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Guides to Pollution Prevention

Metal Casting and Heat Treating Industry

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September 1992

Guides to Pollution Prevention

The Metal Casting and Heat Treating Industry

Risk Reduction Engineering Laboratory
and
Center for Environmental Research Information
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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NOTICE

This guide has been subjected to U.S. Environmental Protection Agency peer and administrative review and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is intended as advisory guidance only to the metal casting and heat treating industries in developing approaches for pollution prevention. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document.

Worksheets are provided for conducting waste minimization assessments of the metal casting and heat treating industries. Users are encouraged to duplicate portions of this publication as needed to implement a waste minimization program.

FOREWORD

This guide identifies and analyzes waste minimization techniques and technologies appropriate for the metal casting and heat treating industries. The guide focuses primarily on source reduction and secondarily on recycling methods.

The majority of waste generated by the metal casting or foundry industry is from melting operations, metal pouring, and disposal of spent molding materials. Generation of waste is directly related to the type of material melted and depends on the types of molds and cores used, as well as the technology employed. The majority of waste generated by the heat treating industry is from spent baths (e.g., cyanide solutions), spent quenchants, wastewater from cleaning parts, spent abrasive media, refractory material, and masking processes.

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Teresa Harten of the U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, was the project officer responsible for the preparation and review of this guide. Other contributors and reviewers include Red Clark, Ross Fuller, Wendy Barrott, James White, and Dieter S. Leidel of the Water Quality and Waste Disposal Committee of the American Foundrymen's Society, Inc.; Thomas Chase, President, Electric Heat Treating Co.; and Ben Fries, California Department of Health Services.

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SECTION 1
INTRODUCTION

This guide is designed to provide the metal casting and heat treating industry with waste minimization options. It also provides worksheets for carrying out waste minimization assessments for metal casting and heat treating plants. It is envisioned that this guide will be used by metal casting and heat treating companies, particularly their plant operators and environmental engineers. Others who may find this document useful are regulatory agency representatives, industry suppliers, and consultants.

In the following sections of this manual you will find:

- A profile of the metal casting and heat treating industry and the processes used in it (Section 2)
- Waste minimization options for the industry (Section 3)
- Waste minimization assessment guidelines and worksheets (Section 4)
- Appendices, containing
  - — Case studies of waste generation and waste minimization practices in the industry
  - — Where to get help: additional sources of information.

The worksheets and the list of waste minimization options were developed from assessments of firms in Southern California commissioned by the California Department of Health Services (DHS 1990). Operations, manufacturing processes, and waste generation and management practices were surveyed, and existing and potential waste minimization options were characterized.

Overview of Waste Minimization

Waste minimization is a policy specifically mandated by the U.S. Congress in the 1984 Hazardous and Solid Wastes Amendments to the Resource Conservation and Recovery Act (RCRA). As the federal agency responsible for writing regulations under RCRA, the U.S. Environmental Protection Agency (EPA) has an interest in ensuring that new methods and approaches are developed for minimizing hazardous waste and that such information is made available to the industries concerned. This guide is one of the approaches EPA is using to provide industry-specific information about hazardous waste minimization. The options and procedures outlined can also be used in efforts to minimize other wastes generated in a business, including air emissions, wastewater discharges, and solid waste.

In the working definition used by EPA, waste minimization consists of source reduction and recycling. Of the two approaches, source reduction is preferable to recycling. While a few states consider treatment of waste an approach to waste minimization, EPA does not, and thus treatment is not addressed in this guide.

Waste Minimization Opportunity Assessment

EPA has developed a general manual for waste minimization in industry. The *Waste Minimization Opportunity Assessment Manual* (USEPA 1988) tells how to conduct a waste minimization assessment and develop options for reducing hazardous waste generation at a facility. It explains the management strategies needed to incorporate waste minimization into company policies and structure, how to establish a company-wide waste minimization program, conduct assessments, implement options, and make the program an ongoing one.

In 1992, EPA published the *Facility Pollution Prevention Guide* (USEPA 1992) as a successor to the *Waste Minimization Opportunity Assessment Manual.* While the *Waste Minimization Opportunity Assessment Manual* concentrated primarily on the waste types covered in the Resource Conservation and Recovery Act (RCRA), the *Facility Pollution Prevention Guide* deals with "multimedia" pollution prevention. It is

intended to help small- to medium-sized production facilities develop broad-based, multimedia pollution prevention programs. Methods of evaluating, adjusting, and maintaining the program are described. Later chapters deal with cost analysis for pollution prevention projects and with the roles of product design and energy conservation in pollution prevention. Appendices consist of materials that will support the pollution prevention effort: assessment worksheets, sources of additional information, examples of evaluative methods, and a glossary.

