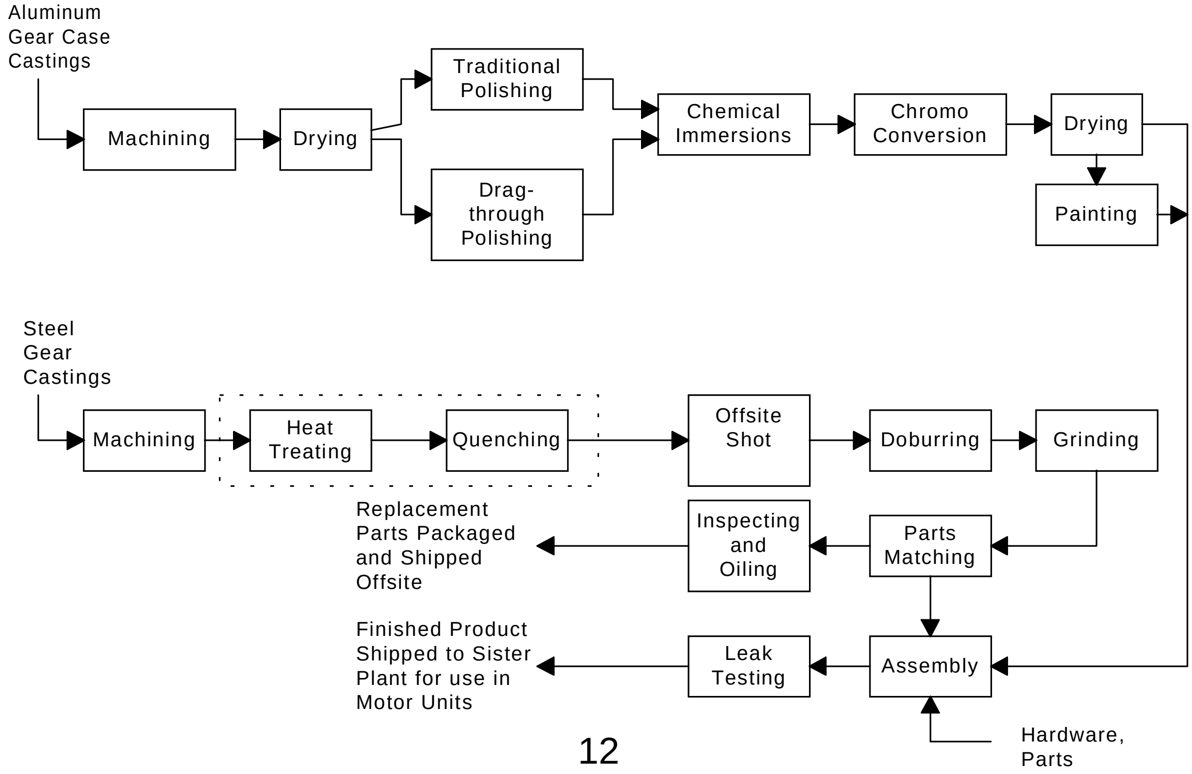


Figure 1.6 *Process Flow Diagram for the Manufacturing of Aluminum or Steel Gears (U.S. EPA 1995*c)



In fluidized-bed furnaces, the parts are placed in a furnace filled with media and flowing gaseous media that gives the furnace its fluidized properties. The temperature that the parts are heated to depends on the substrate and the desired characteristics. Parts are then cooled by quenching (see below) or by allowing them to return to ambient air temperature. There are a variety of media available for use in fluidized-bed furnaces, such as aluminum oxide, silicon carbide, or zirconia sand.

A vacuum furnace is a container that is evacuated and heated by electric radiant heat. Because of advances in design and control, vacuum furnaces are being used as an alternative to salt-bath and atmosphere-controlled furnaces. Vacuum, induction, laser, and electron beam heat treating are covered in more depth in Chapter 6 because they are relatively low polluting methods of heat treating.

Surface (Case) Hardening

Similar in nature to heat treating, surface or case hardening involves heating parts to impart certain surface characteristics. Surface hardening is a thermochemical treatment in which the chemical composition of the steel surface is altered. The types of surface hardening are carbonizing, nitriding, carbonitriding, chromizing, and boronizing. Each type involves heating the substrate in a controlled environment with the presence of a source of the desired case material. Another type of hardening is selective surface hardening, which does not alter the chemical composition of the metal surface but alters the physical properties of the metal surface. The different types of selective surface hardening are: induction hardening, high-frequency resistance hardening, flame hardening, electron-beam hardening, and laser hardening (Goetsch 1991).

Quenching

Metals are cooled after heat treating at varying rates and to varying degrees depending on the type of metal and the desired characteristics. Cooling media may be air, oil, polymer, water, or molten salts, and may be applied in streaming gaseous form, liquid baths, fog, or mist. The quenchant media and application method used depends on the rate of cooling desired, which is again dictated by the phase characteristics of the substrate and the desired characteristics. Typical wastes from quenching operations are spent quenchant and contaminant metalworking fluid.

Quenching is an integral part of liquid carburizing, liquid cyaniding, and liquid nitriding. When the part absorbs sufficient quantities of carbon, cyanide, or nitrogen from a liquid salt bath, it is often quenched in mineral oil, paraffin-based oil, water, or brine to develop a hard surface layer (except tool steels which are liquid nitride cooled) (Goetsch 1991).

Brazing and Soldering

Brazing and soldering use heat and filler metals to produce metallurgical bonds between metal surfaces without melting the base metals. In brazing, the filler metals have liquate temperatures above 840°F, but below those of the metals being joined. The filler metals are distributed between the surfaces to be joined by capillary[7] action. In soldering, the filler metals have liquate

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[7] Involving, held by, or resulting from surface tension.

temperatures below 840°F and the filler metals are distributed by both capillary action and wetting between the surfaces of the components being soldered (Goetsch 1991). Typical wastes and emissions from brazing and soldering processes are used or vaporized fluxes, spent dip baths, filler metal splatter or scrap, and spent rinse baths.

Brazing

Brazing is used in a broad range of applications, from jewelry to aerospace. The use of brazing over welding, adhesive joining, or other methods of joining metals depends on the complexity of the geometries to be joined, the size of the components to be joined, the number of joints to be made, the thickness of the sections, and the service requirements. Heat is applied to the joint to be brazed by one of the following means: torch, induction, dip, infrared, furnace, resistance, laser, electron beam, and exothermic. The method of applying filler metal to the joint is application specific and some of the filler metals may only be brazed by one of the heating methods. Filler metals may be in the form of rings, shims, paste alloys, molten baths, or bars.

Fluxes are used in brazing to facilitate the flow of molten metal into the joint and eliminate oxides that could have a harmful effect on the integrity of the joint. Fluxes are available in both powder and paste form and the type used depends on the application. One of the most commonly used flux materials is borax,[8] although there are a variety of other fluxes available. Brazing of aluminum requires special flux that contain metallic halide salts, sodium chlorides, and potassium chlorides. Like the use of a specific filler metal, the method for applying filler metals depends on the type of brazing employed. After brazing, residual flux is usually removed by immersing in a hot water bath. This is necessary due to the corrosive nature of many of the fluxes used in brazing. Table 1.6 lists some of the advantages and disadvantages of brazing compared to other joining methods.

Soldering

Soldering is a metallurgical intermetallic-type bond[9] between the filler metal and the base metals. Types of soldering, as shown in Table 1.7, are generally classified by the source of heat applied to form the solder joint. In soldering it is important to have a clean joint because unlike brazing, solder fluxes do not eliminate dirt or oxides. The method of application of flux to the joint depends on the process. Fluxes may be either corrosive or noncorrosive. The most widely used noncorrosive flux is rosin.[10] It is used for copper, brass, tin, cadmium, and silver-plated parts soldering. The most widely used corrosive fluxes are muriatic acid and zinc/ammonium chloride, used for soldering bronze, steel, and nickel joints. Table 1.8 lists some of the advantages and disadvantages to soldering compared to other metal joining methods.

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[8] Borax is a white crystalline compound that consists of a hydrated sodium borate that occurs as a mineral or is prepared from other minerals.

[9] Intermetallic-type bonds, by definition, are composed of two or more metals or a metal and a nonmetal.

[10] Rosin is a translucent amber-colored to almost black brittle friable resin that is obtained by chemical means from the oleoresin or deadwood of pine trees or from tall oil.

Table 1.6 Advantages and Limitations of Brazing Compared to Other Joining Methods

Advantages	Limitations
• effective on joints inaccessible to welding • thin-walled tubes and light-gage sheet metal can be brazed • can join dissimilar materials • creates leaktight joints • joining of materials at temperatures below 1300°F • multiple joints can be made at one time • less skilled operators required for high speed applications • brazed joints are ductile • brazing is readily automated	• requires close mating of parts • large assemblies, although brazable, may be more economically made by welding

(Goetsch 1991)

Table 1.7 Types of Soldering and Their Characteristics

Heating Method	Heat Source	Characteristics
Conduction Heating	Irons and Guns	• generally used when the number of joints is few
	Hot Plates	• suitable for automation • longer cooling time required
	Dip	• high production volumes • minimal equipment costs • dross formation is an issue • bath requires skimming
	Wave	• for printed wire board (PWB) manufacturing
	Jet	• jet nozzles of various configuration allow more precise application of solder • may be used with oil for better wetting • requires post cleaning for oil removal
Convection Heating	Torches	• used for soldering preforms and paste alloys • also used for line-soldering enclosures for hermetic sealing
	Ovens or Furnaces	• controlled atmospheres used to eliminate oxidation and the need for corrosive fluxes
	Vapor-phase Soldering	• boiling fluorinated hydrocarbon used as heat-transfer medium • used for joining small parts with unusual configurations
	Hot Gas Blankets	• used for joining small assemblies
Resistance Soldering	NA	• used for electronics
Radiation Heating	Unfocused	• uses ordinary lamps (light waves) as heat source

Table 1.7 Types of Soldering and Their Characteristics (continued)

Radiation Heating (continued)	Focused	• laser is one source of heat used • often used on miniature soldering
Induction Soldering	NA	• electromagnetic induction • part to be soldered is the heating element • flux and solder may be applied prior to joining
Ultrasonics Soldering	NA	• cavitation removes oxides from surfaces • does not require flux in many applications • no wetting provided • may need to pretin or use preformed or solid wire solder on the joint
Other:	NA	• spray gun • screen • abrasion • sweat

(Goetsch 1991)

Table 1.8 Advantages and Disadvantages of Solder Joining Compared to Other Joining Methods

Advantages	Limitations
• versatility • reliability • precise control • fast production • low cost	• poor mechanical properties

Adhesive Joining

Adhesive joints are prepared by applying adhesives and then curing or setting the adhesive. Curing is the change in physical properties of the adhesive by chemical reaction, which may be condensation, polymerization, or vulcanization, often accomplished by heat and/or catalyst, and with or without pressure. Setting is the conversion of an adhesive into a fixed or hardened state by chemical or physical reaction (Goetsch 1991). Typical waste streams and emissions from adhesive joining processes are excess adhesives and volatile organic compound (VOC) and hazardous air pollutant (HAP) emissions from carrier solvents and primers. Adhesive joining operations are defined by the type of adhesive, the method of curing, and the method of adhesive application. Table 1.9 lists the most commonly used types of adhesives.

Table 1.9 Types of Adhesives and Their Characteristics

Type of Adhesive	Characteristics
Natural Adhesives	• not typically used in metal joining applications due to poor bond strength • gums, resins, starch, dextrin,[11] casein,[12] soya flour, and animal products such as blood and collagen
Inorganic Adhesives	• principally sodium silicate and magnesium oxychloride • low cost • poor strength • not very flexible • may be sensitive to moisture
Synthetic Adhesives	• high-strength bonds • elastomers and resins • thermoplastic resins: styrene block copolymers, acrylic, polyolefin, nylon, and vinyl • thermoset resins: acrylic (anaerobics), epoxy, phenolic, polyurethane, and silicone

(Goetsch 1991)

In addition to being classified by type of chemical, adhesives are classified by the methods in which they are converted from a liquid to a solid. The conversion classes and their characteristics are presented in Table 1.10.

There are a relatively large number of Class I adhesives, or chemically reactive adhesives. Therefore, they are further categorized by type of chemical compound, the way in which the reaction is initiated, and other characteristics. The types of Class I adhesives are:

- Plural Components (Class IA)
- Heat-Activated Adhesives (Class IB)
- One-Part Specially Catalyzed Adhesives (Class IC)
- Radiation-Curing Adhesives (Class ID)
- Moisture-Curing Adhesives (Class IE)

Surfaces that are going to be adhesively joined need to be carefully prepared by cleaning, etching, rinsing, and drying. Primers are used in structural adhesive applications for surface protection and adhesion promotion and may be a significant source of air emissions.

There are a variety of adhesive application methods and the method selected depends on the economics, bond filling, and production needs. Table 1.11 lists the various application methods. Vacuum impregnation is commonly used when applying adhesives to die-cast parts, laminates, and powdered metal. In this process, air is evacuated and adhesive is added. Due to vacuum pressures, the adhesive is forced into the microscopic pores of the substrate. The excess adhesive is removed by spinning the parts.

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[11] Dextrin is any of various water-soluble gummy polysaccharides $(C_6H_{10}O_5)_n$ obtained from starch by the action of heat, acids, or enzymes.

[12] Casein is a phosphoprotein of milk.

Table 1.10 Adhesive Classes and Their Characteristics

Adhesive Class	Characteristics
Chemically Reactive Adhesives (Class I)	• undergo curing or crosslinking within the adhesive • high lap-shear strengths • generally have low peel strengths • to improve peel strength, polymer alloys are often employed using thermoplastics and elastomers
Evaporative Adhesives (Class II)	• curing occurs through loss of solvent or water • shear and tensile strengths are low • one of the adherents must be porous or sufficient drying time must be allowed
Hot-Melt Adhesives (Class III)	• must be formulated with thermoplastic resins because a thermoset resin will not form a melt condition upon reheating • polymers used include: ethylene vinyl acetate (EVA), polyethylene, styrene block copolymer, butyl rubber, polyamide, polyurethane, and polyester • must be applied molten
Delayed-Tack Adhesives (Class IV)	• nontacky solids that are heat-activated • blends of resins: polyvinyl acetate, polyamide, or polystyrene
Film Adhesives (Class V)	• similar adhesives as Class IB with similar bond properties • may also be similar to Class III & VI • controlled glue-line thickness • ease of application • freedom from solvent • requires precise heating for extended periods of time • hand application only • most common use in metal laminations • large use in aerospace applications
Pressure-Sensitive Adhesives (Class VI)	• not used in metal joining

(Goetsch 1991)

There are a variety of automatic applicators including stationary, torch, advancing nozzle, rotospray, pressure-time vacuum dispensing systems, and positive-displacement systems.

Table 1.11 Adhesive Application Methods

- manual roller
- screen or stencil printing
- brushing
- extrusion and flow
- troweling
- spraying
- roll coaters
- vacuum impregnation
- manual applicators
- automatic applicators
- robotic applicators

Welding and Weld Cutting

Nearly all metal fabrication processes employ some form of welding. Welding processes vary by heat source, pressure, and filler metals. The various welding processes are:

- oxyfuel gas welding and cutting
- arc welding and cutting
- laser beam welding and cutting
- Thermit welding
- diffusion welding
- friction welding
- ultrasonic welding
- explosive welding and cladding
- other solid-state welding

Typical wastes from welding and weld cutting processes are dross, slag, spent electrodes, and scrap metal.

Buffing and Polishing

Buffing and polishing are performed to smooth and shine the surface of parts to give the product its finished look. A variety of buffing and polishing machines are used, including polishing and buffing lathes, high-speed polishing machines, or off-hand buffing and polishing pads. Wheels, or buffs, are typically made of muslin cloth,[13] mill-treated cloth, sisal,[14] denim, and flannel. The wheels are treated with buffing or polishing compounds that are selected based on the substrate and the level of polishing required for the specific application. Buffing and polishing compounds come in various forms including spray, paste, stick, and powder. Typical wastes from buffing and polishing operations include excess polishing or buffing compounds and spent wheels or pads.

Tumbling and Vibratory Finishing

Tumbling and vibratory finishing are performed for cleaning, oxide removal/descaling, polishing, brightening, and edge-breaking/burr removal. There are wet and dry tumbling and vibratory processes that use a variety of media including ceramics, stone, glass beads, metal shot, nut shells, corn husks, hardwoods, and plastic/resin beads. For wet processes, these media are used in combination with chemistries, such as cleaners and detergents, chelated burnishing compounds, acids, or water. Machines for wet and dry processes may be vibratory bowls, tumblers, centrifugal discs, centrifugal barrels, and continuous vibratory finishers. Typical waste streams from tumbling and vibratory finishing operations are spent media, spent baths, and metal fines.

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[13] Muslin is a plain-woven sheer to coarse cotton fabric.

[14] Sisal is a strong durable white fiber used especially for hard fiber cordage and twine.

CHAPTER 2
Regulatory Overview

This chapter highlights the common waste streams associated with typical metal fabrication and machining processes. It also provides an overview of the federal regulations that pertain to metal fabrication processes.

To an extent, all industrial processes have pollution issues and waste streams. For the most part, metal fabrication processes do not generate wastes as hazardous as those produced by other processes involved in the manufacturing of complex metal parts (i.e., metal finishing or metal coating). However, cutting and shaping processes may generate significant volumes of spent metalworking fluid, which require proper storage, handling, manifesting and overall management. Other processes, such as salt bath heat treating, brazing, and soldering, may generate wastes that are regulated under wastewater, air, or hazardous waste regulations. Fabrication processes that are the most heavily regulated include:

- copper forming
- aluminum forming
- nonferrous metal forming
- cyanide salt bath heat treating
- soldering with cadmium-containing solders
- solvent-based adhesive processes

Metal finishing, metal coating, and primary metal processes will not be covered in this Regulatory Overview, as they were covered in previous volumes in this series, namely *Pollution Prevention in the Metal Finishing Industry*, *Pollution Prevention in the Metal Painting and Coating Industry*, and *Pollution Prevention in the Primary Metals Industry*.

Common Wastes in Metal Fabrication Facilities

As mentioned in Chapter 1, metal fabrication facilities vary greatly in size and operation. In metal shaping and cutting operations, the generation of spent metalworking fluids and scrap metal are the two major waste streams. Other processes in the fabrication of metal parts may have significantly more toxic or hazardous byproducts. This section will define the common sources of wastewater, solid and hazardous waste, and air emissions generated from metal fabrication operations. Table 2.1 lists some of the common wastes by media and process.

Wastewater

Most metal fabricating facilities generate a variety of wastewater streams. Some of the typical sources are water-based metalworking fluids, non-contact cooling water, interim rinse tanks in quenching processes, boiler blow-down water, wet deburring, waterjet cutting, welding quench tanks, and scrubbers. Metalworking fluids are generally handled as hazardous or state regulated oily waste because they contain hazardous constituents and fail fat, oil, and grease (FOG) limits of publicly owned treatment works (POTWs). The contaminants that some of the other process fluids pick up may also make them unsuitable for discharge, and they are often shipped offsite for treatment and disposal through a licensed hauler.

Table 2.1 Common Wastes from Metal Fabrication Processes

Process	Air Emission	Solid/Hazardous Waste	Process Wastewater
Metal Shaping & Metal Removal	• evaporating metalworking fluids* • metalworking fluid mist • smoke	• spent metalworking fluids • tramp oils • spent hydraulic fluids • scrap metal • metal chips and swarf • tool bits • absorbents	• non-contact cooling water • boiler blow-down water • water quenchant
Heat Treating	• vaporized metalworking fluids	• spent salt baths • spent quenchant • refractory material • salt bath bottoms • scale	• spent rinse baths
Soldering & Brazing	• evaporating fluxes	• spent flux • splattering solder	• spent rinse water
Adhesives	• solvent emissions from adhesive curing (i.e., toluene, MEK) • primer evaporative losses • VOCs	• adhesives overspray	
Tumbling, Deburring, Polishing, & Honing		• deburring media • deburring chemicals/bath • honing/polishing compounds • polishing wheels	
Welding		• anti-splatter agents • tungsten electrodes	• quench water

*some fluids are designed to evaporate during the fabricating process; others vaporize due to high process temperatures

Solid and Hazardous Waste

In metal fabrication processes, process fluids that become excessively contaminated are periodically changed and disposed of. Process fluids are shipped off-site for disposal or treatment. Process fluids are usually considered a hazardous material, although in some states, if handled appropriately, they can be exempted. The following are common examples of hazardous waste from metal fabrication operations:

- spent metalworking fluids that cannot be treated in process or have been biologically degraded
- spent salt baths from heat treating processes
- spent quenchant
- tank dredges
- spent filter media
- flux baths from certain soldering operations
- scrubber wastes containing hazardous salts and metalworking fluids

Scrap metal, chips, and swarf are common solid wastes from metal fabrication processes that may require special handling depending on how much metalworking fluid they contain. It is often necessary to reduce the amount of metalworking fluid in these waste streams before a scrap dealer will accept them. Oil contaminated rags and absorbents are other common wastes whose handling also is dictated by how much metalworking fluid they contain. Regulations covering waste oil and spent rags can vary greatly from state to state; for state-specific information contact your state environmental agency's waste management program.

Metal fabrication facilities generate solid waste in the form of broken pallets, cardboard boxes, and other packaging and shipping materials. Many of these waste streams may be recycled and facilities have set up separation programs to divert as much as possible from the solid waste stream to reduce waste disposal costs.

Air Emissions

The use of metal working fluids in metal shaping and metal removal processes may result in fugitive emissions in the form of smoke, mist, or vapor. Other processes may create more hazardous air emissions. Possible sources of air emissions in metal fabrication processes are:

- smoke emissions from metal removal processes
- potential VOC emissions from metalworking fluids
- metalworking fluid mists
- cyanide emissions from salt baths
- evaporating metalworking fluids from salt baths and furnaces
- evaporative losses of solvents from adhesive processes
- vaporized solder fluxes

Regulatory requirements on the above emissions vary depending on the specific application and location. For specific information on regulatory requirements related to these sources, contact your state environmental agency's air quality program.

Overview of Federal Regulations Affecting Metal Fabricators

The metal fabrication industry is regulated under numerous federal, state, and local environmental statutes. Major regulations affecting these processes include the Clean Air Act (CAA), the Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA). Also, facilities using chemicals listed under the Emergency Planning and Community Right-To-Know Act (EPCRA),[15] are required to report their releases of those chemicals under the EPA's Toxics Release Inventory (TRI) program.

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[15] Also know as Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986.

Clean Water Act

The Clean Water Act regulates the amount of chemicals/toxics released via wastewater/effluent discharges. The EPA has promulgated effluent guidelines and standards for different industries under the CWA provisions. These standards usually set concentration-based limits for the discharge of a given chemical. The EPA defines two types of dischargers: direct and indirect.

Direct Dischargers

A facility that is discharging directly into a body of water is regulated under the National Pollution Discharge Elimination System (NPDES) and must apply for a NPDES permit. The permit specifies what type of pollutants can be discharged and includes a schedule for compliance, reporting, and monitoring. The NPDES regulations limit the amount of metals, cyanides, and total toxic organics that a facility can discharge. These limitations are set based on whether the facility is treating wastewater onsite prior to directly discharging to a body of water or the facility is discharging to a POTW (Haveman 1995).

Indirect Dischargers

Most metal fabrication facilities discharge their wastewater to POTWs. These indirect dischargers must adhere to specified pretreatment standards. Often, specific state or local water regulations require more stringent treatment or pretreatment requirements than those in the federal effluent guidelines because of local water quality issues (Haveman 1995). All facilities discharging to a POTW are governed by the General Pretreatment Standards. These standards state that discharges must have a pH greater than 5.0 and cannot:

- Create fire or explosion
- Obstruct the flow of wastewater through the system
- Interfere with sewage plant operations
- Contain excessive heat
- Contain excessive petroleum, minerals, or non-biodegradable oils

In addition to the above requirements, specific regulations for certain fabrication processes apply under the CWA, including:

- Steel and Iron Manufacturing Point Source Category - 40 CFR 420 (as it applies to hot and cold rolling operations)
- Nonferrous Alloy Manufacturing Point Source Category - 40 CFR 421(as it applies to hot and cold rolling)
- Aluminum Forming Point Source Category - 40 CFR 467
- Copper Forming Point Source Category - 40 CFR 468

Existing companies regulated under these standards face stringent effluent standards for specific chemicals when they make modifications to or expansions of their process. New companies are subject to other, more stringent standards. The following lists the requirements for each type of facility.

Existing facilities:

- Pretreatment Standards for Existing Sources (PSES)
- Effluent Limits Based on Best Practicable Control Technology (BPT)
- Effluent Limits Based on Best Conventional Technology (BCT)
- Effluent Limits Based on Best Available Control Technology (BACT)

New facilities:

- New Source Performance Standards (NSPS)
- Pretreatment Standards for New Sources (PSNS)

For more information on these standards contact a local POTW or your state environmental agency's wastewaster treatment program.

The standard that is under development that will have the greatest impact on metal fabricators is the Metal Products and Machinery Standard (40 CFR 438). The proposed standard would set stricter limits on the discharge of a 132 pollutants of concern (POC), including: chromium, copper, nickel, zinc, and cyanide. New standards might be set on direct discharges of aluminum and iron. The first part of this standard, Phase I, was proposed in May of 1995. The second part of the standard, Phase II, was scheduled for promulgation in 2000. Due to significant comment on the initial proposal, the two Phases were combined, and both were proposed in October 2000 and will be promulgated in December of 2002.

Stormwater Discharge

Under the Clean Water Act Amendments of 1987, the EPA was charged with establishing a system to address stormwater discharges. In response, the EPA promulgated the NPDES storm water permit application regulations. These regulations address any conveyance that is used for collecting and conveying stormwater and that is directly related to manufacturing, processing, or raw materials storage areas at an industrial plant. The regulations cover:

- discharges associated with industrial activity
- discharges from a large or medium municipal storm sewer system
- discharges that the EPA or the state determines to contribute to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

The stormwater regulations divide discharges by 11 industrial classifications and metal fabrication facilities are in Category XI. Category XI is unique under the current stormwater regulations in that it contains a "No Exposure Exemption." This exempts metal fabricators, and other industrial sources within this category from the definition of "stormwater discharge associated with industrial activity," and the subsequent requirement to obtain an NPDES permit, provided their industrial materials, material handling operations, and industrial processes are not "exposed" to stormwater (U.S. EPA 1999).

Management of Used Oil

Under the Federal Regulation 40 CFR 279 (Standards for the Management of Used Oil), EPA published specific rules for the accumulation, storage, handling, and on-site burning of used oil as well as prohibitions against onsite burning of certain types of contaminated fluids.[16] The standards decrease the regulatory burden on facilities to encourage the recycling of used oil. Some states have adopted additional requirements for facilities that generate used oil. The federal rule requires that metalworking fluids contaminated with more than 50 ppm of PCBs, 1000 ppm of halogenated substances, or any amount of CFCs, or any metalworking fluids that exhibit RCRA-defined hazardous characteristics, must be handled as hazardous waste. State regulation of waste oil varies and some states require that all waste oil be handled as hazardous waste.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) of 1976 addresses solid (Subtitle D) and hazardous (Subtitle C) waste management activities. Regulations promulgated under Subtitle C establish a "cradle to grave" system that governs these wastes from point of generation to disposal. A material is classified under RCRA as a hazardous waste if the material meets the definition of solid waste[17] and exhibits one of the characteristics of a hazardous waste (i.e., corrosiveness, flammability, toxicity, or reactivity, designated with the code "D") or if it is specifically listed by the EPA as a hazardous waste (designated with the code "F"). The range of listed wastes may vary from state to state because states may add wastes to the list of those that are regulated as hazardous waste.

Within RCRA Subtitle C, the EPA includes hazardous waste from non-specific sources in a series of "F" listings. Table 2.2 presents the F-listed wastes that might be generated from metal fabrication processes.

Another category of hazardous waste is a characteristic waste. These wastes exhibit one or more of the RCRA Subtitle C characteristics (i.e., flammable, corrosive, reactive, or explosive) and are not specifically listed. Common characteristic wastes generated in metal fabrication operations include:

- Spent metalworking fluid whose reaction products between the fluids, additives, and the metals being machined may cause spent fluid to be hazardous even if the "clean" product was not hazardous
- Corrosive salt baths
- Heat treating rinsewater, which might have a low or high pH depending on the contents of the preceding bath
- Spent quenchant media that may be contaminated with heavy metals (other than cyanide) (NCMS 1997)

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[16] This standard was established under authority from the Solid Waste Disposal Act and CERCLA.

[17] The term ''solid waste'' means any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under section 1342 of Title 33, or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended (68 Stat. 923) (42 U.S.C. 2011 et seq.).

Table 2.2 RCRA Listed Wastes (U.S. EPA 1996)

Listing	Waste Description
F002	Spent halogenated solvents: tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-thrichloroethane chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, trichlorofluoromethane, and 1,1,2-trichloroethane; vapor degreasing still bottoms
F003	Spent non-halogenated solvents: xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, methyl isobutyl ketonen-butyl alcohol, cyclohexanon, and methanol
F004	Spent nonhalogenated solvents: cresols and cryesylic acid, and nitrobenzene
F005	Spent nonhalogenated solvents: toluene, methyl ethyl ketone, carbon disulfide, isobutanol, pyridine, benzene, 2-ethoxyethanol, and 2-nitropropane
F010	Quench bath residues from oil baths in metal heat treating operations using cyanides
F011	Spent cyanide solutions from salt bath pot cleaning in metal heat treating operations

After determining whether or not the facility generates hazardous waste, the fabricator must determine its generator status. Generator status is based upon the amount of waste generated on a monthly basis. The first step in determining generator status is to determine the quantity of waste that is regulated by RCRA. The following are some general guidelines to determine whether or not a material counts towards RCRA generation status:

- Material remaining in a production process is not counted as waste until it is no longer being used in that process
- Waste discharged directly and legally to a POTW in compliance with CWA pretreatment standards is not counted toward RCRA generation total
- Any material that is characteristic or listed as a hazardous waste, and is accumulated after its removal from the process before being sent off site for treatment, storage, or disposal, is counted toward RCRA Subtitle C generation total

In general, there are three classes of generators:

- Large Quantity Generators: Facilities that generate more than 1,000 kilograms (2,200 pounds) of hazardous waste per month or that generate or accumulate more than 1 kilogram (2.2 pounds) of acute hazardous waste at one time
- Small Quantity Generators: Facilities that generate between 100 kilograms (220 pounds) and 1,000 kilograms (2,200 pounds) of hazardous waste in any calendar month
- Conditionally Exempt Small Quantity Generators: Facilities that generate less than 100 kilograms (220 pounds) of hazardous waste per month or that generate less than 1 kilogram (2.2 pounds) of acute hazardous waste in any calendar month (NEWMOA 1997)

EPA delegates the oversight of RCRA generators to states, and the generator status groups may differ from state to state by name and threshold limit values. Each state has varying degrees of regulation for the three generator classes. At a minimum, however, the EPA requires each class to comply with the following requirements:

Large Quantity Generators

- Notify the EPA and obtain an EPA ID number
- Store waste for no more than 90 days
- Comply with container standards and tank rules
- Prepare and retain a written Contingency Plan
- Prepare and retain written training plan, including annual training of employees
- Prepare a written waste minimization plan
- Dispose of hazardous materials only at RCRA-permitted sites
- Only use transporters with EPA ID numbers
- Use proper Department of Transportation (DOT) packaging and labeling
- Use the full Uniform Hazardous Waste Manifest
- Place a 24-hour emergency telephone number on all manifests
- Report serious spills or fires to the National Response Center
- Obtain a DOT registration number for shipments over 5,000 pounds
- Keep all records for three years
- Make sure that any treatment or recycling done onsite is permitted
- Report missing shipments in writing
- Submit biennial reports of hazardous waste activities, including waste minimization

Small Quantity Generators

- Notify the EPA and obtain an EPA ID number
- Store waste for no more than 180 days (270 days if the waste is shipped more than 200 miles)
- Comply with container standards and tank rules
- Dispose of hazardous materials only at RCRA permitted sites
- Only use transporters with EPA ID numbers
- Use proper Department of Transportation (DOT) packaging and labeling
- Use the full Uniform Hazardous Waste Manifest
- Place a 24-hour emergency telephone number on all manifests
- Post emergency response telephone numbers near telephones
- Provide informal employee training
- Make sure that any treatment or recycling done onsite is permitted
- Report missing shipments in writing
- Keep all records for three years

Conditionally Exempt Small Quantity Generators

- Avoid accumulating more than 1,000 kg (2,200 pounds) of hazardous waste onsite at any one time
- Send waste to a facility that is at least approved to manage municipal or industrial solid waste (NEWMOA 1997)

Toxics Release Inventory Reporting

Manufacturing facilities included in the SIC codes 20 to 39, which have ten or more employees, and which manufacture, process, or otherwise use specified chemicals in volumes greater than threshold limits, must publicly report their releases of these chemicals. Facilities report information on a TRI data form (Form R) for each toxic chemical that is used over the threshold amount. Basic information reported in a Form R includes:

- Facility identification
- Parent company information
- Certification by corporate official
- SIC code
- Chemical activity and use information
- Chemical release and transfers
- Off-site transfer information
- On-site waste treatment
- Source reduction and recycling activities

The releases and transfers reported on a Form R include:

- Emissions of gases or particulates to the air
- Wastewater discharges into rivers, streams, and other bodies of water
- Releases to land on site, including landfill, surface impoundment, land treatment, or other mode of land disposal
- Disposal of wastes in underground injection wells
- Transfers of wastewater to POTWs
- Transfers of wastes to other off-site facilities for treatment, storage, and disposal

The thresholds for manufacturing and processing are 25,000 pounds and 10,000 pounds for the “otherwise used” category. Some of the TRI chemicals commonly used in metal fabrication facilities are listed in the Table 2.3.

Metalworking Fluid Requirement

Another federal regulation - 40 CFR 747 - Metalworking Fluids - applies to fabricators who use fluids that contain certain amine compounds, specifically mixed mono- and diamides of an organic acid, thriethanolamine salt of a substitute organic acid, and thiethanolamine salt of a tricarboxylic acid. These fluids are clearly marked on the container, which is required of the manufacturer as part of this rule. This rule was created under the authority of the Toxic Substances Control Act (TSCA). Under TSCA, the EPA is required to set limits on the manufacture and use of substances known to the EPA to present unreasonable risk of injury to human health or the environment (15 U.S.C. 2605).

Fabricators who use fluids containing these substances are prohibited from adding nitrosating agents to the fluid because this would cause the formation of nitrosamines, a known carcinogen (40 CFR Part 747).

Table 2.3 Chemicals on the TRI that Fabricators Commonly Use (PPRC 1997)

- Ammonia
- Barium
- Cadmium
- Chromium
- Copper
- Cumene
- Cydohexane
- Ethylbenzene
- Ethylene glycol
- Ethylene oxide
- Formaldehyde
- Freon 113
- Hydrochloric acid
- Hydroquinone
- Lead
- Methanol
- Methyl ethyl ketone
- Methyl isobutyl ketone
- Methylene chloride
- Perchloroethylene
- Phosphoric acid
- Silver
- Sulfuric acid
- Toluene
- Trichloroethylene
- 1,1,1-trichloroethane
- Xylene

Clean Air Act

Under the Clean Air Act Amendments (CAAA), metal fabricating operations with processes that could emit Hazardous Air Pollutants (HAPs) or volatile organic compounds (VOCs), as defined in the CAAA, could be required to obtain an operating permit and/or comply with other regulatory requirements for those processes. This is not the case for many fabricators that are only involved in metal shaping and cutting operations. However, facilities that perform adhesive joining, brazing, soldering, and heat treating may emit HAPs and VOCs and may need to obtain a permit.

Hazardous Air Pollutants

Under the Clean Air Act Amendments of 1990, the EPA is required to regulate the emissions of 188 hazardous air pollutants (HAPs). Table 2.4 lists some of the HAP listed chemicals that fabricators commonly use.

Table 2.4 Common HAPs Used by Metal Fabricators (PPRC 1997)

- Benzene
- Cadmium compounds
- Carbon tetrachloride
- Chromium compounds
- Cumene
- Dibutylphthalate
- Diethanolamine
- Ethyl benzene
- Formaldehyde
- Glycol ethers
- Hexane
- Hydrochloric acid
- Isophrone
- Lead compounds
- Methanol
- Methyl ethyl ketone
- Methylene chloride
- Perchloroethylene
- Polycyclic organic matter
- Propylene oxide
- Toluene
- 2,4-toluene diisocyanate
- 1,1,1-trichloroethane
- Vinyl chloride
- Xylene

The CAAA classifies facilities by the amount of HAPs they emit. Listed below are a few examples.

Major Source -- Any source of toxic air pollution that emits or has the potential to emit 10 tons per year of any listed hazardous air pollutant, or 25 tons or more of a combination of listed hazardous air pollutants.

Lesser Quantity Major Source -- Certain other sources that are considered major sources even though they emit less than the 10/25-ton limit figure. Lesser quantities (meaning less than the 10 or 25 tons per year definitions in the Act), can be set for pollutants that are highly toxic to human health or the environment. If the EPA sets a lesser quantity limit for a particular industrial group, all sources within that group that emit more than the established limit will be classified as major sources.

Area Source -- These smaller sources emit less than 10 tons per year of a single air toxic, or less than 25 tons per year of a combination of air toxics. The EPA has discretion over whether to regulate categories of these sources. Most area source emissions are small, but the collective volume can be hazardous in densely developed areas where large numbers of such facilities are packed tightly into urban neighborhoods and industrial parks.

Congress requires the EPA to identify major and area source categories associated with the emissions of one or more listed HAPs. To date, the EPA has identified 174 categories. Congress also requires the EPA to promulgate emissions standards for listed source categories within 10 years of the enactment of the CAAA (November 15, 2000). These standards are called the National Emission Standards for Hazardous Air Pollutants (NESHAPs).

Metal fabrication facilities may fall within a number of the source categories that have or will have NESHAPs. The NESHAPs most likely to affect metal fabrication operations have been promulgated for coating, plating, finishing, and organic solvent degreasing operations. For more information on these NESHAPs visit http://www.newmoa.org/publications and view the *Pollution Prevention in Metal Finishing* and *Pollution Prevention in Metal Painting and Coating* manuals. To date, no NESHAPs have been developed for the processes covered in this Manual. However, adhesives use has been mentioned in the Preliminary Industrial Characterization (PIC) of some developing standards, including those for the Metal Coil Coating Industry, the Metal Furniture Industry, and the Large Appliance Industry (U.S. EPA 1998). Depending on the final language of these NESHAPs, fabricators who apply adhesives may be required to meet specific emission standards in the future.