A Waste Minimization Opportunity Assessment (WMOA), sometimes called a waste minimization audit, is a systematic procedure for identifying ways to reduce or eliminate waste. The four phases of a waste minimization opportunity assessment are planning and organization, assessment, feasibility analysis, and implementation. The steps involved in conducting a waste minimization assessment are outlined in Figure 1 and presented in more detail below. Briefly, the assessment consists of a careful review of a plant's operations and waste streams and the selection of specific areas to assess. After a particular waste stream or area is established as the WMOA focus, a number of options with the potential to minimize waste are developed and screened. The technical and economic feasibility of the selected options are then evaluated. Finally, the most promising options are selected for implementation. The following sections describe these steps in more detail.

PLANNING AND ORGANIZATION PHASE

Essential elements of planning and organization for a waste minimization program are: getting management commitment for the program, setting waste minimization goals, and organizing an assessment program task force.

ASSESSMENT PHASE

The assessment phase involves a number of steps:

- Collect process and facility data
- Prioritize and select assessment targets
- Select assessment team
- Review data and inspect site
- Generate options
- Screen and select options for feasibility study.

Collect Process and Site Data

The waste streams at a facility should be identified and characterized. Information about waste streams may be available on hazardous waste manifests, National Pollutant Discharge Elimination System (NPDES) reports, Toxic Release Inventory reports, routine sampling programs, and other sources.

Developing a basic understanding of the processes that generate waste at a facility is essential to the WMOA process. Flow diagrams should be prepared to identify the quantity, types, and rates of waste generating processes. Also, preparing material balances for the different processes can be useful in tracking various process components and identifying losses or emissions that may have been unaccounted for previously.

Prioritize and Select Assessment Targets

Ideally, all waste streams in a facility should be evaluated for potential waste minimization opportunities. If resources are limited, however, the plant manager may need to concentrate waste minimization efforts in a specific area. Such considerations as quantity of waste, hazardous properties of the waste, regulations, safety of employees, economics, and other characteristics need to be evaluated in selecting target streams or operations.

Select Assessment Team

The team should include people with direct responsibility for and knowledge of the particular waste stream or area of the facility being assessed. Equipment operators and people involved in routine waste management should not be ignored.

Review Data and Inspect Site

The assessment team evaluates process data in advance of the inspection. The inspection should follow the target process from the point where raw materials enter to the point where products and wastes leave. The team should identify the suspected sources of waste. This may include the production processes;