For major sources that do not fall under a NESHAP Source Category, facilities must obtain a Title V Air Operating Permit from their state or local air permitting agency and report their emissions of listed pollutants. For more information on Title V Operating Permits contact your state or local air permitting authority.

Volatile Organic Compounds

In an effort to limit the emission of certain criteria pollutants, Title I of the CAA required the EPA to develop standards on the following substances:

- Inhalable particulates
- Nitrogen oxide
- Ozone
- Sulfur oxides
- Lead
- Carbon monoxide

The standard of interest to metal fabricators is ozone. Ground level ozone results from the reaction of volatile organic compounds, or VOCs, with nitrogen oxides in the presence of heat and sunlight. VOCs may be emitted from metalworking fluids, adhesives, and fluxes. The level of VOCs regulation depends upon the air quality where the facility is located. Basically, if a source is located in an "attainment" area (i.e., in compliance with the National Ambient Air Quality Standards), it will be required to obtain a permit if its potential to emit is greater than 100 tons of VOCs per year. If the facility is located in an attainment area in the Northeast or Mid-Atlantic states (otherwise known as the Ozone Transport Region), it is required to get a permit from the state if it has the potential to emit 50 tons of VOCs per year (Haveman 1995).

For those facilities located in non-attainment areas, the regulatory thresholds are much lower. How much lower depends on the degree of non-compliance with NAAQSs in that region. The EPA classifies non-attainment areas into five categories: marginal, moderate, serious, severe, and extreme.

As regional or statewide air quality problems increase, the likelihood that a small source of VOCs will be required to obtain a permit increases. This added regulatory burden may be an important impetus for facilities to more closely scrutinize the compounds they are using.

Metalworking fluids, adhesives, solder fluxes, and weld anti-splatter compounds may contain VOCs. If these materials are found to contain VOCs upon examination of their MSDS, then they must be included when determining the facilities emissions or potential to emit. Firms may be required to determine their VOC emissions, or potential to emit VOCs, from the use of these materials under their specific operating conditions.

Three areas where metal fabrication facilities have the greatest potential to emit VOCs include:

- Operations that use solvents containing VOCs, such as parts cleaning or adhesives application
- Operations that use solvent-based paints or coatings
- Operations that use fluxes, such as soldering and brazing

Metal fabricating facilities must take all sources of VOCs into consideration when determining whether or not they need a permit. For more information on determining whether or not a source needs a permit, contact your state air permitting authority.

State Pollution Prevention and Toxics Use Reduction Laws

Many states throughout the U.S. have toxics use reduction or pollution prevention planning laws that require facilities of a certain size to go through a formal planning process where they evaluate alternatives aimed at reducing toxics use or the generation of pollution at its source. The Sections below list the status of pollution prevention and toxics use reduction laws for states in the Northeast.

Connecticut

Connecticut does not have any toxics use reduction or pollution prevention planning requirements.

Maine

In 1999 Maine reauthorized its pollution prevention law. The reauthorization encourages toxic use reduction, reductions in releases of toxics during manufacturing and other processes, and reductions in hazardous waste generation. The Law requires that there be a pollution prevention system for state facilities by 2005. The Law sets goals for toxics use reduction, toxics release reduction, and hazardous waste generation minimization, as listed below.

Toxics Use Reduction Goals

Using the amount of toxics used statewide in 1990 as a baseline figure, the statewide goals for toxics use reduction are a 40 percent reduction in the amount of toxic substances used in the State by January 1, 2002, a 50 percent reduction by January 1, 2004 and a 60 percent reduction by January 1, 2006.

Toxics Release Reduction Goals

Using an average of the aggregate amounts of toxics released at a facility statewide in calendar years 1990 and 1991 as a baseline figure, the goals for reducing the aggregate amount of toxics released to the environment at the facility statewide are a 40 percent reduction by January 1, 2002, a 50 percent reduction by January 1, 2004 and a 60 percent reduction by January 1, 2006.

Hazardous Waste Generation Minimization Goals

The goals for minimizing the amount of hazardous waste generated at a facility statewide are a 40 percent reduction by January l, 2002; a 50 percent reduction by January 1, 2004; and a 60 percent reduction by January 1, 2006. Reductions must be based on a facility's average generation rate in the State for the years 1987 and 1989.

Under the Law, facilities are required to go through a planning process. The minimum planning requirements are:

- development of a facility-wide management policy for the reduction of toxics use, release and waste generation.
- completion of a production unit analysis that:
  -characterizes the toxics used and released, and the hazardous waste generated
  -identifies and evaluates appropriate use and release reduction techniques
  -analyzes the costs and benefits of reducing the amounts of toxics used
  -proposes a strategy for implementing selected reduction technologies, including a schedule
  -identifies available markets for recycling the hazardous waste generated
  -establishes a record keeping program
- development of an employee awareness and training program

Facilities are required to submit a biennial progress report that includes:

- the facilities' goals
- progress achieved
- methods used to achieve reductions
- an explanation of why the facilities' progress is less than or greater than the goals
- a description of how employees were involved in the planning process
- future P2 methods that will be used to achieve reductions
- a certification of the progress report by senior management

The Law requires that all data collected be made available in electronic format and on the Internet (Maine 1999).

Massachusetts

Massachusetts passed the Toxic Use Reduction Act (TURA) in 1989. TURA requires that large quantity toxics users (i.e. manufacturing or processing 25,000 pounds per year, or otherwise using 10,000 pounds per year) develop a toxic use reduction (TUR) plan. The goal of the planning process is to identify TUR opportunities that are cost-effective so as to stimulate companies to implement them voluntarily. The TUR plan should:

- examine how toxic chemicals are used and lost during production
- calculate the cost of toxic chemical usage
- identify potential TUR techniques
- evaluate the feasibility of the TUR techniques
- evaluate the costs and savings of implementing the various TUR techniques (NEWMOA 1997)

Contact the Massachusetts DEP or the Office of Technical Assistance (OTA) for more information about TURA requirements.

New Hampshire

New Hampshire does not have any toxisc use reduction or pollution prevention planning requirements.

New Jersey

New Jersey has a comprehensive pollution prevention planning requirement. Facilities that are required to file at least one Form R under the federal Emergency Planning and Community Right-to-Know Act (EPCRA) must prepare a P2 plan. The chemicals that must be considered in the plan are those listed under Title III, Section 313 of SARA for TRI reporting under EPCRA and are used, manufactured or processed at the facility in a quantity greater than 10,000 pounds per year. The goal of New Jersey's mandatory planning program is that companies will discover economically attractive source reduction opportunities that they will implement voluntarily. New Jersey requires the following elements in a P2 plan:

- list of chemicals used or manufactured in quantities greater than 10,000 pounds per year
- inventory data for each chemical to show annual inputs
- inventory data for each chemical to show annual outputs
- out-of-process recycling data for each chemical
- release data for each chemical
- quantities used for each chemical
- description of each production process using or generating a listed chemical
- inventory data for each process showing the amount of hazardous substance:
  -contained in the product
  -consumed by the process
  -used by the process
  -generated asnonproduct output (NPO) from the process
  -released from the process
  -sent for recycling from the process
- hazardous waste information, including total quantities generated, treated, recycled, stored, and disposed, as well as identification of off-sitetreatment/storage/disposal facility (TSDFs) used
- type(s) and quantity of hazardous waste produced by each production process
- comprehensive financial analysis for each production process
- description of processes targeted for P2
- quantification of nonproduct output for each targeted process
- list of available P2 opportunities for each targeted process
- technical analysis of each option
- a comprehensive comparative financial analysis of each option
- a discussion of all options that are technically and financially feasible
- identification of numeric five-year goals for the facility to reduce use and/or generation of each hazardous substance, the facility's impact on releases, and the reduction of per unit use and/or generation of each hazardous substance
- a schedule for implementation of feasible P2 techniques (NEWMOA 1997)

New York

New York has had a Waste Reduction Policy since 1987, which established the following hazardous waste management hierarchy:

- reduction or elimination of hazardous waste generation
- recover, reuse or recycle wastes that are produced
- detoxify, treat or destroy wastes that cannot be recovered, reused or recycled
- land disposal

In July 1990, the Hazardous Waste Reduction Act (HWRA) was signed into law. The law requires that generators of 25 tons or more of hazardous waste per year prepare and submit to the state a Hazardous Waste Reduction Plan (HWRP). The HWRP is to be implemented according to a phased schedule. The HWRP is to be updated biennially and annual status reports are to be submitted. The requirements of the HWRA apply to manufacturers that have RCRA hazardous waste generation of 25 tpy or more. Therefore, most machinists and metal fabricators will not be affected by HWRP requirements (NEWMOA 1997).

Rhode Island

Rhode Island has no toxic use reduction or pollution prevention planning requirements.

Vermont

Under Act 100, passed in 1991, Vermont requires that facilities that use toxic substances and/or generate hazardous waste develop a pollution prevention plan. All facilities that manufacture, process or use more than 10,000 pounds per year of a toxic substance are required to develop a plan, as well as facilities that use more than 1,000 pounds per year if that amount accounts for more than 10% of the total toxic substances manufactured, processed or used. A toxic substance is defined as those listed under Title III, Section 313 of SARA. Generators of hazardous waste are required to plan if they generate more than 2,200 pounds of hazardous waste in any one month or if they generate more than 2,640 pounds per year. The P2 plan should include the following:

- general information about the facility, including a description of the products made and production levels
- description of the management policy, and employee training and awareness program regarding P2
- description of current and past P2 efforts
- listing of toxic substance use in each product, including total quantity used and production level (for those required to file because of toxic substance use), or a list of hazardous waste generation by production process (for those required to file because of hazardous waste generation)
- detailed description of each process using toxic substances or producing hazardous waste, including input and outputs (i.e. process flow diagram)
- list of P2 opportunities for each process
- technical feasibility analysis for each opportunity
- economic feasibility analysis for each opportunity
- list of selected P2 opportunities and performance goals (i.e. level of reduction and schedule)

The state requires that facilities submit the summary of their P2 plan for public record. The full plan is to be maintained at the facility and made available on site to state inspectors on request. Metal fabricators that emit/use more than 1,000 pounds (½ ton) per year of a SARA 313 substance are subject to Vermont's P2 planning requirements (NEWMOA 1997).

CHAPTER 3

Overview of Pollution Prevention Opportunities and Methods

This chapter provides an overview of pollution prevention opportunities in metal fabrication processes. It highlights the "low-hanging fruit" and introduces some of the techniques and technologies that will be covered in more depth in later chapters.

Table 3.1 provides a brief overview of some of the pollution prevention opportunities for metal shaping, metal removal, and other processes that are integral to the fabrication of metal parts. These opportunities are discussed in greater detail below and in subsequent chapters.

Metalworking Fluids

Metalworking fluids are used in machining and fabricating operations to cool the tool and work piece, to lubricate, to flush chips away from the work zone, and to prevent corrosion of the workpiece and tool bit. However, metalworking fluids are a significant source of waste from metal cutting and shaping processes and often contaminate subsequent process baths. This section provides an overview of input substitutions, process modifications, and operation and maintenance changes that can reduce the generation of waste associated with the metalworking fluids. Newer, innovative technologies related to metalworking fluids reduction and elimination are covered in Chapter 4.

Fluid Selection

The first question that needs to be resolved before beginning the fluid selection process is whether a fluid is required; for certain applications, they may not be. In the following situations facilities may not need to use cutting fluids:

- Stock may arrive coated with sufficient lubricant for some applications
- The machining environment may not be severe enough to warrant fluid use, such as manual stamping operations performed on very thin, malleable substrates

In applications where fluids have been necessary in the past, recent advances make it possible to eliminate the use of metalworking fluids and to eliminate the thermal distortion caused by fluid use. Various tool bit material and coating advances have made it possible to eliminate the use of fluids from a number of processes. For more information on dry machining, see Chapter 5, Innovative Pollution Prevention Technology.

Many firms lack a formal process for selecting the metalworking fluids they use. Often fluid selection decisions are made based only on its functionality in the machining process. The fluid can have a significant pollution impact on later processes if these processes are not considered during the selection process. For example, heavy mineral oils used in metalworking processes, when vaporized in subsequent heat treating processes, can significantly contaminate scrubber systems and interfere with their effectiveness. Health and safety, environmental impacts, and maintenance issues should also be considered in the selection process. Figure 3.1 outlines the most basic issues that firms should address during the fluid selection process.

Figure 3.1 *Metalworking Fluid Selection Process (NCMS 1997)*
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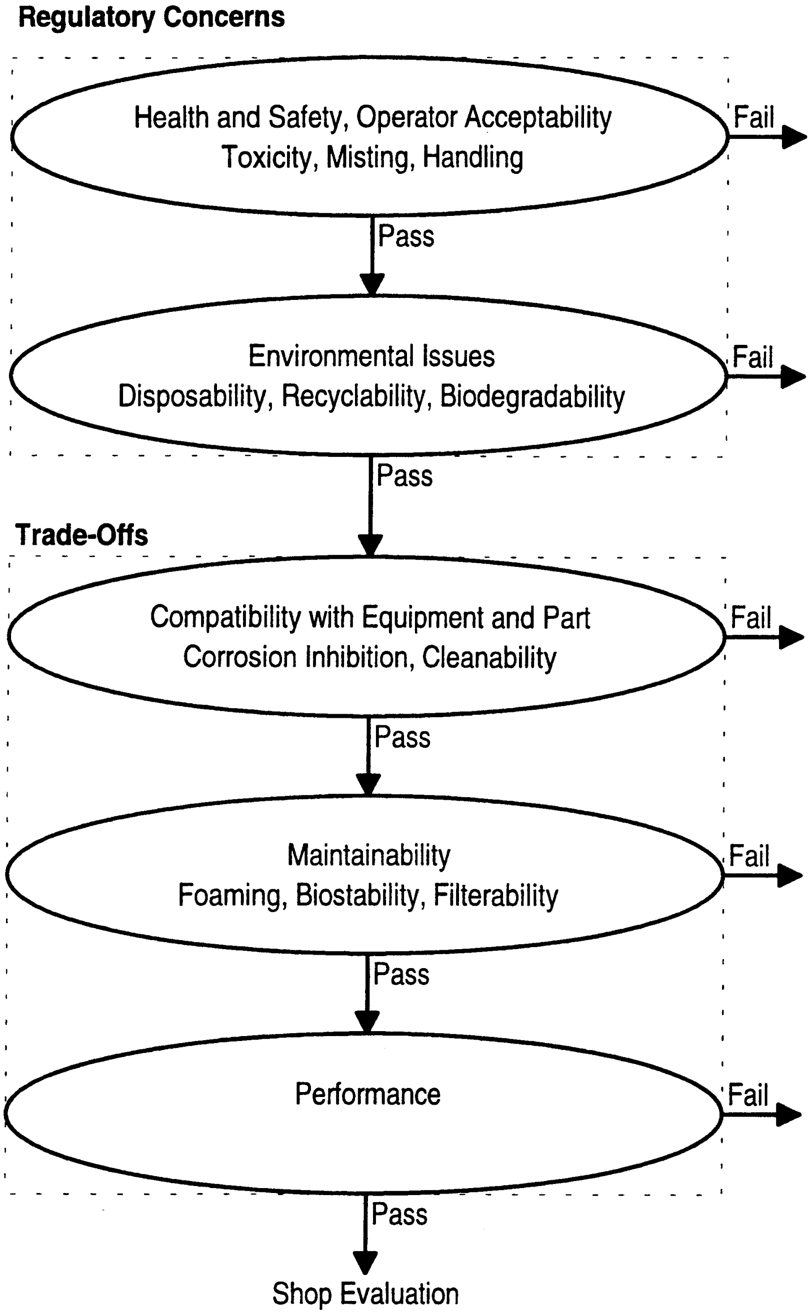

Table 3.1 Pollution Prevention Overview of Metal Fabrication Processes

Application	Pollution Prevention Opportunities
Metal Stock	• selecting appropriately sized stock can eliminate unnecessary cutting and subsequent scrap
Pattern Layout	• layouts should be fully optimized to minimize scrap
Machine Maintenance	• a machine maintenance program should be instituted when persistent leaks are present to minimize unnecessary floor cleanups and tramp oil contamination of metalworking fluids
Dry Machining	• the metalworking conditions should be evaluated to determine if fluid is necessary • quench fluid or fluid used to protect parts during shipping may provide sufficient lubrication • process parameters may be optimized to eliminate the use of fluids (i.e., cutting speed, feed rates, chip removal)
Metalworking Fluid Selection	• the in-process recyclability of fluids should be considered during selection • the compatibility of the fluid with other processes should be evaluated
Metalworking Fluid Application	• modernizing application equipment and optimizing application techniques can greatly reduce the volume of fluid used
Fluid Maintenance	• fluids should be tested periodically to monitor pH, concentration, and microbial levels • tramp oils and particulate contaminants should be periodically or continuously removed from metalworking fluids • microbial degradation of fluid should be prevented or limited
Fabrication Process	• alternative tool bit materials and coatings may eliminate the need for metalworking fluids • alternative technologies are available that do not require the use of fluids
Heat Treating	• metalworking fluids and other contaminants going into the baths or furnaces should be minimized at the source • drag-out from salt baths may be minimized by increasing hang time, decreasing removal rates, and using racks in place of trays • where possible, salt bath heat treatment should be replaced with another form of heat treating • when salt baths are still employed, impurities should be removed periodically
Quenching	• quenchant drag-out should be minimized to reduce contamination of subsequent water rinse and cleaning baths • oil and salt quench media should be replaced with polymeric quenchants or other alternatives, where possible
Welding	• use alternative technologies, such as laser or plasma arc welding, to eliminate the generation of slag and scale and the subsequent wastes resulting from their removal • use automatic regulators on ventilation systems to significantly reduce energy losses • use water-only quenching
Brazing	• cadmium fumes from filler metals can be eliminated by using alternatives

Table 3.1 Pollution Prevention Overview of Metal Fabrication Processes (continued)

Soldering	• in some applications, the need for fluxes may be eliminated • flux application should be optimized • there are alternative fluxes available
Buffing and Polishing	• alternative buffing and polishing compounds should be used where feasible • overheating should be avoided
Tumbling	• dry tumbling should be used where feasible • reusable media such as ceramics significantly reduce waste generation • rough work (deburring) should be separate from finish work (polishing) to extend media and bath life and allow for more efficient bath filtering and treatment • process water and chemistries should be filtered and recirculated • metal fines should be removed, drained, and pressed for recycling as scrap
Adhesive joining	• application techniques and technologies should be optimized to deliver only the required amount of adhesive • solvent-free alternatives should be used when available

Another issue to factor into the fluid selection process is fluid standardization, or using as few types as possible. Benefits associated with fluid standardization include:

- simplified treatment schemes designed to extend fluid useful life
- simplified fluid storage
- fewer spent fluid disposal issues

For more information on fluid selection see Chapter 4, Fluid Selection.

Fluid Application

Firms can minimize waste generation associated with metalworking fluid use by reducing the amount of fluid applied in any given process. By modernizing and optimizing application equipment, firms can greatly reduce fluid use and associated waste issues. Firms should reduce the volume of fluid applied to the greatest extent possible by:

- analyzing the lubrication and cooling requirements of the machining process
- using bulk fluid delivery systems only when absolutely necessary
- using microdispersion and other low-volume fluid applicators with metalworking fluids that have higher lubricating qualities

Cutting and shaping operations that generate a lot of heat use large volumes of fluid. Excessive volumes of fluid are used for cooling in some processes even though that particular metal cutting or shaping process does not have excessive heat build-up or generation. Also, excessive metalworking fluid may be applied to provide lubrication. For example, in some processes metalworking fluid is grossly applied with a brush when all that is required is a thin layer applied with a spray bottle nozzle.