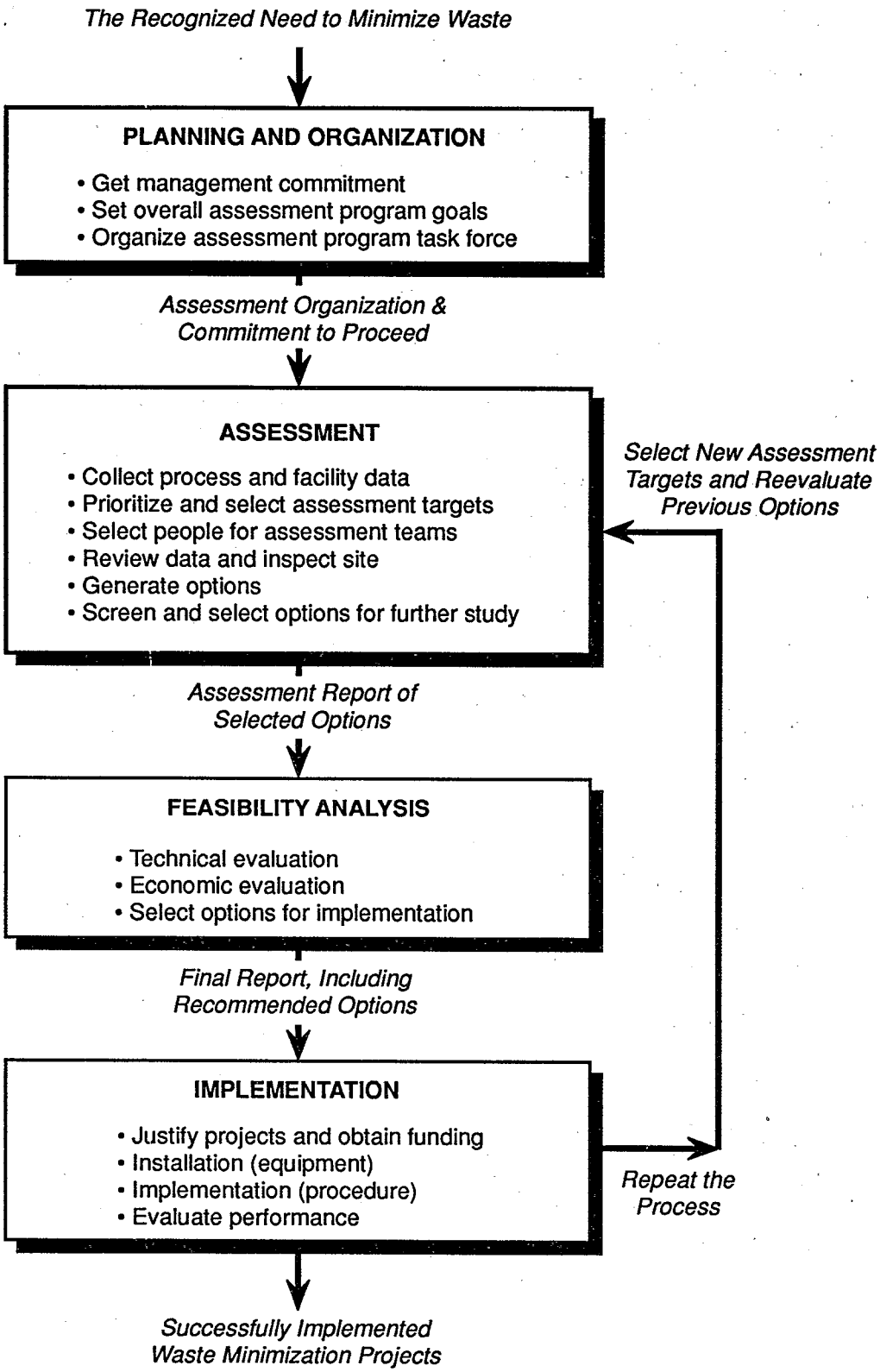

Figure 1. The Waste Minimization Assessment Procedure

maintenance operations; and storage areas for raw materials, finished products, and work in progress. The inspection may result in the formation of preliminary conclusions about waste minimization opportunities. Full confirmation of these conclusions may require additional data collection, analysis, and/or site visits.

Generate Options

The objective of this step is to generate a comprehensive set of waste minimization options for further consideration. Since technical and economic concerns will be considered in the later feasibility step, no options are ruled out at this time. Information from the site inspection, as well as from trade associations, government agencies, technical and trade reports, equipment vendors, consultants, plant engineers, and operators may serve as sources of ideas for waste minimization options.

Both source reduction and recycling options should be considered. Source reduction may be accomplished through good operating practices, technology changes, input material changes, and product changes. Recycling includes use and reuse of water, solvents, and other recyclable materials, where appropriate.

Screen and Select Options for Further Study

This screening process is intended to select the most promising options for a full technical and economic feasibility study. Through either an informal review or a quantitative decision-making process, options that appear marginal, impractical, or inferior are eliminated from further consideration.

FEASIBILITY ANALYSIS PHASE

An option must be shown to be technically and economically feasible in order to merit serious consideration for adoption at a facility. A technical evaluation determines whether a proposed option will work in a specific application. Both process and equipment changes need to be assessed for their overall effects on waste quantity and product quality.

An economic evaluation is carried out using standard measures of profitability, such as payback period, return on investment, and net present value. As in any project, the cost elements of a waste minimization project can be broken down into capital costs and operating costs. Savings and changes in revenue and waste disposal costs also need to be considered, as do present and future cost avoidances. In cases of increasingly stringent government requirements, actions that increase the cost of production may be necessary.