In addition to looking at the amount of fluid being used and the method of application, it is also beneficial to look at the lubricating quality of the fluid being used. Usually the higher cost of metalworking fluids with better lubricating qualities would be quickly offset by the reduction in volume used.[19]

Fluid Maintenance

Metalworking fluids require constant and periodic maintenance to monitor fluid properties, remove contaminants, and add make-up fluid. Elements of a successful maintenance regimen include:

- testing of the fluid for pH, concentration, and microbial growth
- adding make-up fluid, water, biocide, or other additives where needed
- filtering the fluid to remove both oil and particulate contaminants

A well-crafted maintenance regimen can greatly extend the life of metalworking fluids or extend the fluid life indefinitely. By testing the fluid continuously or periodically, maintaining the appropriate proportion of ingredients, and removing metal particles and tramp oils using filtering equipment, degradation of fluid by microbes may be prevented. If particles and tramp oils are not removed by filters, they provide sites for microbial growth and may damage the tool and fluid circulating system.

Filtering equipment vary greatly in scale, complexity, and cost. Selecting the right type of filtering equipment for a given application is dependent on a number of factors including:

- the type of fluid used
- the type of material being machined
- the machining process
- the size of the particles formed
- the rate of contaminant loading
- the cleanliness requirements of the metalworking fluid for the specific application

For more information on fluid maintenance and filtering equipment, refer to Chapter 4, Contaminant Removal.

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[19] For example, a circular sawing operation that previously used gross spray application switched to a fine-mist applicator and a metalworking fluid with better lubricating qualities, which greatly reduced the volume of fluid used while providing sufficient lubrication and saving the firm money. (Piekunka 1999)

Metal Waste Reduction

Parts are fabricated from metal stock that come in the form of blanks, billets, or sheets. When the parts have been formed or cut from stock, there is often bulk scrap left over that is then sold to a scrap dealer for a small fraction of the initial stock purchase price. In addition to this bulk scrap, cutting and grinding operations generate chips and swarf that are often contaminated with metalworking fluids. The section below discusses methods for minimizing bulk scrap and getting the most value out of scrap chips and swarf.

The blanks, billets, or other forms of metal stock should be selected specific to each work order to reduce the generation of unnecessary scrap. Often firms are required to perform unnecessary cutting steps due to stock being larger than needed. Firms should work with the suppliers when this is the case so that stock cutting happens only as needed to create the desired geometry.

Optimizing pattern layout is another way of reducing metal scrap waste. The pattern layout may be optimized using existing software packages, such as CAD/CAM. Decreases in material costs and scrap volume will result in cost savings for the facility.

For metal wastes in the form of chips or swarf, firms should employ a means of removing metalworking fluid from the metal wastes. Chips and swarf can entrain significant amounts of fluid, which makes scrap dealers reluctant to accept these types of scraps. These wastes may entrain as much fluid as metal particles. Fluids pose potential environmental and health and safety risks and potential liabilities for scrap dealers and also cause problems with processing the scrap. Mineral oils pose explosion hazards for electric arc furnaces and the smoke generated may foul bag house filters. Additionally, water-based fluids require excess heat to evaporate the fluids from the scrap (Hunter 1998).

Recycling Grinding Swarf at Hyde Tool

Hyde Tool, a division of Hyde Manufacturing Corp, located in Southbridge, Massachusetts is a 300-employee firm with two lines of products: an industrial tool line featuring machine blades, saw blades, and hand knives; and a trade line of knives, scrapers, and other surface preparation tools designed for do-it-yourself home improvement projects.

Knife blades are ground to sharp edges. The swarf from these grinding operations is compacted, removing the fluid and returning it to the process. The dewatered swarf is then sold as scrap. The machine used to compact the swarf is a modified dung hopper. In the hopper the swarf fluid content is reduced from 48 percent to 2 percent (DeVries 1999).

The mechanism employed to remove excess fluid depends largely on the size of the particles and the type of metalworking fluid that is present. At a minimum, chips and swarf should be initially stored in a container that allows for drainage of fluid. Centrifuges can remove mineral oil-based metalworking fluids from chips and swarf. Hydroclones are effective at separating very fine particles from water-based fluids. Compaction is another way of removing metal working fluids from fine particles. These processes ensure the recovery of as much of the metalworking fluid as possible and increase the value of the metal waste.

Machine Maintenance/leak Prevention

Another source of pollution in the metal fabricating process is hydraulic and metalworking fluid leaks. Over time, machine gaskets, seals, and wipers become worn and cracked, causing fluid to drip onto the floor, machine parts, or in the case of hydraulic fluids, into the metalworking fluid baths. Drips to floors and machine parts require cleanup that is usually performed using mops, granular absorbent, rags, or absorbent pads. In the case of hydraulic fluids dripping into metalworking fluid baths, the tramp oil[20] acts as a site for bacterial growth, and also causes smoke and odor problems, all of which result in the need to change the fluid (Ohio EPA 1995).

To eliminate these problems firms should design a gasket, seal, and wiper maintenance program that is appropriate to the application. Wear on the parts will depend upon the severity of the application and the fluid environment, and the program should be tailored appropriately. A maintenance program might include:

- a list of all plant equipment, including equipment location
- an operating schedule for each piece of equipment
- a service history (days since last tune up)
- a maintenance history or log (days since last breakdown)
- maintenance manuals for all equipment (MA TURI 1996)

Cleanup Processes/persistent Leaks

For applications where leaks persist, alternative forms of fluid clean-up should be employed. The use of drip trays, pans, and channels are a good way to recover, or at least capture, lost fluid. Firms should explore using reusable absorbent pads and rags in place of disposable granular absorbents or mops and buckets. When saturated, absorbent pads may be wrung out and reused. Wringers are available that may be installed on top of 55 gallon drums. Unsaturated rags should be stored separately from saturated rags, and saturated rags should be sent to an industrial laundry for cleaning. Rags that are used for cleaning machines at the end of each shift or day should be handled in the same manor.

The use of mops for gross clean-up of leaks and spills should be discouraged because a small volume of spilt metalworking fluid added to a large volume of water will greatly increase the volume of waste that must be treated as oily contaminated waste or hazardous waste. If granular absorbents are still preferred over reusable pads and rags, the use of organic absorbents, such as ground

The use of corn husks was very well received at one facility. Employees had previously complained of allergic reactions to silica-based absorbent and did not have the same reactions to the corn husk absorbents (Piekunka 1999).

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[20] Tramp oil is oil that is present in the metalworking fluid that should not be there. This oil is most often hydraulic fluid that has leaked from machines.

corn husks, could have some advantages over traditional silicate-based because these absorbents will not saturate with fluid due to their nature, and their handling may be simplified. Granular absorbent tends to clump, so to maximize the use of granular absorbents, they should be screened to recover the unused portion for reuse.

Parts Cleaning

Parts cleaning operations present a significant opportunity for pollution prevention in metal fabrication processes due to the nature and frequency of cleaning operations. The section below briefly touches upon when and why parts are cleaned, and provides references the reader may use to learn more about P2 opportunities in parts cleaning operations.

Why Are Parts Cleaned?

Parts may be cleaned throughout the metal fabrication process for a variety of reasons. Stock is often contaminated with oils that were used to quench the parts at the foundry, or the oil may have been applied as a protective coating to prevent rusting or marring of the stock during storage and shipping. These fluids are sometimes removed prior to processing the stock. After parts have gone through the metal fabricating process, the fluids must be removed before the part can be further processed. In other instances, parts are cleaned between subsequent fabrication processes to prevent fluids from negatively interacting with tool bits or the part, or just as a precautionary step.

Historically, parts cleaning has been performed using chlorinated solvent vapor degreasing. The increasing cost of using solvents and disposing of them, the diminishing supply due to phase outs, as well as the increasing environmental liability associated with their use has caused many firms to seek alternatives. Because parts cleaning has been addressed in one of the other manuals in this series, titled *Pollution Prevention for the Metal Finishing Industry: A Manual for Pollution Prevention Technical Assistance Providers*,[21] it will not be discussed at length here. The reader should refer to the aforementioned publication or, for a more detailed discussion of the issues involved in parts cleaning, refer to: Thomas, Karen; Laplante, John; and Buckley, Alan, *Guidebook of Parts Cleaning Alternatives: Making Cleaning Greener in Massachusetts*, The Massachusetts Toxics Use Reduction Institute, and The Massachusetts Office of Technical Assistance for Toxics Use Reduction, March 1997.[22]

Tumbling

Tumbling is performed to clean, remove oxides and scale, polish, brighten, or deburr parts after they have been machined. Tumbling processes may be wet or dry, may employ one of many available media, and may use chemicals such as chelating agents, acids, or cleaners. Tumbling may be unnecessary on some workpieces when other processes have been optimized

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[21] This manual may be found online at http://www.newmoa.org/publications/

[22] This guidebook may be found online at http://www.state.ma.us/ota/pubs/partsguide.pdf

and the need for tumbling has been assessed. Wet tumbling processes are historically inefficient in chemical and water use and should be replaced with dry processes where possible. When wet tumbling is still employed, the use of chemicals that are able to be reused in-process can greatly minimize the impact of wet tumbling. Work should be segregated into rough jobs, such as deburring, and finishing jobs, such as oxide removal and descaling. By doing this, and filtering and recirculating, the media or bath life may be greatly extended.

Heat Treating

Heat treating is performed at various stages throughout the fabrication process to impart a variety of characteristics on metals, such as improved machinability, ductility, toughness, impact resistance, and elongation. The process involves heating the substrate in salt baths, furnaces, or alternative technologies, and then cooling the workpieces at varying rates, depending on the desired characteristics. As mentioned under the Metalworking Fluid Application Section above, minimizing the amount of metalworking fluid applied will decrease the contaminant loading on salt baths and furnace scrubber systems.

Where possible, salt bath heat treating should be replaced with other heat treating methods to eliminate the salt contamination of rinse and quench baths and the need for post-processing (East Midlands Electric 1998). Where salt baths are still used, drag-out from salt baths may be minimized by decreasing removal rates, increasing hang time, replacing trays with racks, and orienting parts properly on racks (U.S. EPA 1992a). Cyanide-containing salt baths are of particular concern because of the toxic nature of cyanide. Where possible, cyanide-containing salts should be eliminated, as there are readily available alternatives, including vacuum furnaces, atmospheric furnaces, and fluidized bed furnaces (Environment Australia 1997). For more information on P2 in heat treating, see Chapter 6.

Quenching

Parts are cooled after heat treating by being immersed in a liquid bath or a gaseous stream. Firms choose a method for quenching based upon the need to give the metal its desired properties. The quenching media used is dictated, to some extent, by the type of metal being quenched, the rate and degree of cooling required, and the desired properties. Quenching wastes represent a large portion of the waste generated from heat treating processes. Similar to drag-out reduction for heat treat baths, drag-out of quench media into rinse baths or other subsequent process baths may be greatly reduced by decreasing removal rates, increasing hang time, replacing trays with racks, orienting parts properly on racks, and switching to a less viscous media. Waste from quenching may also be greatly reduced by switching from oil and salt bath media to alternatives, such as polymeric media where possible. For more information on quenching, see Chapter 6.

Welding

Metal parts are joined using a number of welding technologies. In the case of arc welding, common wastes from the process include slag and scale that need to be removed. Also, arc welding shops lose a great deal of energy through their ventilation systems because of the high rate of air changes required. Automatic exhaust regulation is a way to curb this energy loss. Because welding activities typically only occur 10-15 percent of the time, ventilation systems only need to be operated at maximum capacity during those times (Nygren 1998). After welding, parts often require a quick quenching step that may be effectively performed using only water (Inglese 1992).

There is very little published information available on pollution prevention in welding operations and more work and documentation is needed in this area of metal fabrication.

Brazing

In brazing, closely fitted surfaces are joined together by a filler metal. When heated, the filler material distributes evenly in the space between the two parts. The heat may be applied a number of ways such as induction, torch, or dip. Before adding the filler, flux is applied to the surfaces to prevent oxidation and remove oxides. There are a variety of fluxes and filler metals used in brazing. Certain silver fillers give off cadmium and zinc fumes and because cadmium is considered poisonous when vaporized, many users are changing to cadmium-free filler metals. For more information on P2 opportunities for brazing operations, see Chapter 6.

Soldering

Much like brazing, soldering involves the joining of two metal pieces by applying fluxes to the substrates prior to heating, and allowing filler metal to flow into the space between the pieces. There are a variety of fluxes, solders, and flux/solder pastes available, which may be applied to the joint using a variety of application techniques. Modern application techniques, such as metered nozzles, are much more precise than manual methods delivering flux and solder, or solder paste, and thereby reduce the waste associated with flux removal and the formation of solder balls from excess solder.

Fluxes present a problem because they require cleaning after soldering and because some fluxes contain lead. There are alternatives to the use of traditional fluxes. These include:

- fluxless applications developed to eliminate the need for cleaning
- alternative fluxes developed to greatly reduce the VOC emissions from soldering processes and hence reduce or eliminate the need for VOC destruction (i.e., burning the VOC gas emissions) (U.S. EPA 1993)
- lead-free solders, which are available for various applications

To minimize unnecessary fumes from soldering, temperatures should be minimized whenever possible.

Adhesion Joining

Adhesives used for joining metals are applied using various application techniques and technologies and are then cured. The selection of an adhesive and the choice of the method used to apply it represent the greatest opportunities for pollution prevention in adhesion joining. Application methods should be optimized to reduce wastes. Solvent-free adhesives are available for a variety of applications. Also, there are primerless adhesives available that eliminate the need for chlorinated solvents (Rudolph 1999). For more information on pollution prevention opportunities in adhesive joining processes, see Chapter 6.

Buffing and Polishing

To give the surface of parts a fine finish, parts may be buffed or polished. In these processes workpieces come in contact with rotating wheels or buffs that may or may not be coated with chemical compounds. Water-based liquid compounds should be used (MnTAP 1998). Buffing and polishing compounds are used to decrease friction between the part and the wheel and hence prevent metal discoloring, distorting, and warping. Wheels wear over time and need to be treated or replaced. Treatments are often done on-site by applying the buffing or polishing compound to the wheel and then heating the wheel. When the life of the wheel can no longer be extended, metal and wheel scrap are collected and disposed of. In drag-through polishing applications, spent abrasives and filter cakes are generated that are typically shipped offsite to municipal landfills (U.S. EPA 1995b). Firms are exploring ways of recovering the metal from these wastes and looking for beneficial uses for them.

CHAPTER 4

Pollution Prevention and Metalworking Fluids - Selection, Maintenance, and Application

The selection of a fluid that is easily serviced and that does not interact adversely with other processes can eliminate many of the pollution problems resulting from fluid use. The use of in-process treatment technologies may greatly extend the useful life of metalworking fluids.

Microbial degradation of fluids is one the most frequent causes of premature fluid disposal and therefore must be addressed. To further reduce the environmental burden created by spent fluids, the application method used to apply the fluid and the volume of fluid applied should be optimized to minimize contamination of the work area as well as the process baths.

This Chapter covers the fluid selection process, fluid maintenance programs and technologies, and fluid application techniques.

Table 4.1 Metalworking Fluid Selection, Maintenance, and Application

Fluid Selection	• evaluating if fluids are necessary • standardizing - using as few types of fluids as possible • recyclability/treatability • cleanability/cleaning bath life extension
Fluid Maintenance	• water quality • fluid testing • contaminant removal (see summary table, p. 58) • preventing and inhibiting microbial growth
Fluid Application	• optimize application methods • implement microdispersion, where appropriate

Fluid Selection

Firms have been using fluids in the fabrication of metal parts for over a hundred years to provide lubrication and chip removal, and more recently cooling. The industry's use of fluids has evolved as the fluid industry has evolved. There may be a number of factors that drive a firm to select a new fluid:

- the company is looking for a fluid to use in a new or expanded product line
- the existing fluid has become incompatible with some new equipment
- the existing fluid is incompatible with changes to subsequent processes
- the company wants to increase process times and needs increased lubricity and/or cooling
- the fluid life is too short and hence the fluid is too costly

The process firms use to select a fluid may vary greatly based on company size and level of in-house technical expertise. Some firms may select a fluid based solely on its lubricating qualities and its compatibility with the tools and workpieces while other firms may do a more detailed analysis. The time spent carefully selecting a fluid can greatly reduce wastes from metal fabrication processes and subsequent processes. Issues that should be considered in fluid selection are discussed in the sections below. These issues are:

- cost
- recyclability
- cleanability
- standardization

Cost

It is more important to select a fluid that is appropriate to the process than it is to select a fluid that is the least expensive. The hidden costs that result from fluid use are much greater than the fluid material costs. Metalworking fluid management costs range from 7 to 17 percent of manufacturing costs, with purchase costs being a small fraction of that (Heine 1997). Much of a firm's labor and overhead costs are associated with machine downtime and other maintenance related to fluid use.

Recyclability/treatability

The volume of fluid applied and the method of fluid application varies depending on the cooling, lubricating, and chip removal requirements of a given application. These factors, as well as the amount of fluid carried out on parts, will dictate the need for and applicability of fluid recycling. Many processes continually re-circulate and reuse metalworking fluids. These processes employ some form of treatment ranging from gross chip removal using a simple screen to final particle removal in a flatbed wedge-wire pressure filter. Any time fluid can be recovered in a process its life may be extended to some extent by treating it. For more information on the treatment of metalworking fluids, see the Contaminant Removal Systems section later in this Chapter.

Circular Sawing at Bartley Machine with Vegetable-based Metalworking Fluid

Bartley Machine, a fabrication job shop in Amesbury, Massachusetts, cuts stock into two-inch lengths using a circular saw. This saw previously used a lard-based fluid, applied to the saw blade manually using a brush at a rate of 1.5 quarts of fluid per day. The saw now uses a vegetable-based fluid, delivered directly to the cutting area by two fine misting nozzles with a consumption rate of two ounces per day. The old fluid was purchased at a cost of $15 per gallon ($5.63/day), while the new fluid is purchased for $80 per gallon ($1.25/day).

In the old process, the fluid would hit the saw blade and spray all over. To contain the spraying fluid, the operator needed to cut cardboard and build an enclosure around the machine and work area at the beginning of every shift and remove the enclosure at the end of every shift and dispose of it. This process had high waste handling charges and setup and breakdown labor costs; building and removing the cardboard enclosure was about a 20 minute process. No enclosure is required with the new fluid and application method. Chips are dry and clean-up time is minimal.

Another benefit of the change to higher quality vegetable-based fluid and low-volume mist spray application is the increase in tool life. With the old fluid, a carbide blade would last for five production runs. With the new fluid, the operator gets sixty production runs out of a single carbide blade and the steel blade-life has been increased five-fold (Piekunka 1999).

Research is underway through both the Massachusetts Toxics Use Reduction Institute and UCLA to evaluate the recovery of metalworking fluids from cleaning baths for reuse in the process. Trials to date have had mixed results. However, further developments in this area can have a significant impact on closing the loop of metal fabrication processes.

Cleanability/cleaning Bath Life Extension

When selecting a metalworking fluid it is crucial to consider the entire process that the fluid will affect. The machine shop will most likely need to remove the fluid it has applied, or if the workpiece is going off-site for further processing, someone else will have to remove the fluid before the workpiece can be further processed. By working with metalworking fluid vendors, firms should select a fluid that may be easily removed, collected, and disposed of or recycled. Metal fabricators should also talk with their metal stock suppliers to determine what fluids they apply to metal stock during primary metals manufacturing or as a protective coating during storing and shipping. It may be possible for fabricators to ask them to use a fluid that is more compatible with the fluid the fabricator is using or to use a fluid that is easier to clean off.