IMPLEMENTATION PHASE

An option that passes both technical and economic feasibility reviews should be implemented. The project can be turned over to the appropriate group for execution while the WMOA team, with management support, continues the process of tracking wastes and identifying other opportunities for waste minimization. Periodic reassessments may be conducted to see if the anticipated waste reductions were achieved. Data can be tracked and reported for each implemented idea in terms such as pounds of waste per production unit. Either initial investigations of waste minimization opportunities or the reassessments can be conducted using the worksheets in this manual.

References

DHS. 1990. *Waste Audit Study: Thermal Metal Working Industry*. Prepared by Jacobs Engineering Group for Alternative Technology Section, Toxic Substances Control Division, California Department of Health Services.

USEPA. 1992. *Facility Pollution Prevention Guide.* U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., EPA/600/R-92/088.

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SECTION 2
METAL CASTING AND HEAT TREATING INDUSTRY PROFILES

Industry Description

The Standard Industrial Classification (SIC) system categorizes the metal casting and heat treating industries as foundries, casting (SIC 332X, 336X), and metal heat treating (SIC 3398).

This document treats the metal casting and heat treating industries as distinct from other thermally intensive metal industries such as SIC 3312 (steel works, blast furnaces, coke ovens, and rolling mills), SIC 333X (primary/secondary smelting or refining of nonferrous metals), SIC 335X (rolling, drawing, extrusion), and SIC 346X (forging and stamping).

Metal Casting Industry

Metal casting foundries range in size from small job shops to large manufacturing plants that turn out thousands of tons of castings each day. Generation of waste is directly related to the type of material melted (cast iron, steel, brass/bronze, or aluminum) and depends on the type of molds and cores used, as well as the technology employed. Wastes from sand casting operations are inherently greater than those from permanent mold or die casting foundry operations. Therefore, this guide focuses on sand foundries. Table 1 lists the waste generated as a result of metal casting processes.

Table 1. Waste Generating Processes—Metal Casting

Process	Waste
Molding and Coremaking	Spent system sand Sweepings, core butts Dust and sludge
Melting	Dust and fumes Slag
Casting	Investment casting Shells and waxes
Cleaning	Cleaning room waste

PROCESS DESCRIPTION

The sand casting process (Figure 2) begins with patternmaking. A pattern is a specially made model of a component to be produced. Sand is placed around the pattern to make a mold. Molds are usually produced in two halves so that the pattern can be easily removed. When the two halves are reassembled, a cavity remains inside the mold in the shape of the pattern.

Cores are made of sand and a binder and must be strong enough to be inserted into a mold. Cores shape the interior surfaces of a casting that cannot be shaped by the mold cavity surface. The patternmaker supplies core boxes which are filled with specially bonded sand for producing precisely dimensioned cores. Cores are placed in the mold, and the mold is closed. Molten metal is then poured into the mold cavity, where it is allowed to solidify within the space defined by the sand mold and cores.

Molding and Core Making

The molds used in sand casting consist of a particulate refractory material (sand) that is bonded together to hold its shape during pouring. The most common type of molding process is green sand molding. Green sand is typically composed of sand, clay, carbonaceous material, and water. Sand constitutes 85 to 95 percent of the green sand mixture. Often the sand is silica, but olivine and zircon are also used. Approximately 4 to 10 percent of the mixture is clay. The clay acts as a binder, providing strength and plasticity. Carbonaceous materials may make up 2 to 10 percent of the green sand mixture. Carbonaceous materials are added to the mold to provide a reducing atmosphere and a gas film during pouring that protects against oxidation of the metal. Some of the more common carbonaceous materials include sea coal (a finely ground bituminous coal), and proprietary petroleum products. Other carbonaceous materials such as cereal (ground corn starch) and cellulose (wood flour)