With the phase out of chlorinated solvents and their use in cleaning systems, firms have switched to a number of different alternatives. Alternative cleaning chemistries and systems require a more tailored approach to cleaning than did their chlorinated solvent counterparts. Certain cleaning systems may be more effective at removing a given contaminant than others. For example, aqueous cleaning systems are effective at removing soluble oils but may be less effective at removing dry-film lubricants. For more information on various cleaning processes and P2 alternatives, see *Pollution Prevention in the Metal Finishing Industry: A Manual for Technical Assistance Providers*, http://www.newmoa.org/publications.

Milling Machines at Bartley Machine

In the milling operations at Bartley Machine, a soluble metalworking fluid is applied to the work area by an air nozzle. A vacuum draws off chips and lube mist overspray. Oil-coated chips and lube overspray are carried to a barrel where chips are retained and fluid is recirculated to the feed. A water-soluble metalworking fluid was selected for this process because it is easier to clean off the parts and it was already being used by a belt sander that has a filtration system. When the fluid starts to foul, it is added to the belt sander sump where it is filtered through a settling tank and cyclone filters to remove fines. By standardizing fluids, Bartley has been able to greatly extend the useful life of its fluid by using a sophisticated centralized filtering system. For more information on metalworking fluid treatment systems, see the Fluid Maintenance Section in this Chapter (Piekunka 1999).

Aqueous cleaning systems are effective at removing metalworking fluids, but some systems do not have the proper filtration equipment to remove emulsified fluids from the cleaning fluid bath, which causes the bath to be changed frequently at potentially significant disposal and purchase costs. In this situation another metalworking fluid could be selected that provides the necessary lubricity, cooling, and chip removal while simplifying separation of the metalworking fluid from the cleaner bath and hence extending the life of the cleaner bath (MA TURI 1996). For other applications, where the volume of fluid used in metal fabrication processes has been minimized and the cleaning bath has a small loading rate, it may be possible to install an inexpensive media filter, such as a polypropylene bag, to capture the emulsified machining fluid.

Firms that out source metal parts and products for further processing should be encouraged to identify the fluids they are using so that the electroplater, coater, or other parts/product processor may make educated decisions about which cleaning processes to use for cleaning a given work order. Electroplating job shops usually employ multiple cleaning systems to preclean the various work orders they fill. By knowing more about the contaminants on a given part, job shops can make much better decisions about how to clean it, therefore eliminating the time-consuming and costly trial and error cleaning trials, the costs of which are passed on to the metal fabricator.

Standardization - Using as Few Fluids as Possible

Using as few fluids as possible reduces paper work burdens and simplifies recycling, reuse, and disposal issues. For non-centralized metalworking fluid systems that employ mobile recycling units, using as few types of fluids as possible reduces technical requirements of mobile units. (See the Mobile Recycling Units section later in this Chapter). By first examining what fluids are used, where, and why, a facility can gain a lot of insight into its fluid requirements and fluid use.

Some facilities have switched to a standardized fluid by using various concentrations of the same fluid at different machines to meet varying cooling and lubricating requirements. This allows them to buy bulk fluid, blend spent fluids, treat them in a central system, and reuse them.

Vegetable-based Fluids

Although the present worldwide supply of petroleum is sufficient to service demand into the near future, the environmental impacts of obtaining, processing, and transporting petroleum make it undesirable. Vegetable-based fluids have been used in place of mineral oils as a lubricant for some time and compete well with synthetic fluids. The most common vegetable-based fluids used for metalworking are rapeseed, canola, and soy oil. They are derived from renewable resources, have excellent lubricity, may be readily biodegraded, may be easily removed from parts and machinery, and have a high flash point. All of the desirable traits of these oils contribute to an increase in the use of vegetable-based fluids (Honary 1998).

The use of vegetable-based fluids is limited to applications where temperatures do not exceed 248°F (120°C) because of their thermal and oxidative instability above this temperature. In applications where moderate operating temperatures exist, and especially in total-loss applications and partial loss-applications, vegetable-based fluids can compete with biodegradable synthetic fluids with the added benefit of being produced from renewable resources (Miles 1998). Advances are continuing in the thermal and oxidative stability of vegetable-based fluids through the use of selective plant breeding.

Fluid Maintenance

There are a number of steps firms may take to maintain the quality of metalworking fluids including: insuring water quality, testing the fluid periodically, removing contaminants on a continuous or batch basis, and preventing or inhibiting biological degradation of the fluid. Table 4.2 briefly outlines these issues, which are covered in the following sections.

Table 4.2 Fluid Maintenance Summary

Water Quality	• water hardness effects on metalworking fluids • water treatment technologies
Fluid Testing	• concentration • pH • bacteria
Contaminant Removal	• factors that affect fluid recycling • summary table of chip/swarf and tramp oil removal technologies • description of contaminant removal technologies
Steps to Prevent or Reduce Biological Activity	• preventative maintenance measures • aeration • ozonation • pasteurization

Water Quality

Water quality affects the performance of a coolant more than any other factor (Willa 1997). Water is mixed with soluble, semisynthetic, and synthetic fluids, and make-up water is added on a regular basis to replace water lost to evaporation. Minerals present in this water can cause numerous problems if not removed before the water is combined with the oil. Hardness, calcium and magnesium ions, can promote the formation of insoluble soaps that may clog lines and filters or even plate out on machines. Hard ions may also react with fluid additives, such as surfactants and wetting agents, making them unavailable. Table 4.3 lists the ranges of water hardness.

Table 4.3 Water Quality

Water Quality	Hardness
Soft	0-100 ppm
Medium	100-300 ppm
Hard	300-500 ppm

In addition to hard ions, other salts that contain chloride or sulfate can cause corrosion to occur in otherwise well-maintained systems (Willa 1997).

On the other extreme, water that has a low mineral content can increase the tendency for certain types of coolants to foam. This is often corrected by the periodic addition of defoaming agents until enough dirt and tramp oil builds up to suppress foaming. An alternative approach to using defoaming agents is to mix hard water (20 to 50 percent) and pure water (80-50 percent) for preparing new or cleaned metalworking fluids. However, pure water should always be used for make-up water to eliminate the accumulation of salts over time (E.F. Houghton 1995). Between 5 and 10 percent of the coolant is lost each day and about 80 percent of that loss is water. Over the course of two weeks the mineral content may more than double (DCNR 1995).

The three most common treatment technologies used to remove impurities from incoming water are deionized water (DI), reverse osmosis (RO), and ultrafiltration (UF). Exchange type deionizer systems are recommended for smaller metal fabrication shops where water requirements are less than 300 gpd or less and the hardness is less than 10 grains. For systems with greater flow or hardness, tank type deionizers become uneconomical because of the size of the system required and the rate of fouling. In these instances, self-regenerating deionizers or RO is suggested. RO does not produce as high water purity as DI, but is usually sufficiently pure for coolant applications. Some larger systems may want to use DI and RO in combination, where RO removes most impurities, and DI polishes the water, hence creating large volumes of high purity water at relatively low cost.

Water softening chemicals are not recommended as a means of removing minerals from water that is being used in coolants, because these chemicals do not remove corrosive sulfate and chlorine ions that are present. The total ionic content of the softened water is the same and is often sufficiently high enough to affect emulsion stability. Rust, corrosion, and staining problems on machines, tools, fixtures, and workpieces can actually be more severe with the use of chemically softened water (DCNR 1995).

Sometimes boiler condensate water is used as make-up water for fluids when it is not contaminated with anticorrosion, anti-scale agents, or biocides (EF Houghton 1995).

Fluid Testing

Metalworking fluid concentration, pH, and microbial levels should be periodically or continuously monitored to prevent unfavorable conditions in the coolant from occurring. The methods available for monitoring each and the significance of each indicator are discussed in the sections below.

Concentration

Concentration of metalworking fluid is important from a pollution prevention standpoint because too low a concentration may mean the fluid is susceptible to microbial attack, resulting in a shorter useful life, or parts and machines are susceptible to rusting due to a lack of rust inhibitors. Tests to determine the concentration indicate when more fluid or a specific additive needs to be added as a result of degradation losses or losses to evaporation and carry-out. Too high a concentration means that too much fluid is being used, and is costing the company money and increasing waste generation in applications where water is separated from oil prior to disposal. Too high a concentration may also cause foaming problems and increase the likelihood of dermatitis among workers.

There are numerous properties that are indicators of fluid concentration, and there are various tests available to measure the concentration of specific ingredients of metalworking fluids.

Indicators of concentration:
- refractive index
- alkalinity
- conductivity
- pH
- oil split
- emulsion stability
- physical appearance

Test for concentration of specific ingredients:
- titration
- high performance liquid chromatography (HPLC)
- electrochemical
- spot test (NCMS 1997)

The most commonly used methods for monitoring fluid concentration are refractometer (hand-held or hard wired), titration, or the oil split method. In addition to measuring metalworking fluid concentration, the oil split method is also effective at measuring tramp oil concentrations (see Tramp Oil Removal below).

pH

It was mentioned above that pH is an indicator of fluid concentration; however, it may be an indicator of many characteristics of a fluid. Bacteria that are typically found in metalworking fluid grow within the range of pH 7.0 to 9.0 while a pH of 9.5 or above eliminates nearly all bacteria. Yeasts and molds are more tolerant of high and low pH and may thrive in an environment above 9.5 (EF Houghton 1995). The pH range of typical fluids are 8.9 to 9.2. If the fluid's pH is not within this range it is an indication that the fluid is more susceptible to microbial growth. An acidic pH may indicate that biological activity is taking place, since the metabolic byproducts will cause pH to decrease.

There are various ways of measuring pH in-house, including portable or in-line pH meters, pH papers, or potentiometers. Some firms use off-site testing labs for pH, as well as other testing needs. It is important to monitor pH daily to prevent serious degradation of the fluid. Fluid pH may be adjusted by adding new fluid, but this may not fix the problem. Maintaining fluid pH is necessary to maintain the fluid quality, but the underlying cause for the change in pH must be addressed to eliminate future needs to purchase chemicals to adjust the pH. When the pH changes markedly, the other fluid characteristics should be tested to identify the problem.

Bacteria Levels

Bacteria can have a significant detrimental impact on metalworking fluids. Premature fluid breakdown can result from the biological activity of bacterial growth in the fluid. Fluid additives act as nutrients for the bacteria and are consumed. The consumption of specific ingredients in the fluid by the bacteria can result in a decrease in a number of positive qualities of the fluid, including lubricity, anti-foaming, and anti-rusting.

Monitoring bacteria levels through in-house testing or through the use of off-site labs can identify significant increases in levels before they negatively impact fluid quality and require fluid to be disposed of. The most common on-site test method is the use of low-tech dip slides which indicate the bacterial count in the fluid. Another test method used is total acid number (TAN) test that measures changes in biological activity. The "Controlling Microbial Growth" section appearing later in this Chapter explains some techniques for preventing or inhibiting microbial growth.

In addition to monitoring the above mentioned fluid characteristics, some firms periodically measure suspended solids, alkalinity, and spot corrosion and make adjustments in fluid chemistry as needed using additive packages.

Contaminant Removal Systems

Continuous or intermittent contaminant removal systems may be effective at extending a metalworking fluid's bath life indefinitely. This eliminates expensive change out costs for materials and disposal of spent fluid, as well as expensive process down times. Table 4.4 provides an overview of the different types of contaminant removal systems available and their removal process. Listed below are some of the factors that firms should be advised of when selecting a contaminant removal system.

<u>Contaminant Loading Rate</u>: The contaminant loading rate is the rate at which contaminants enter the system. This will determine the size of the removal system needed based on capacity and residence time required.

<u>Size of the Chips and Particles</u>: The size of the chips or particles formed in the metal fabrication process has a significant impact on the type of contaminant removal technology used, and hence the cost of the system. Chip formation is dependant on:

machining process	- different types of machines will form various types of chips because of differences in mechanical action
rate of machining	- faster machining may form smaller chips
substrate	- how ductile a material is indicates the length of the chips
tool bit geometry	- different tool bits for the same process may form different sized chips
lubricant	- an increase in lubricity and a decrease in friction results in decreased heat and less brittle hardening

<u>Mobility versus Centralization</u>: Some metal fabrication facilities supply fluid to numerous machines from a central sump, while other facilities have a separate sump for each machine. Where possible it is usually more beneficial to design systems with a centralized sump. This makes it easier to maintain the fluid and allows for the use of one central, sophisticated treatment system.

For remote machines where chips are large, stationary rough contaminant removal methods such as a screen may be sufficient. For remote stations with smaller particle contamination, a more sophisticated mobile unit that is capable of treating numerous remote units within a facility would be required. There are companies that lease the servicing of fluid sumps by bringing a mobile unit into the metal fabrication facility and performing the fluid filtering onsite.

Mobile Recycling of Coolant at Wonder Machine

Wonder Machine is a Cleveland, Ohio job shop that specializes in precision machining of prototype and production parts for medical applications. The number of CNC* machines in the shop doubled over a two-year time from five to 10 machines. With this growth came an increased concern for the time spent cleaning out sumps and the money spent on waste coolant. Wonder Machine decided to explore fluid reconditioning systems.

In the existing system, the five machines were maintained by manually skimming to remove tramp oils and by cleaning out sumps every three months. The sump clean out process took two people five hours per machine, for a cost of $600. Each sump contained 50 to 60 gallons of coolant, at a replacement cost of $1.50 per gallon. The total coolant purchase and disposal cost for one series of sump clean-outs was $1,500 to $2,000.

After evaluating three alternatives, Wonder Machine selected a mobile recycling unit manufactured by Coolant Wizard. The unit removes tramp oil and particulate by coalescing, skimming, and filtering. Microbes are destroyed by an on-board ozone generator that creates ozone from the ambient air and circulates it in the contaminated fluid. This unit cost $10,000.

By reconditioning the fluid in the mobile unit, the sump clean-out interval is now every six months, and there is much less grime present in the sumps, which cuts down on the time it takes for clean-outs (Owen 1999).

*CNC stands for Computer Numeric Control.

Table 4.4 lists the metalworking fluid treatment technologies available and some of the characteristics of each. Because metal fabrication processes vary by fluid, chip, and/or particle size and scale, fluid treatment schemes need to be tailored to the specific application. A combination of treatment methods is often required.

Tramp Oil Removal

The technology employed to remove tramp oils from a given application depends largely on the loading rate and the accessibility of the sumps. The Section below provides a description of the various tramp oil removal mechanisms.

Belts and Skimmers

Belts and skimmers can be used to remove free-floating tramp oils from accessible sumps and settling tanks. These devices are low-tech and inexpensive and are effective on processes where entrained tramp oils are not an issue. Skimmers are most effective when placed near a circulating pump, since tramp oil usually drifts to that area (Singleton 1993). Belts and skimmers are not effective at removing emulsified tramp oils.

Skimmer Used at Los Alamos National Laboratory

By installing skimmers on each machine tool the Los Alamos National Laboratory has minimized coolant waste by removing tramp oils, on which bacteria thrive. This has reduced coolant waste generation from 14,000 kg to 4,000 kg per year, saving $94,000 annually (DOE 1998).

Table 4.4 Chip/Swarf & Tramp Oil Removal

	Equipment/Technique	Removal Process
Tramp Oil Removal	Belts and Skimmers	removes free-floating tramp oils from accessible sumps or settling tanks
	Settling Tanks	allows tramp oils to settle to the top of the tank for manual or mechanical removal
	Controlled Settling	helps localize tramp oil by adding baffles to a settling tank
	Coalescers	causes smaller oil droplets to form larger droplets making them easier to remove
	Centrifuges	can remove partially emulsified oils
Metal Chips and Swarf Removal	Screens and Conveyors	removes large particles at the sump
	Settling Tanks	settles particles out due to differences in density
	Controlled Settling	aids in settling by adding baffles to the tank
	Magnetic Separation	removes ferrous particles from the fluid by a magnet
	Flotation	effectively removes particles less dense than fluid
	Hydrocyclones	forces particles to the outside through high pressure fluid cyclone; fluid moves to the middle
	Centrifuges	forces particles to the outside through rotating mechanical bowl while fluid flows out the bottom
	Rolled Media Vacuum Filters	retains particles on paper media
	Wedge-wire Vacuum Filters	retains the particles on panels or cylinders of wedge-wire
	Pre-coat Vacuum Filters	adds loose pre-coat to rolled or wedge-wire to aid in particulate removal
	Bag or Cartridge Pressure Filters	passes fluid through canister, where a bag or cartridge retains particles
	Flat Bed Pressure Filters	removes contaminants using disposable rolled media or permanent plastic belting; pressure chamber on top of a filter bed forces metalworking fluid through media
	Pressure Tube Filters	removes contaminants using long cylindrical tubes suspended in a pressure chamber, precoated usually with diatomaceous earth

Settling Tanks

Because of the density gradient between the tramp oils and the metalworking fluid, tramp oils float to the surface of the sump where they may be removed. Tramp oil may be removed from the surface of the sump by mechanical means, such as belts and skimmers, or manual means, such as absorbent pads placed on the surface by the operator. Tramp oil removal in settling tanks requires that the fluid sit in the tank for some period of time to allow for separation to occur. Setting tanks are not an effective means of removing emulsified tramp oils.

Controlled Settling

In some instances where the required retention time in the settling tank is a consideration, the addition of baffles to the tank will improve separation time and decrease the tank size requirements.

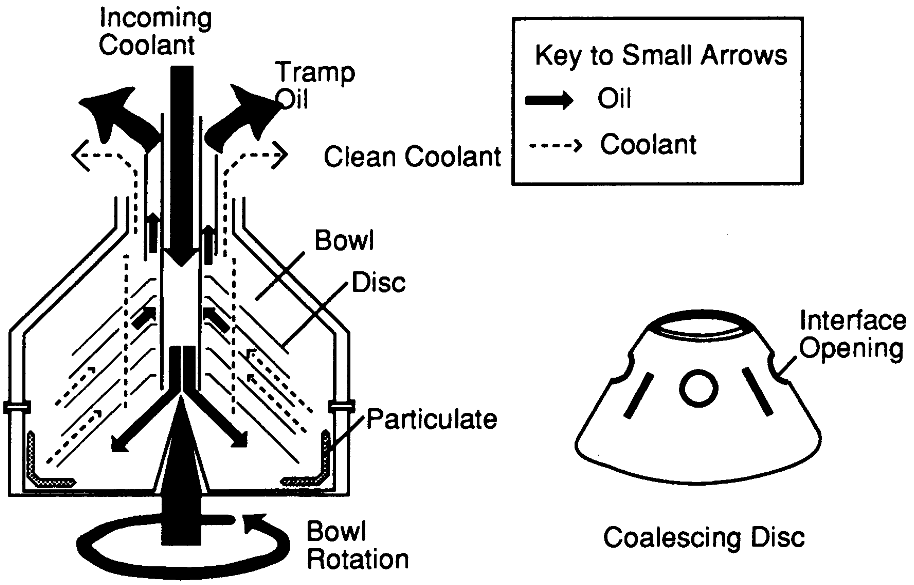
Coalescing Filters

Coalescing filters contain plates, disks, or screens that cause smaller oil droplets to collect, forming larger droplets that rise to the surface of the bath due to density gradients. Once tramp oil floats to the top of the tank, it can be removed either by mechanical means or manually.

Centrifuges

Centrifuges used to remove tramp oils contain a number of coalescing disks or plates that aid in the separation of oil and water. Centrifuges are effective at removing partially emulsified oils and can remove fine particles if they are more dense than the liquid. When a centrifuge is used to remove tramp oil, it needs to be combined with some other process that is removing particles or else the unit will clog. There are centrifuge units that are designed specifically for fine particle removal.

Figure 4.1 *Schematic of Centrifuge Typically Used for Tramp Oil Removal (Berger 1990)*



Metal Chips and Swarf Removal

There are a number of technologies available to remove metals chips and swarf from metalworking fluids. The mechanism or mechanisms selected for a particular application is determined largely by the size of the particles formed, the loading rate, and the cleanliness requirements for that application. Often numerous mechanisms are combined in one single commercial unit. The sections below discuss each mechanism separately to provide background on their effectiveness.

Screens, Basket Strainers, and Conveyors

Large particles may be removed at the sump or collection area using screens, basket strainers, or conveyors. Depending on the size of the operation, or the specific fabrication process, these techniques can include a range of devices from a simple wire mesh screen that covers the inlet on a small two gallon sump, to a large conveyor that continuously dredges a 500 gallon sump. These rough forms of filtration are effective at removing larger particles, which may otherwise clog lines, filters, or pumps.

Chip Basket and Settling

A multiple spindle die table at Bartley Machine in Amesbury, Massachusetts has a custom fabricated tray below the die table to capture fluid from the work area. The fluid flows from the tray, carrying the chips with it, to a chip collection basket below. The large chips are retained in the basket, while a vacuum line carries the fluid and finer particles to a 55 gallon drum where the oil settles to the bottom and the fine chips and particulate are retained by a screen. The metalworking fluid is drawn from the 55 gallon drum through a valve inserted at the bottom of the barrel and is re-used as a supply for the machine. The vacuum unit is an off-the-shelf 55 gallon drum-top unit (Piekunka 1999).

Settling Tanks

Settling tanks, as mentioned above for tramp oil removal, take advantage of the density gradients between the metalworking fluid and the contaminants. Particles settle to the bottom of the tank where they may be removed by dredging or periodically emptying the tank.

Controlled Settling

For applications involving small chips, the retention time required for particles to settle is significant and would require a sizable tank. The addition of baffles to the settling tank in these situations, can greatly reduce residence time and tank size requirements.

Magnetic Separation

Ferrous particles can be removed from the fluid by a belt magnet that passes through the tank and carries away any ferrous particles. Magnetic separators can also be contained in a tank that acts as a settler for particles missed by the magnetic belt.

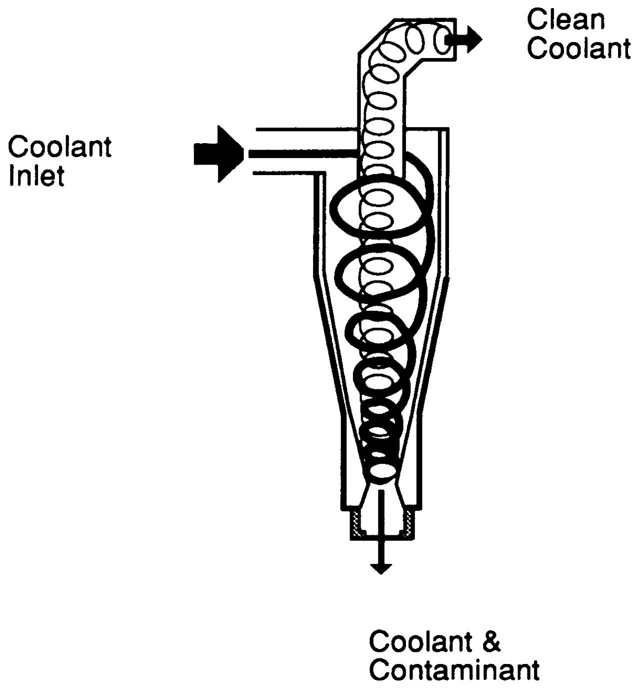
Flotation

Flotation can be effective at removing particles less dense than the metalworking fluid. Pressurized air is bubbled into the fluid to a point of saturation. The bubbles are then released at near-zero pressure. These bubbles form smaller bubbles, which contacted suspended particles, adhere to them, and carry the suspended particles to the surface of the tank. Particles may then be removed by skimming the top of the tank.

Hydrocyclones

In hydrocyclones, a high pressure fluid cyclone forces particles to the outside while fluid moves to the center of the chamber. Figure 4.2 shows the action of a hydrocyclone. Particles that are forced to the outside congregate and fall to the bottom. The opening in the bottom of the chamber is too small for all of the fluid to pass, and most of it is forced back upward by the cyclone. Some small amount of fluid is carried out with the particulate matter. Hydrocyclones usually have a settling tank before the cyclone unit to remove the larger particles. The forces from the fluid cyclone tend to stabilize fluid emulsions; however, tramp oils may also become emulsified.

Figure 4.2 *Typical Flow Through a Hydrocyclone (Berger 1990)*



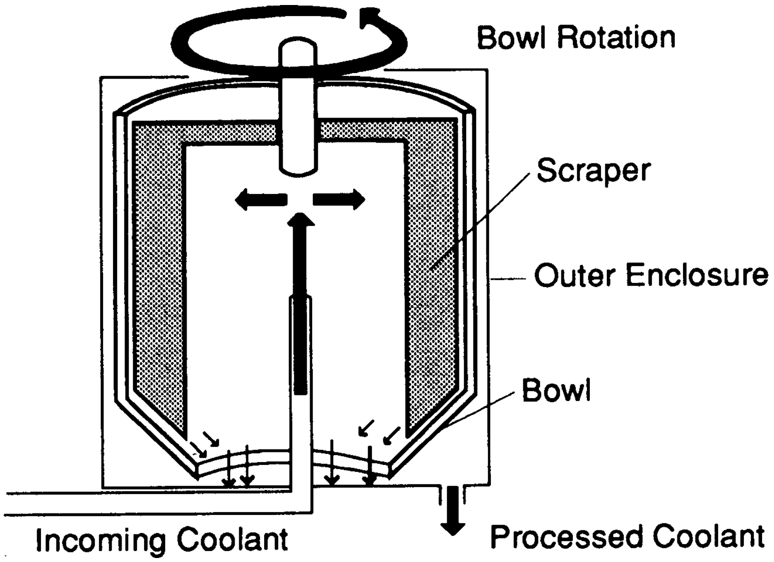
Centrifuges
In a particle separation centrifuge, a rotating mechanical bowl forces particles to the outside of the chamber, while fluid flows out the bottom. Figure 4.3 shows a schematic of this type of centrifuge. Particle centrifuges are usually used with some other form of particle removal because of centrifuges' slow removal rate. Unlike centrifuges that remove tramp oils, this type of centrifuge does not contain coalescing disks or plates because they would clog with particulate.

Rolled Media Vacuum Filters
Paper media filters retain particles as the fluid is drawn through it by a vacuum in a tank. When the filter requires indexing, the media is changed by conveyor belt. The media rests in the tank on a wedge-wire screen or perforated plate. The media requires periodic changing when the roll is used up.

Wedge-wire Vacuum Filters
In a wedge-wire vacuum filter, panels or cylinders of wedge-wire retain the particles. There are a few different types of these filters. For example, there is a variation on the rolled-media filter, where the media has been eliminated. This design may require high maintenance in the form of manual clean-outs if the screen begins to plug. A modification on this design that eliminates the aforementioned maintenance issue is suspending the wedge-wire in the tank. Another design

contains two or more wedge-wire cylinders. In this system filters are set to index[23] at a preset vacuum level, which is done by rotating the wedge-wire mechanism.

Figure 4.3 *Schematic of Centrifuge Used for Particle Separation (Berger 1990)*



Pre-coat Vacuum Filters

Pre-coat vacuum filters add a loose pre-coat to a rolled or wedge-wire filter system to aid in particulate removal. However, use of a pre-coat filter will decrease the throughput and require a larger unit.

Bag or Cartridge Pressure Filters

In a bag or cartridge pressure filter the fluid is passed through a canister that retains the particulate. These filters are generally used for polishing. By design they are not effective on large contaminant loads because the media would foul too quickly. This issue is further complicated by the fact that the media must be manually changed. Bags and cartridges are available in various sizes and micron ratings.

Flat Bed Pressure Filters

These filters consist of a pressure chamber on top of a filter bed. The filter barrier is either disposable rolled media or permanent plastic belting and is placed on top of a support grid. The top of the filter closes down and seals around the edges. The fluid is pumped into the chamber from the reservoir and is forced through the septum. When the pressure difference reaches a preset value, the filter indexes, removing the contaminant from the surface of the media; the chamber drains, and a new section of media replaces the old.

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[23] Indexing refers to the clearing of material from the filter media or apparatus through various means such as backwashing the filter.

Pressure Tube Filters
Pressure tube filters have long, cylindrical tubes precoated, usually with diatomaceous earth, that are suspended in a pressure chamber. Similar to flat bed pressure filters, when the pressure difference reaches a predetermined point, the filter indexes the particles and diatomaceous earth.

Controlling Microbial Contamination

This section discusses traditional and non-chemical methods for controlling microbial growth and hence microbial degradation of metalworking fluids. Previous sections in this Chapter cover related topics, including the microbiology of metalworking fluids, the effects pH has on microbial growth, and methods for monitoring microbial levels.

Chemical treatment is the conventional means of controlling bacterial growth. The fluid is formulated with biocides and biocide additive packages are often used. However, by creating and maintaining an environment that is not favorable to microbial growth, the use of these chemicals can be greatly reduced. For example, uncirculated sumps, such as those caused by weekend shutdowns, form an environment that is conducive to anaerobic bacterial growth. The metabolic activity of these bacteria generates sulphurized byproducts that give off very offensive odors, commonly referred to as Monday morning odor. One way to eliminate this problem is to re-circulate or aerate the fluid periodically during shutdowns, which will keep the fluid well aerated.

Other nonchemical methods of inhibiting biological growth are pasteurization, distillation, and ozonation. In pasteurization and distillation, fluids are heated to between 140° and 250°F to kill bacteria. The biomass is then removed by a particulate separation system (Healy nd). Ozonation is performed by circulating ozone in the contaminated fluid. The mechanisms by which ozone kills bacteria is not yet known, however successful laboratory and industrial trials have demonstrated its effectiveness (Owen 1999).

As discussed in the above sections, periodic or continuous contaminant removal is important to prevent biological degradation of fluid. Chips, particles, and tramp oils all provide sites for microbial growth to occur, and tramp oils may provide nutrients for some bacteria. A regular maintenance system is an effective preventative measure to inhibit biological activity in metalworking fluids.

Another maintenance step that helps to prevent microbial growth is the cleaning of equipment during fluid changes by flushing out the system and wiping down equipment. This removes biological growth from the fluid system walls which otherwise would immediately inoculate the fresh fluid with microbes.

Fluid Application

Various methods are used to apply metalworking fluids to workpieces and machine tool bits, including:

- flood
- mist
- splash
- immersion
- vapor
- through the tool

The application method may facilitate removal of chips by flooding or pressure spray removing them from the work area. The operating conditions may have high cooling requirements, and therefore a high rate of fluid flow is traditionally used to facilitate temperature removal from the work area.

However, often the application methods and volume delivered have not been optimized to minimize fluid use because fluid material costs are low and often not all costs associated with fluids are evident to a firm. For example, when fluids are grossly applied, they may cause the area around the machine to be coated with fluid, requiring time-intensive clean-ups at the end of each shift.

Alternative application techniques replace traditional methods for lubricating and cooling the work area. The use of microdispersion nozzles to apply the metalworking fluid that lubricates the work area, combined with compressed air to remove chips and cool the work piece and tool, is an effective alternative to flood application in certain machining operations.

Like fluid selection, selecting an appropriate application method is critical to minimizing fluid loads to later processes, such as cleaning baths and heat treating baths. By minimizing the volume of fluid applied, the cleaning bath life may be increased due to its decreased loading, and for cleaning systems that employ oil removal from the cleaning system, the capacity requirements of this system are also decreased. Additional costs saving are achieved through fewer bath and filter change-outs and decreased waste volumes.

When firms analyze the way they apply fluids, they may find that no fluid is necessary on certain jobs. There are companies that specialize in helping firms reduce their fluid use through a systemized approach to reducing the amount of fluid that is delivered to the work area. They can monitor product qualities, such as surface finish, to insure that workpiece quality is being maintained during this process. They can also monitor machine tool quality to insure that the machine tool is not being damaged.

CHAPTER 5

Innovative Pollution Prevention Technologies

Industry vendors have developed innovative processes that greatly reduce the waste from traditional metal shaping and metal removal processes. This chapter will discuss recently developed dry machining techniques and technologies and three other innovative pollution prevention technologies: waterjet cutting, laser cutting, and electronic discharge machining (EDM).

Dry Machining

Metal fabricators, machiners, and researchers have been increasingly interested in the elimination of metalworking fluid use in the machining of ferrous and nonferrous metals. Fluid purchase and management costs are between 7.5 and 17 percent of total manufacturing costs. Maintenance costs comprise most of these costs while the purchase costs are a relatively small portion (Heine 1997). Dry machining may alleviate some of the following fluid management issues:

- need for continuous treatment of the fluid
- need to maintain fluid composition
- disposal of the fluid if and when it reaches the end of its useful life
- continual use of biocides to prevent or reduce microbial growth

Are Fluids Necessary?

In some fabrication processes where the operating conditions are not severe, such as when feed rates and temperatures are low, the use of fluids may simply be eliminated. For applications that do not make chips and where heat build-up is not an issue, fluids have historically been used only out of habit to prevent unforeseen damage to the tool or workpiece. As long as the tool bit is kept clean, sharp, and within tolerances, fluid use in these operations can be eliminated.

Dry Forming and Stamping at Bartley Machine

Bright tin-plated brass 0.012" sheet is stamped and formed to make flat rectangular parts with beveled edges and holes punched out. This process is performed dry, without the use of metalworking fluids. Performing this operation dry simplifies cleaning issues and eliminates wastes associated with the use of fluid. This is significant for this operation because the workpiece has high cleanliness requirements (Piekunka 1999).

For other operations where lubrication, cooling, and chip removal are of concern, these problems may be mitigated by modified tool bit materials, coatings, or designs (Winkler 1998). A number of tool coatings and tool materials have been developed to specifically replace the functions of the metalworking fluid. Coatings and advanced tool materials reduce frictional forces between the tool and chip and minimize heat build-up on the rake[24] face and adhesion between the chip and tool bit, preventing built-up edge (BUE). The most desirable characteristics of tool materials for dry machining are high-temperature wear resistance and hardness at elevated temperatures. Table 5.1 presents some of alternative tool materials and their advantages and disadvantages.

Table 5.1 Tool Coatings: Applications and Advantages/Limitations (Heine 1997)

Tool Material/Coating	Example Applications	Advantages and Limitations
Titanium Aluminum Nitride (TiAlN) Coatings	machining cast iron, steel, and titanium alloys	• heat-resistant • oxidation-resistant
Cermets and Ceramics	cutting	• high temperature wear resistance • hardness at elevated temperature • low bending strength
Silicone Nitride (SiN) Ceramics	milling of ductile iron	• increased cutting speed
Titanium Carbon Nitride (TiCN) and Aluminum Oxide (Al_2O_3) Coatings	cutting	• produce low workpiece temperatures
Gradient-sintered Carbide Substrates	cutting	• produce low workpiece temperatures
CVD Coating	drilling, reaming, and countersinking non-ferrous metals	• reduces adhesion tendencies • minimizes friction between the tool and chip • extends tool life
Cobalt-enriched Substrate with Alumina-zirconia Coating	interrupted cutting; light roughing to high speed finishing of gray and nodular cast irons	

Other alternative coatings and tool materials that have been used are:

- coated carbide and cermets[25]
- silicon-nitride ceramics
- cubic-boron nitride (CBN) materials

Dry machining is possible in many cases as long as the cutting conditions are appropriately adapted. Compressed air may be used to remove chips from the work area. Metal-removal rates need to be high to minimize the contact time between the chip and tool and prevent thermal

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[24] Rake is the angle between the top cutting surface of a tool and a plane perpendicular to the surface of the work.

[25] A ceremt is a composite structural material of a heat-resistant compound (as titanium carbide) and a metal (as nickel).

shock to the tool or workpiece. Tool geometries may be modified to effectively minimize chip/tool contact time, hence reducing subsequent heat transfer as shown in Figure 5.1 (Grasson 1997).

Figure 5.1 *Alternative Tool Geometries (Grasson 1997; reprinted with permission from American Machinist)*

Conventional Milling Insert

Insert with Ribbed Rake Face

Laser Drilling and Cutting

Lasers are beams of monochromatic[26] light focused precisely to produce a very intense energy beam. Lasers are very flexible because they have no inertia and can be easily and rapidly controlled in intensity and direction using computer control systems. Lasers may be used for drilling and cutting, as well as welding, heat treating, and engraving. They can replace mechanical metal removal processes as well as arc and gas welding, and induction, flame, and plasma hardening. Wastes reduced by using laser processing include metal cutting fluids, wastewater, slag, and scale.

Laser Heat Treating of Malleable Cast Iron

A manufacturer of housings for power steering gears has switched from induction heat treating to laser heat treating. This switch has allowed the firm to selectively harden only the areas of the parts that have metal-to-metal contact. This has saved 10 percent on energy costs, eliminated the need for spray quenching, has been faster, required less labor, and saved about 11¢ per part (TVA: Laser nd).

Table 5.2 Advantages and Limitations of Laser Processing (TVA: Laser nd)

Advantages	Limitations
• fast cutting and welding	• high capital cost
• high surface quality	• line-of-sight limitation
• ability to machine difficult materials	
• reduced material loss	
• flexible and controllable	
• repeatable (non-contact processing)	
• minimal or no thermal effects	

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[26] Monochromatic waves consist of a single wavelength or of a very small range of wavelengths.

For laser cutting of certain metals, particularly stainless steel, air emissions may be an issue. Air emissions created by laser cutting include characteristic (i.e., ozone, nitrogen, VOC, and aerosols), toxic (i.e., Mn and Zn), and carcinogenic (i.e., Ni, Co, PAH) pollutants. For laser cutting of stainless steel, additional emissions of concern are toxic-soluble chromium (VI) and carcinogenic-insoluble chromium (VI) (Haferkamp 1998).

Capital costs for laser equipment are high, typically ten times higher than other cutting and welding processes and five times higher than induction heat treating, and hence it is usually not an option for small shops (TVA: Laser nd).

Laser Welding of Hot-Rolled Steel

An appliance manufacturer replaced arc welding with laser welding in the manufacture of metal doors. The laser system requires 16 percent less energy and less set-up time. The annual net savings from switching to this process is $150,000 on 970,000 doors (TVA: Laser nd).

Waterjet Cutting

Waterjet cutting is used to replace conventional mechanical cutting methods as well as laser, plasma, or oxyfuel cutting. Waterjet systems use special pumps and pressure intensifiers to boost the water pressures in excess of 3400 atmospheres. Water is then concentrated through a metal or sapphire nozzle to a stream diameter of a couple of micrometers and reaches a velocity several times the speed of sound. For very hard materials, abrasives may be added to enhance cutting action of the water stream.

Although there is limited information available on the overall environmental performance of waterjet cutting, it is known that switching to waterjet cutting may reduce or eliminate certain wastes, including: metal cutting fluids, contaminated wastewater, and slag and scale from oxyfuel cutting.

Cutting Brake Lining Strips

An automaker installed six waterjet cutting systems to cut asbestos brake lining strips. The waterjet system produced minimum kerf (<0.01"), eliminated hazardous airborne dust, and has been simple to automate for safety and production control. Cutting efficiency was increased by 30 to 50 percent with annual savings of $25,000 (TVA: Waterjet nd).