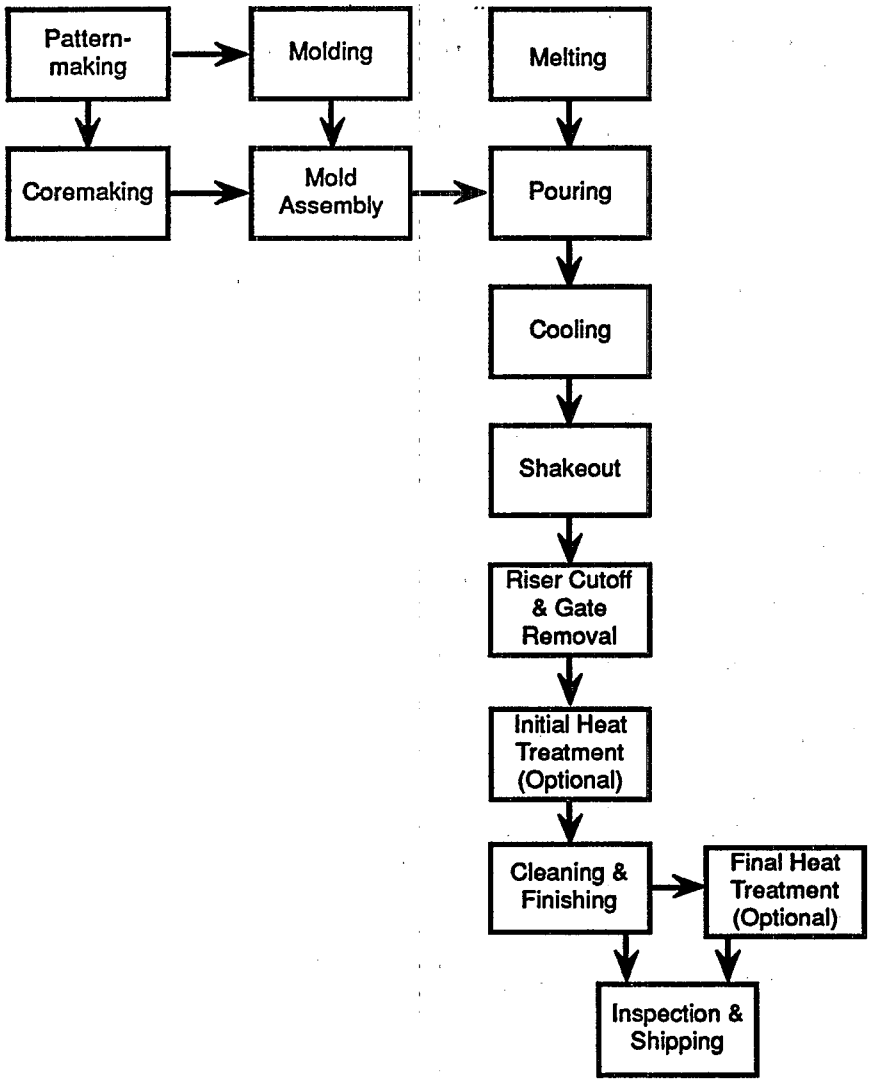


Figure 2. Simplified Flow Diagram of the Basic Operations for Producing a Steel Casting

may be added to control sand expansion defects. Water activates the clay binder and is usually added in small percentages (2 to 5 percent).

Core sands composed of mixtures of sand, with small percentages of binder, are used to produce internal cavities within a casting. Cores must be strong, hard, and collapsible. Often the cores must be removed within a casting through a small orifice and, therefore, the sand must collapse after the casting solidifies.

Core sand is typically silica. Olivine and zircon have also been used when specifications require core sands with higher fusion points or densities. Binder materials to hold the individual grains of sand together vary considerably in composition and binding properties. Oil binders and synthetic binders are common. Oil binders are combinations of vegetable or animal oils and petrochemicals. Typical synthetic resin binders include phenolics, phenolformaldehyde, urea-formaldehyde, urea-formaldehyde/furfuryl alcohol, phenolic-isocyanate, and alkyd isocyanate.

Chemical resin binders are frequently used for foundry cores and less extensively for foundry molds. Chemical binders provide increased productivity, improved dimensional control, and better casting surface quality. A wide variety of binders are available, including:

- Furan acid catalyzed no-bake binders. Furfuryl alcohol is the basic raw material. The binders can be modified with urea, formaldehyde, and phenol. Phosphoric or sulfonic acids are used as catalysts. The amount of resin ranges between 0.9 to 2.0 wt% based on sand weight. Acid catalyst levels vary between 20 to 50 percent based on the weight of binder.

- Phenolic acid catalyzed no-bake binders. These are formed in a phenol/formaldehyde condensation reaction. Strong sulfonic acids are used as catalysts.

- Ester-cured alkaline phenolic no-bake binders. These are formed with a two-part binder system consisting of a water-soluble alkaline phenolic resin and liquid ester co-reactants. Typically 1.5 to 2.0 percent binder based on sand weight and 20 to 25 percent co-reactant based on the resin are used to coat washed and dried silica sand in core and molding operations.