Table 5.3 Advantages and Limitations of Waterjet Cutting (TVA: Waterjet nd)

Advantages	Limitations
• fast cutting	• higher capital costs
• better tolerances than mechanical or torch	• larger tolerances than lasers and EDM
• cuts difficult materials	
• clean cut	
• no thermal effects	
• flexible and controllable	
• reduces material loss	

Capital costs of waterjet cutting systems are in the range of $165,000 to $600,000, and therefore are probably not a good option for small shops.

Abrasive Waterjet Cutting of Titanium

An aerospace firm installed a waterjet cutting system equipped with hydroabrasive nozzles to cut titanium and other hard materials. The waterjet system feeds two cutting systems, a manual operation system for cutting complex contours, and a CNC X-Y positioning table for cutting sheet metal. The systems cut 1.5 mm (1/16") titanium plates at a rate of 5mm/second (1 foot/minute). The company estimates overall production cost savings have been 50 percent (TVA: Waterjet nd).

Electrical Discharge Machining (EDM)

EDM can be used to cut various complex shapes, particularly in hard materials, such as tool steel. Metal is removed by a series of rapidly recurring electrical discharges between the cutting tool (electrode) and the workpiece in the presence of a dielectric fluid. The workpiece is immersed in a dielectric fluid, such as oil, and is brought close to the tool. The tool is connected to DC high voltage, high frequency power. This power creates millions of tiny electric arcs which erode microscopic bits of the workpiece (TVA: EDM nd). Particles of metal, generally in the shape of hollow spheres, are flushed from the work zone by dielectric fluid.

EDM eliminates the need for heat treating metal products and parts, and possible subsequent distortion associated with heat treating. It is particularly effective on extremely hard materials or on parts with complicated geometries or small or odd shaped holes, many holes, holes with shallow entrance angles, intricate cavities, or intricate contours. EDM is also effective on very thin materials. For example, EDM can be used for small round or irregular-shaped holes (to 0.002", or 0.05 mm) with length-to-diameter ratios of 20:1 and very thin slots in the range of 0.002-0.012" (0.05-0.30 mm) may be achieved (Goetsch 1991).

EDM Die-Making

An aerospace fastener firm replaced its conventional machining process for producing specialty dies with a Computer Numeric Control (CNC) wire EDM machine. The time required to produce prototypes decreased from 40 to four hours. Production die sets are now produced in 125 hours as compared to 300 to 400 hours previously. The production time decreases allowed for a substantial reduction in inventory requirements.

Die quality and durability were improved since EDM produces higher tolerance parts and is effective on harder steels than conventional methods. Scrap rates have been reduced from 10 to 20 percent to less than 1 percent. The company estimates its payback period to be less than six months (TVA: EDM nd).

EDM may be used for cutting, drilling, die-making, punching, and mold-making. It may be used as a replacement for mechanical milling, cutting, and drilling as well as laser cutting and drilling. The major waste stream reduced by using EDM is broken cutting and drilling tools. This can be significant in applications where tool breakage is high.

Table 5.4 Advantages and Disadvantages of EDM Versus Traditional Machining (TVA: EDM nd)

Advantages	Disadvantages
• handles delicate tasks	• slow cutting rates
• may cut or drill very hard materials	• electrode wear
• highly accurate	• thin, brittle heat-affected zone
• very small kerf for wire EDM	
• produces complex, deep, or 3-D shapes	
• no burrs	

Capital costs for EDM equipment is in the range of $100,000 to $200,000 per unit and hence it is usually not an option for small shops (TVA: EDM nd).

EDM Drilling

An automobile manufacturing facility previously used conventional drills to make holes in fuel injector nozzles. However, tolerance and accuracy were a problem. Additionally, replacement costs for drills were $180,000 annually.

The facility switched to EDM, improving tolerances to 0.0025 mm (0.0001") on hole diameters of 0.175 mm (0.0069"). In addition to improved repeatability, annual tool replacement costs have been reduced dramatically to $2,000 (TVA: EDM nd).

CHAPTER 6

Pollution Prevention Opportunities in Heat Treating, Soldering and Brazing, and Adhesive Joining

Besides metal shaping and cutting operations, a number of processes are involved in the manufacturing of complex metal parts. Processes, such as heat treating and metal joining, help to make the complex shapes that make up the products we use in everyday living. However, these processes also contribute to the pollution generated from the manufacture of metal products. This Chapter covers techniques for reducing or eliminating waste generation from heat treating, brazing and soldering, and adhesive joining operations.

Pollution Prevention Opportunities in Heat Treating

As discussed in Chapter One, fabricators perform heat treating at various stages throughout the fabrication process to impart a variety of characteristics on metals such as improved machinability, ductility, toughness, impact resistance, and elongation. The heat treating process involves heating the substrate in salt baths, furnaces, or alternative technologies, and then cooling the workpieces at varying rates, depending on the desired characteristics. Most pollution prevention opportunities in heat treating can be found in salt bath heat treating processes. Waste may be reduced by removing contaminants from the salt bath, modifying the operating procedures, changing the operating parameters or the bath chemistry, and replacing salt bath heat treating with another type of heat treating.

Replace Salt Bath Furnaces

Fabricators should replace barium and cyanide salt heat treating with carbonate/chloride carbon mixtures or with

Electric Heat Treatment Furnaces Replace Soluble Salt Baths at Tamworth Heat Treatment

Tamworth provides hardening, annealing, stress relieving, tempering and nitriding services, all of which were previously performed in salt baths. The salt bath heat treating processes were labor intensive, created discoloration and scaling of components, and created the need for post-treatment such as shot blasting and washing. Additionally, the salts might be toxic, and might contaminate subsequent wash and rinse baths.

The old salt bath processes were replaced with two controlled atmosphere furnaces using ammonia to provide nitriding; one vacuum furnace dedicated to tempering; and three vacuum furnaces for hardening, using high pressure nitrogen to achieve rapid quenching. These hardening furnaces combine convection and radiant heat for improved efficiency and include sophisticated control systems using local interlock and thermocouples to measure temperature of the workpiece and not the temperature of the furnace.

Benefits of the change to electric heat treatment furnaces are:

- output increased by 25%, without the need for increased labor costs
- eliminates the need for post-treatment
- energy use reduced by 30%
- reject rates cut from 2.5% to less than 0.5%
- waste disposal issues with salts eliminated
- better work environment (cooler) (East Midland Electric 1998)

furnace heat treating. The various types of furnace heat treating are preferable to all types of salt bath heat treating because they do not generate the spent salt baths that must then be handled as hazardous waste. The sections below discuss a few alternatives.

Replacement of Salt Baths with Fluidized Bed Furnaces

The main environmental benefits of replacing salt baths with fluidized bed furnaces include:

- elimination of spent salt disposal
- elimination of the need to neutralize quench oil or water due to salt carryover
- elimination of the need to chemically clean off gases or vapors from the bath
- improved quality through rapid and uniform heating, cooling and temperature uniformity
- lower installation costs
- low capital costs
- lower energy consumption
- improved working environment (Environment Australia 1997)

Direct Resistance Heating

Also referred to as conductive heating, direct resistance heating involves passing an alternating current through the workpiece to heat the workpiece. In addition to heat treating, direct resistance may be used for hot metal working (i.e., forging, stamping, extruding, rolling, and upsetting), and metal joining (i.e., spot, seam, and flash welding). Clamp or roll type electrodes are used to deliver the current to the workpiece. The resistance of the workpiece to the current being passed through it generates the heat. Low frequency current (60 Hz) is used to heat the part throughout, while high frequency current (400 Hz) is used to heat the surface of the part.

Direct resistance heating may be used to replace salt/lead bath heat treating, fossil/electric (indirect resistance) furnace, flame hardening, and torch welding. Wastes reduced or eliminated by switching to direct resistance heating include: combustion pollutants, such as reactive organic gases (ROG), SOx, NOx, COx, and particulate; material oxidation (slag, scale); and spent salt/lead baths. Capital costs for direct resistance systems range from $25,000 to $100,000 (TVA: DR nd).

Table 6.1 Advantages and Limitations of Direct Resistance Heating (TVA: DR nd)

Advantages	Limitations
• fast heating	• for heating, uniform cross-sections are required
• selective and uniform heating	• for heating, parts must be long and slender
• small space requirements	• for heating, low to moderate production rates
• moderate cost	• contact surfaces must be clean for good electrical connection
• high efficiency	• for welding, part configuration must provide high resistance to current flow

Indirect Resistance

In indirect resistance heating, heat is transferred to the workpiece via conduction, convection, and/or radiation. This is usually carried out in a well-insulated enclosure such as an electric oven. In addition to heat treating, indirect resistance may be used for forming, drying, joining, sintering, or curing. It is used to replace salt/lead bath heat treating, and fuel-fired furnace or flame hardening. Wastes reduced by using indirect resistance include combustion pollutants (ROG, SOx, NOx, COx, particulate) and spent salt/lead baths (TVA: IR nd).

Table 6.2 Advantages and Limitations of Indirect Resistance (TVA: IR nd)

Advantages	Limitations
• application flexibility	• operating costs may be high*
• precise temperature control	
• accommodates special atmosphere or vacuum	

*depends on the cost of electricity

Capital costs for indirect resistance processes are on par with their fossil fueled counterparts. They are low maintenance operations and operating costs are highly dependent on the electric rates for a given facility.

Contaminant Removal and Prevention

The following Sections outline steps for preventing and removing contaminants from heat treating processes.

Eliminate Contaminants at the Source

The amount of metalworking fluid used in previous processes should be reduced to the greatest extent possible to reduce the amount of contaminant entering the heat treating process. Fluids that enter the process are volatilized in the furnace and then removed from the flue gas by a scrubber system, before being hauled away or used as fuel for heat on-site. Reducing fluid use, or performing dry machining where possible, reduces the resource drains of this process. For information on reducing metalworking fluids going into heat treating furnaces or baths, see Chapter 3, Fluid Application.

Firms have reduced contamination of salt baths and scrubber systems by installing a hot water rinse bath before the heat treating step. This reduces the contaminant loading on the salt bath or scrubber system and reduces the amount of contaminant removal required. For salt baths, this results in an extended bath life and for scrubber systems reduces the need for costly clean outs and downtime. Contaminants may be more easily removed from the water rinse and cleaning baths. It is imperative that parts are dried before being placed in the salt bath, as the presence of water may cause splattering or an explosion (Environment Australia 1997).

Salt Bath Maintenance

Periodic cleaning of salt baths to remove oxidation products can increase bath life. Cooling the bath to 454°C (850°F) allows the precipitated carbonate salts to settle to the bottom of the bath where they may be removed using a perforated ladle (U.S. EPA 1992a). This is a simple procedure that is easy and cheap to implement. However, the facility will have to shut down the line for a period of time or bring in employees at down times to conduct this work.

Drag-out Reduction

Drag-out of salts into subsequent baths is a significant source of contamination and chemical loss in salt-bath heat treating. Drag-out may be minimized through process modifications, such as increasing the hang-time of parts during withdrawal, decreasing the withdrawal rate of parts, orienting the parts to minimize drag-out, and installing mechanical blowers to force excess salt from the surface of parts (U.S. EPA 1992a). These steps are easy to implement and mainly require training employees on proper withdrawal methods and part placement on racks.

Furnace Modifications for Cyanide-Containing Salt Baths

For cyanide-containing salt baths, the use of a graphite cover will prevent fugitive emissions. Also, replacing ceramic pot liners with brick liners will increase furnace life.

Controlling Furnace Atmospheres

Some heat treating applications require a controlled environment[27] within the heat treating furnace. Chemicals such as ammonia are used to prevent the formation of oxides that form when the surface reacts with the air. One innovative approach has greatly reduced the amount of ammonia used though process modifications and input substitutions. In this application, the atmosphere is achieved by dissociating (splitting) anhydrous ammonia into its basic components: 75 percent hydrogen, and 25 pecent nitrogen by volume. The use of ammonia in this application has been reduced by diluting the dissociated ammonia (DA) with nitrogen as shown in the process flow diagram below (MA TURI 1997b).

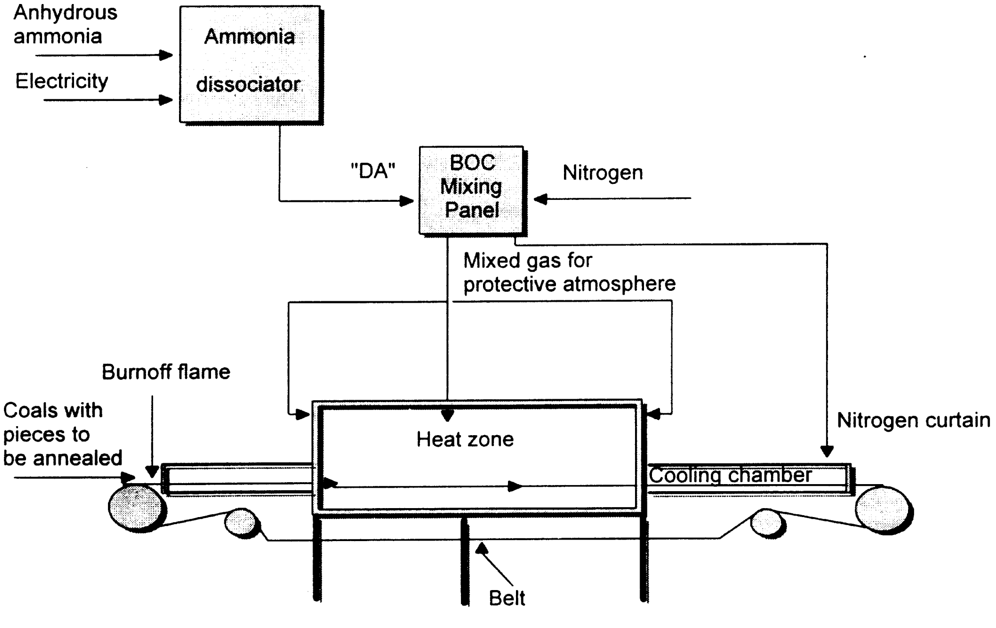

Figure 6.1 *Annealing/Soldering Process Flow Diagram with Ammonia Dissociator (MA TURI 199b)*

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[27] Controlled furnace environments are used to prevent oxides from forming on the surface of parts. These controlled environments are created by adding certain chemicals to the furnace atmosphere.

Nitrogen Dilution of Ammonia at General Findings

General Findings, a Division of Leach & Garner that serves the jewelry industry, has employed nitrogen dilution in the ammonia dissociator that feeds its furnace used for both heat treating and batch soldering.

In 1996 General Findings used roughly 104,000 pounds of anhydrous ammonia to produce more than 202 million units through its furnaces, resulting in roughly 1,900 units/pound of ammonia. At 37.5 percent hydrogen (50 percent reduction) General Findings will process approximately 3,900 units/pound of ammonia and at 20 percent hydrogen, about 7,250 units/pound of ammonia. This reflects reductions in ammonia of 50 percent and 73 percent respectively.

Chemical cost savings of nearly $11,500/year are anticipated at a 20 percent hydrogen mix. Additional savings will be realized from reduced electrical usage resulting from the shut-down of one dissociator and reduced heat load on the air conditioning system from the shut down dissociator to total more than $13,200/year. Payback is more than four years (MA TURI 1997b).

Quenching

After heat treating, parts are quenched at various rates and to varying degrees. The quenching process is a significant source of waste in heat treating processes. Oil, one of the most commonly used quenchants, must often be handled as a hazardous waste when it is spent because of contamination with salts and metals. Pollution prevention opportunities in quenching processes are:

- contaminant removal from quenchants
- use of alternate quenchants
- reduce drag-out
- employing dead rinse tanks before and after quenching

These opportunities are covered in the following sections.

Contaminant Removal From Quenchants

Continuous or batch removal of contaminants from liquid quench baths can greatly increase the bath life. Recycling of quenching oil is done by mechanical or thermal means such as filtering, evaporating, or draining. Common contaminants that need to be removed include:

- scale
- carbonaceous sludges
- insoluble solids, such as sands
- water
- soluble compounds, such as carbon dioxide, removed in thermal conditioning

Examples of in-process recycling are desludging quenchant oil, dewatering quenchant oil, and ultrafiltration of water-polymer quenchants. The type of contaminant removal employed depends on the specific process and its contaminant loading. Waste oil collected in underground clarifiers is often sent off-site for recycling. However, on-site recycling is also a possibility. The various types of contaminant removal technologies are listed in Table 6.3.

Table 6.3 Quenchant Contaminant Removal Technologies

Contaminant Removal Method	Characteristics
Magnetic Filters, Traps, and Strainers	• effective at removing scale and other foreign objects
Filtering or Centrifuging	• may remove water, but expensive and rarely used
Draining	• bulk water removal
Heating	• removes suspended water and carbon dioxide

Drag-Out Reduction

Drag-out is a significant source of contamination to subsequent wash and rinse baths. Similar to salt bath heat treating, drag-out in quenching may be reduced by increasing hang times, decreasing withdrawal rates, installing mechanical blowers, or reorienting parts on racks. Drag-out may also be reduced by substituting a less viscous quench media for a more viscous media. A less viscous fluid would shear more easily from the surface of parts upon withdrawal. Employees should be trained on proper removal techniques and part orientation methods. Installation of blowers and changing quenchant would require some downtime.

Hyde Tool

Hyde Tool is a manufacturer of home and industrial tools located in Southbridge, Massachusetts. Hyde Tool installed a filtration system capable of recycling the wash and rinse water as well as the quench oil. The filtration system reduced the amount of oil sent off site for reclamation by 1,730 gallons per year. The project also reduced water usage in the wash process by 19,200 gallons per year.

Purchase and installation costs for Hyde's new filtration and recycling system totaled $25,055. Hyde also installed an alarm system that automatically shuts off the unit's pump when the oil/water combination in the sump nears capacity. The purchase and installation cost of this safety system was $750, bringing the total up-front cost to $25,805.

The new system has reduced Hyde's purchases of quench oil by $4,844 every year. In addition, Hyde saves $8,760 in water bills, $4,200 in NPDES permits and $300 in laboratory testing costs each year. The only new expenditures associated with the system are the filtercake purchase and disposal costs, which total $2,800 per year. Thus, the payback period for the investment is about 2.5 years. This does not take into account the potential $2,500 per day fines or the potential liability associated with discharging into the sewer (MA OTA 1994).

Alternative Quenchants

Traditional oil quenching is a very messy process that has a significant impact on the work environment. Extra resources must be dedicated to proper management of the process to prevent contamination of the work area during oil use. Alternatives are available that eliminate these issues, and like traditional quenchants, are selected based on the substrate and the rate of cooling required.

Polymer quenchants are effective replacements for oil quenchants. They do not pose the fire hazards associated with oil use and are much cleaner to work with. Purchase costs for polymer quenchants are competitive with oil quenchants. Polymer quenchants require closer temperature control, but because they only have half the heat rise of oil quenchants, they require less cooling capacity.

Heat exchangers used with polymer quenchants require less maintenance than those used with oil quenchants. This creates savings in down time and labor costs. It is important to control the ration of work load to quenchant. For existing systems the ratio should be maintained at one pound of work to one gallon of quenchant. For new systems, the ratio should be set at one pound of work to one and a half gallons of quenchant. Polymer systems should be circulated. This will allow for heat extraction and prevent the surface of the bath from being heated by the vestibule gases. If the surface of the bath is allowed to vaporize it may interfere with the heat treating process (Texanol nd).