- Silicate/ester-catalyzed no-bake binders. Sodium silicate binder and a liquid organic ester (glycerol diacetate and triacetate or ethylene glycol diacetate) that functions as a hardening agent are used. They may also be catalyzed with CO_2.

- Oil urethane no-bake resins. These resins consist of an alkyd oil type resin, a liquid amine/metallic catalyst, and a polymeric methyl di-isocyanate.

- Phenolic urethane no-bake (PUN) binder.

- Polyol-isocyanate system (mainly for aluminum, magnesium, and other light-alloy foundries). The nonferrous binders are similar to a PUN system consisting of Part I (a phenol formaldehyde resin dissolved in a special blend of solvents), Part II (a polymeric MDI-type isocyanate in solvents), and Part III (an amine catalyst).

- Alumina-phosphate no-bake binder. This binder consists of an acidic, water soluble alumina-phosphate liquid binder and a free-flowing powdered metal oxide hardener.

- Novolac shell-molding binders. Novolac resins of phenol-formaldehyde and lubricant (calcium stearate in the quantity of 4 to 6 percent of resin weight) are used as a cross-linking agent.

- Hot box binders. The resins are classified as furan or phenolic types. The furan types contain furfuryl alcohol, the phenolic types are based on phenol, and the furan-modified has both. Both chloride and nitrate catalysts are used. The binders contain urea and formaldehyde.

- Warm box binders. These consist of a furfuryl alcohol resin that is formulated for a nitrogen content less than 2.5 percent. Copper salts of aromatic sulfonic acids in an aqueous methanol solution are used as catalyst.

Precision foundries often use the investment casting (or the lost-wax) process to make molds. In this process molds are made by building up a shell comprised of alternating layers of refractory slurries and stuccos, such as fused silica, around a wax pattern. The ceramic shells are fired to remove the wax pattern and to preheat the shells for pouring.

Another sand molding process that is finding commercial acceptance uses a polystyrene foam pattern imbedded in loose unbonded traditional sand. The foam pattern left in the sand mold is decomposed by molten metal, hence the process is called "evaporative pattern casting" or the "lost foam process."

Melting

The metal casting process begins with melting metal to pour into foundry molds. Cupola, electric arc, induction, hearth (reverberatory), and crucible furnaces are all used to melt metal.

The cupola furnace (patented in 1794) is the oldest type of furnace used in the metal casting industry and is still used for producing cast iron. It is a fixed bed cylindrical shaft furnace, in which alternate layers of metal scrap and ferroalloys, together with foundry

coke and limestone or dolomite, are charged at the top. The metal is melted by direct contact with a counter-current flow of hot gases from the coke combustion. Molten metal collects in the well, where it is discharged by intermittent tapping or by continuous flow. Conventional cupola furnaces are lined with refractory to protect the shell against abrasion, heat, and oxidation. Lining thickness ranges from 4.5 to 12 inches. The most commonly used lining is fireclay brick, or block. As the heat progresses, the refractory lining in the melting zone is progressively fluxed away by the high temperature and oxidizing atmosphere and becomes part of the furnace slag.

A cupola furnace is usually equipped with an emission control system. The two most common types of emission collection are the high-energy wet scrubber and the dry baghouse. High-quality foundry grade coke is used as a fuel source. The amount of coke in the charge usually falls within a range of 8 to 16 percent of the metal charge. Coke burning is intensified by blowing oxygen enriched air through nozzles.

Electric arc furnaces are used primarily by large steel foundries and steel mills. Heat is supplied by an electrical arc established from three carbon or graphite electrodes. The furnace is lined with refractories that deteriorate during the melting process, thereby generating slag. Protective slag layers are formed in the furnace by intentional addition of silica and lime. Fluxes such as calcium fluoride may be added to make the slag more fluid and easier to remove from the melt. The slag protects the molten metal from the air and extracts certain impurities. The slag removed from the melt may be hazardous depending on the alloys being melted.

Metal scrap, shop returns (such as risers, gates, and casting scrap), a carbon raiser (or carbon rich scrap), and lime or limestone are added to the furnace charge. Fume and dust collection equipment controls air emissions from the electric arc furnace.