Scot Forge Company
Spring Grove, Illinois

Scot Forge is a custom open die forge shop that performs its own heat treating. In its quenching operations, a polymer-based quenchant is used. This type of quenchant was selected over oil-based on the basis of cleanliness, safety, and economics. "Our economic analysis also took into account the extensive capital expenditures required for fire protection and pollution control. In that sense the decision to use polymer quenchants was a no-brainer," said Bob Krysiak, Vice President and Manager of Rolled RIng Products at Scot Forge (Tenaxol nd).

Substitution of less viscous "fast" quench oil (i.e., mineral oil with proprietary additives), results in decreased drag-out of oil, thereby lowering oil consumption and contamination of subsequent baths with excess quench oil. Also, the addition of antioxidants retard oxidation of quench oil, extending its useful life (U.S. EPA 1992a).

Dead Rinse Tanks

Dead rinse tanks are static water rinses that are used before quenching and after successive treatment baths. The use of dead rinse tanks before quenching and after successive treatment baths reduces cross contamination and prolongs the useful life of rinses and baths. The dead rinse bath can be used to make up evaporative losses in acid baths and other aqueous solutions. The dead rinse bath can be replenished with water from the cleaner rinse baths (U.S. EPA 1992a).

Soldering and Brazing

Wastes resulting from soldering and brazing operations include excess fluxes, solders, and filler metals, spent cleaner baths, and VOC emissions from fluxes. Changing the materials or more strictly controlling the operating parameters may reduce or eliminate waste generation. The section below discusses some benefits and limitations of these alternatives.

Alternative Fluxes and Solders

Use of alternative solders, fluxes, and filler metals can reduce the toxicity of the waste stream and improve the work environment. There are suitable alternatives for many existing applications using cadmium-bearing solders, lead-bearing solders, and low-VOC solder and brazing fluxes.

Elimination of Post-cleaning

In most operations, excess flux remaining after soldering or brazing is removed to prevent corrosive damage to the joint or assembly. Most facilities use alcohol, chlorinated hydrocarbon solvents, alkaline cleaners, or dilute acids to clean off the excess flux; alkaline cleaners are preferable from a pollution prevention standpoint. Excess flux removal may not be necessary if the facility uses a non-corrosive flux, such as rosin-type fluxes. In these cases, post cleaning may be eliminated.

Optimize Flux Delivery

Application methods should be optimized or modified to deliver only as much flux, solder, or filler metal as needed to form the joint. Besides reducing material costs, optimized delivery can also reduce the need for cleaning to remove excess flux. Excess amounts of flux should be removed after joining to prevent corrosion of the workpiece and insure product quality. Modern flux delivery nozzles with digitally controlled actuators allow for the delivery of precise amounts of flux, reducing much of the excess.

Optimize Heating of Filler Metal

Excessive heating of the joint, solder, or filler metal is a source of unnecessary emissions from soldering processes. This can be prevented through improved equipment control, monitoring, and worker training (Goetsch 1991).

Dross Removal

The formation of dross[28] in flux and solder baths may cause them to be disposed prematurely. Continuous or batch removal of dross and other contaminants can increase bath life and insure product quality. Dross may be removed by manually skimming the bath.

Controlling Furnace Atmospheres

For brazing of some substrates, the atmosphere of the brazing furnace must be controlled to prevent the formation of surface oxides. When atmospheric conditions are not properly controlled, an additional cleaning step is necessary to remove the difficult to remove oxide layers. Regular process monitoring and control can prevent formation of surface oxides. Temperatures and process times that are set for that specific application must be strictly monitored by operators.

Adhesive Joining

Reducing the amount of solvents used in adhesive joining represents one of the greatest opportunities for pollution prevention. Solvent-free alternatives include water-based, hot melt,

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[28] Dross is the extraneous matter or impurities risen to or formed on the surface of molten metals.

and radiation-cured adhesives. There are many advantages and disadvantages to each. The sections below provide some background on the characteristics, the advantages over traditional solvent-based adhesives, and the limitations of the three most commonly used alternatives.

Water-based Adhesives

Water-based adhesives are used to a limited extent in the joining of metals. They are formulated from rubber components with water as the carrier fluid. Curing may be performed in ovens or under ambient conditions. Water-based adhesives may be applied using existing equipment, if the equipment is compatible. For example, the plumbing would need to be made of stainless steel or another corrosion-resistant material (PPRC 1998a).

Table 6.4 Advantages and Limitations of Water-based Adhesives (PPRC 1998a)

Advantages	Limitations
• no HAPS or VOCs • no explosion risk	• lower peel strength • lower shear strength • lower humidity resistance • less flexible • may need an oven, hence energy costs may increase

For facilities that have a lot of application equipment, water-based adhesives are preferable to other alternatives because they may use the same application equipment, eliminating the need to train employees on new application equipment.

Costs

Costs of purchasing water-based adhesives are 15 to 20 percent lower than solvent-based. For firms that use entirely water-based systems, the need for pollution control equipment and the associated capital and operating costs of this equipment are eliminated. If water-based adhesives are formulated on-site, tanks, piping, and pumps may need to be upgraded to corrosion-resistant stainless steel and PVC. Using formulated products can eliminate the need to upgrade plumbing if adequate mixing is provided. An aqueous waste stream is created when switching from solvent-based to water-based adhesive operations. However, overall operating costs for water-based are estimated to be 33 percent lower than solvent-based systems (1993 dollars) (PPRC 1998a).

Hot Melt Adhesives

Hot melt adhesives are solvent-free and are solids at temperatures below 180°F. Besides eliminating the need for solvents, such as MEK and TCA, hot melt adhesives eliminate VOCs since the solvent is the volatile portion of the adhesive formula. Examples of resins used in hot-melt adhesives are:

- ethylene vinyl acetate (EVA) copolymers
- styrene-isopropene-styreneopolymers
- styrene-butadiene-styrene (SBS) copolymers

- ethylene ethyl acrylate (EEA) copolymers
- polyurethane reactive (PUR)

These polymers are generally used in combination with tackifying resins, waxes, antioxidants, and plasticizers to provide some characteristics that they lack. Standard hot melts are applied with a slot die or roll coater, and PUR hot melts may be applied in dots or thin glue lines, allowing them to replace mechanical fasteners in various applications (PPRC 1998b).

Typical solvent-based adhesives may be applied at room temperatures. Hot melt adhesives are applied at elevated temperatures, often above 300°F. Because of this, application equipment used for solvent-based systems are incompatible with hot melt adhesives. Employees would require training on the operation of new application equipment if a switch to hot melt adhesives is made.

Costs

On a per volume basis, solvent-based adhesives are much less expensive than hot melt adhesives. However, this is not an effective way to compare costs because 50 to 70 percent of solvent-based adhesives are lost to evaporation. A more accurate comparison would be on the basis of dry solids applied and coating thickness yielded per pound. Capital equipment costs for hot melt systems are much less than solvent-based systems when control equipment is included in the analysis. Overall, operating costs are less for hot melt systems because of decreased processing time. However, for firms switching from solvent-based to hot melt, employees would require training with the new equipment, and there will be downtime during the change over (PPRC 1998b).

Table 6.5 Advantages and Limitations of Hot Melt Adhesives (PPRC 1998b)

Advantages

- form a strong bond quickly
- compatible with most materials
- easy to handle
- less water sensitive than other thermoplastic polymers
- once applied, unaffected by water, moisture, or humidity
- 100 percent solids; no VOCs, no HAPs
- rapid set-up
- less expensive than solvent-based adhesives, pound for pound dry solids weight

Limitations

- can not be used with heat sensitive substrates
- lose strength at high temperatures
- chemical resistance may be lacking
- exposure to high temperatures can cause the adhesive to melt
- must be applied at temperatures above 300°F
- clean-up must be done immediately

Radiation-cured Adhesives

Radiation-cured adhesives are solvent-free adhesives cured when exposed to radiant energy. The two most widely used are ultraviolet (UV) and electron beam (EB) systems. UV adhesives are best suited for small-scale applications, and EB adhesives are better suited for high-volume operations. UV light-cured adhesives use photoinitiators to activate the cure. The photoinitiators absorb energy in the ultraviolet range (200-400 nanometers), causing a photochemically driven cure. In EB-cured adhesives, an electron beam within the equipment exposes the adhesives to low-energy electrons, curing the adhesive within seconds. EB adhesives have higher installation costs, but unlike UV, may cure the area between two substrates. UV adhesives may be applied on heat sensitive substrates, and are unaffected by ambient temperature or humidity (PPRC 1998c). Other advantages and limitations of each are listed in Table 6.6.

Speed and feed rates of radiation-cured adhesives can be increased and production line lengths may be significantly decreased. Regulatory costs associated with radiation-cured adhesives are much less than solvent-based adhesives because EB and UV systems do not require emission control equipment, permitting fees, and monitoring costs. These systems also generate less hazardous waste and therefore fewer hazardous waste management and disposal costs.

Costs

Radiation-cured adhesives are more expensive than solvent-based adhesives on a per volume basis. However, because radiation-cured adhesives are 100 percent solids, they provide more coverage per unit volume, therefore much less radiation-cured adhesive is required to provide the same coverage. Capital costs for radiation-cured systems are 27 percent less than solvent-based systems (based on 1994 dollars), not including pollution control equipment required for solvent-based systems. There are costs associated with training operators to use the equipment; however, radiation-cured systems typically have reduced overall operator costs (PPRC 1998c).

Table 6.6 Advantages and Limitations of UV- and EB-Cured Adhesives (PPRC 1998c)

Advantages

- no VOCs or HAPs
- no dryers needed
- lower labor costs
- for EB, overall equipment cost comparable to solvent-based when control equiptment is included
- for UV, equipment cost 25% less than solvent-based (not including control equipment)
- spills and overflows may be cleaned up without solvents
- do not require ovens for curing or after burning
- can be applied using retrofit conventional equipment
- EB can be precisely controlled and cure adhesives in hard-to-reach places

Limitations

- expensive initial capital costs
- may need secondary post cure step
- UV bond strength may decrease above 140°F
- EB may require an inert gas blanket to maintain environmental conditions
- EB requires more skilled operators

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Information Resources

Technical Assistance Programs

Connecticut

Connecticut Department of Environmental Protection
Office of Pollution Prevention
79 Elm Street
Hartford, CT 06106-5127
860-424-3297
Fax: 860-424-4081
http://dep.state.ct.us/

CONNSTEP, Inc., The Connecticut State Technology Extension Program
8 Two Mile Road
Farmington, CT 06032
860-507-5620
Fax: 860-507-5659
http://www.connstep.org

Maine

Maine Department of Environmental Protection
Office of Innovation and Assistance
17 State House Station
Augusta, ME 04333
207-287-4152
Fax: 207-287-2814
http://janus.state.me.us/dep/oia/p2home.htm

Massachusetts

Massachusetts Executive Office of Environmental Affairs
Office of Technical Assistance
251 Causeway Street, Suite 900
Boston, MA 02114-2136
617-626-1060
Fax: 617-626-1095
http://www.state.ma.us/ota

Massachusetts Department of Environmental Protection
Bureau of Waste Prevention
One Winter Street
Boston, MA 02108
617-292-5500
Fax: 617-292-5778
http://www.state.ma.us/dep/bwp/

Massachusetts Toxics Use Reduction Institute
University of Massachusetts, Lowell
One University Avenue
Lowell, MA 01854
978-934-3275
Fax: 978-934-3050
http://www.turi.org

Minnesota

Minnesota Technical Assistance Program
University of Minnesota Gateway
200 Oak Street, Suite 350
Minneapolis, MN 55455
612-624-1300
Fax: 612-624-3370
http://www.mntap.umn.edu/

New Hampshire

New Hampshire Department of Environmental Services
New Hampshire Pollution Prevention Program
Waste Management Division
6 Hazen Drive
Concord, NH 03301-6509
603-271-2902
Fax: 603-271-2456
http://www.des.state.nh.us/nhppp/

New Hampshire Department of
Environmental Services
New Hampshire Small Business Technical
Assistance Program
6 Hazen Drive
Concord, NH 03301-6509
603-271-1379
Fax: 603-271-1381

New Jersey

New Jersey Technical Assistance Program for
Industrial Pollution Prevention (NJTAP)
138 Warren Street
Newark, NJ 07102
973-596-6367
Fax: 973-596-6367
http://www.cees.njit.edu/njtap

New York

New York Department of Environmental
Conservation
Pollution Prevention Unit
50 Wolf Road, Room 298
Albany, NY 12233-8010
518-457-7276
Fax: 518-457-2570
http://www.dec.state.ny.us/website/ppu

Empire State Development
Environmental Ombudsman Unit
633 Third Avenue, 32nd Floor
New York, NY 10017-6706
212-803-2280
Fax: 212-803-2309
http://www.empire.state.ny.us

New York State Environmental Facilities
Corporation
Small Business Assistance Program (SBAP)
50 Wolf Road
Albany, NY 12205
800-780-7227
Fax: 518-457-8681
http://www.nysefc.org/tas/SBAP/SBAP.htm

Erie County Office of Pollution Prevention
95 Franklin Street, Room 1077
Buffalo, NY 14202
716-858-7674
Fax: 716-858-7713
http://www.erie.gov/environment/
compliance/index.phtml

New York City Department of
Environmental Protection
Pollution Prevention Program
59-17 Junction Blvd. – 11th floor
Corona, NY 11368
718-595-4359
Fax: 718-595-4422
http://www.ci.nyc.ny.us/html/dep

North Carolina

North Carolina Department of
Environment and Natural Resources
Division of Pollution Prevention and
Environmental Assistance
1639 Mail Service Center
Raleigh, NC 27699-1639
919-715-6500
Fax: 919-715-6794
http://www.p2pays.org

Rhode Island

Rhode Island Department of Environmental
Management
Office of Technical and Customer Assistance
235 Promenade Street, Room 250
Providence, RI 02908
401-222-4700
Fax: 401-222-3810
http://www.state.ri.us/dem

The Narragansett Bay Commission
235 Promenade Street
Providence, RI 02908
401-222-6680
Fax: 401-222-2584
http://www.narrabay.com

Vermont

Vermont Agency of Natural Resources
Environmental Assistance Division
103 South Main Street
Waterbury, VT 05671-0411
802-241-3626
Fax: 802-241-3273
http://www.anr.state.vt.us/dec/ead/eadhome/default.htm

Vermont Small Business Development Center (SBDC)
Environmental Assistance Program
PO Box 188
Randolph, VT 05061
802-728-1423
Fax: 802-728-3026
http://www.vtsbdc.org

National and Regional Organizations

Northeast Waste Management Officials' Association (NEWMOA)
129 Portland Street, Sixth Floor
Boston, MA 02114
617-367-8558
Fax: 617-367-0449
http://www.newmoa.org

National Pollution Prevention Roundtable (NPPR)
11 Dupont Circle, Suite 201
Washington, DC 20036
202-466-P2P2
Fax: 202-466-7964
http://www.p2.org

Pacific Northwest Pollution Prevention Resource Center (PPRC)
513 1st Avenue, W
Seattle, WA 98119
206-352-2050
Fax: 206-352-2049
http://www.pprc.org

Waste Reduction Resource Center (WRRC)
1639 Mail Service Center
Raleigh, NC 27699-1639
800-476-8686
Fax: 919-715-1612
http://wrrc.p2pays.org

Pollution Prevention Resource Exchange (P2Rx)
http://www.p2rx.org

Trade Associations

The Association of Iron and Steel Engineers (AISE)
Three Gateway Center, Suite 1900
Pittsburgh, PA 15222-1004
412-281-6323
Fax: 412-281-4657
http://www.aise.org/

American Iron and Steel Institute (AISI)
1101 17th Street, NW
Suite 1300
Washington, DC 20036
202-452-7100
http://www.steel.org/

American Machine Tool Distributors
Association (AMTDA)
1445 Research Blvd., #450
Rockville, MD 20850
301-738-1200
Fax: 301-738-9499
http://www.amtda.org/

American Welding Society
550 NW LeJeune Road
Miami, FL 33126
800-443-9353
Fax: 305-443-7559
http://www.amweld.org/

Association for Forming & Fabricating
Technologies of the Society of
Manufacturing Engineers (AFFT/SME)
http://www.sme.org/afft/

Association For Manufacturing Technology
(AMT)
7901 Westpark Drive
McLean VA 22102
703-893-2900
Fax: 703-893-1151
http://www.mfgtech.org

ASM International
9639 Kinsman Road
Materials Park, OH 44073-0002
440-338-5151
Fax: 440-338-4634
http://www.asm-intl.org/

Can Manufacturers Institute (CMI)
http://www.cancentral.com

Fabricators & Manufacturers Association,
International
833 Featherstone Road
Rockford, IL 61107-6302
815-399-8700
Fax: 815-484-7700
http://www.fmametalfab.org/

Forging Industry Association (FIA)
25 Prospect Avenue West, Suite 300
Cleveland, Ohio 44115
216-781-6260
Fax: 216-781-0102
http://www.forging.org/

Independent Lubricant Manufacturers
Association (ILMA)
651 S. Washington Street
Alexandria, VA 22314
703-684-5574
Fax: 703-836-8503
http://www.ilma.org

National Tooling & Machining Association
(NTMA)
9300 Livingston Road
Fort Washington, MD 20744-4998
800-248-6862
Fax: 301-248-7104
http://www.ntma.org/

Oregon Precision Metal
Fabricators Association
P.O. Box 1326
Tualatin, OR 97062
http://www.opmfa.org/

Machining Technology Association of the
Society of Manufacturing Engineers
http://www.sme.org/mta/

Precision Machined Products Association
(PMPA)
6700 West Snowville Road
Brecksville, OH 44141-3292
440-526-0300
Fax: 440-526-5803
http://www.pmpa.org/

Precision Metalforming Association (PMA)
6363 Oak Tree Blvd.
Independence, OH 44131-2500
216-901-8800
Fax: 216-901-9190
http://www.metalforming.com/
http://www.pma.org

Society of Manufacturing Engineers (SME)
One SME Drive
P.O. Box 930
Dearborn, MI 48121-0930
313-271-1500
Fax: 313-271-2861
http://www.sme.org

Society of Tribologists and Lubrication
Engineers (STLE)
840 Busse Highway
Park Ridge, IL 60068-2376
847-825-5536
Fax: 847-825-1456
http://www.stle.org

Tooling & Manufacturing Association
1177 S. Dee Road
Park Ridge, IL 60068
847-825-1120
Fax: 847-825-0041
http://www.tmanet.com

Tube & Pipe Association (TPA),
International
833 Featherstone Road
Rockford, IL 61107-6302
815-399-8700
Fax: 815-484-7700
http://www.tpatube.org

United States Cutting Tool Institute
216-241-7333
Fax: 216-241-0105
http://www.taol.com/uscti/

Research Institutions

Metalworking Fluid Product Stewardship
Group
http://www.mwfpsg.org/

Oak Ridge Centers for Manufacturing
Technology (ORCMT)
Post Office Box 2009
Bldg. 9737, MS 8091
Oak Ridge, TN 37831
1-800-356-4USA
http://orcmt.oakridge.org/

National Center for Excellence in
Metalworking Technology (NCEMT)
Johnstown, PA
http://www.ncemt.ctc.com

North American Manufacturing Research
Institution of the Society of Manufacturing
Engineers
http://www.sme.org/cgi-bin/new-gethtml.pl?/namri/nammemb.htm&GROUP&MEMBNUM&NAMRI&

Best Manufacturing Practices Center of
Excellence
4321 Hartwick Road, Suite 400
College Park, MD 20740
800-789-4267
Fax: 301-403-8180
http://www.bmpcoe.org/

Index