Induction furnaces have gradually become the most widely used furnaces for melting iron and, increasingly, for nonferrous alloys. These furnaces have excellent metallurgical control and are relatively pollution free. Induction furnaces are available in capacities from a few pounds to 75 tons. Coreless induction furnaces are more typically in the range of 5 tons to 10 tons. In a coreless furnace, the refractory-lined crucible is completely surrounded by a water-cooled copper coil. In channel furnaces, the coil surrounds an inductor. Some large channel units have a capacity of over 200 tons. Channel induction furnaces are commonly used as holding furnaces.

Induction furnaces are alternating current electric furnaces. The primary conductor is a coil, which generates a secondary current by electromagnetic induction. Silica (SiO_2), which is classified as an acid; alumina (Al_2O_3), classified as neutral; and magnesia (MgO), classified as a basic material, are typically used as refractories. Silica is often used in iron melting because of its low cost and because it does not readily react with the acid slag produced when melting high silicon cast iron.

Reverberatory (hearth) and crucible furnaces are widely used for batch melting of nonferrous metals such as aluminum, copper, zinc, and magnesium. In a crucible furnace, the molten metal is contained in a pot-shaped shell (crucible). Electric heaters or fuel-fired burners outside the shell generate the heat that passes through the shell to the molten metal. In many metal-melting operations, slag or dross builds up at the metal surface line, and heavy unmelted slush residue collects on the bottom. Both of these residues shorten crucible life and must be removed and either recycled or managed as waste.

Casting

Once the molten metal has been treated to achieve the desired properties, it is transfered to the pouring area in refractory-lined ladles. Slag is removed from the bath surface and the metal is poured into molds. When the poured metal has solidified and cooled, the casting is shaken out of the mold, and the risers and gates are removed. Fumes or smoke from the metal pouring area are typically exhausted to a dust collection device such as a baghouse.

Cleaning

After cooling, risers and runners are removed from the casting using bandsaws, abrasive cut-off wheels, or arc cut-off devices. Parting line flash is removed with chipping hammers. Contouring of the cut-off areas and parting line is done with grinders. Castings may be weld-repaired to eliminate defects.

After mechanical cleaning, the metal casting is blast cleaned to remove casting sand, metal flash, or oxide. In blast cleaning, abrasive particles, usually steel shot or grit, are propelled at high velocity onto the casting surface to remove surface contaminants. For aluminum castings, the process provides a uniform cosmetic finish, in addition to cleaning the workpiece.

High-carbon steel shot is typically used to clean ferrous castings; sometimes a shot and grit mixture is used. In the past, chilled iron grit and malleable abrasives were used. Aluminum castings are sandblasted typically using an abrasion-resistant sand or crushed slag.

Cast components that require special surface characteristics (such as resistance to deterioration or an appealing appearance) may be coated. Chemical cleaning and coating operations may be performed at the foundry, but often are performed off site at firms specializing in coating operations. The most important prerequisite of any coating process is cleaning the surface. The choice of cleaning process depends not only on the types of soil to be removed, but also on the characteristics of the masking to be applied; typical coating operations include electroplating, hardfacing, hot dipping, thermal spraying, diffusion, conversion, porcelain enameling, and organic or fused dry-resin coating. The cleaning process must leave the surface in a condition that is compatible with the coating process. For example, if a casting is to be treated with phosphate and then painted, all oil and oxide scale must be removed because these inhibit good phosphating. If castings are heat treated before they are coated, the choice of heat treatment conditions can influence the properties of the coating, particularly a metallic or conversion coating. In most cases, castings should be heat treated in an atmosphere that is not oxidizing.

Molten salt baths, pickling acids, alkaline solutions, organic solvents, and emulsifiers are the basic materials used in cleaning operations. Molten salt baths may be used to clean complex interior passages in castings. In one electrolytic, molten salt cleaning process, the electrode potential is changed so that the salt bath is alternately oxidizing and reducing. Scale and graphite are easily removed with reducing and oxidizing baths, respectively. Molten salt baths clean faster than other nonmechanical methods, but castings may crack if they are still hot when salt residues are rinsed off with water.

Parts are usually pickled in an acid bath prior to hot dip coating or electroplating. Overpickling should be avoided because a graphite smudge can form on the surface. Because cast iron contains silicon, a film of silica also can form on the surface as a result of heavy pickling. This film can be avoided by adding hydrofluoric acid to the pickling bath.

Chemical cleaning differs from pickling in that chemical cleaners attack only the surface contaminants, not the iron substrate. Many chemical cleaners are proprietary formulations; but, in general, they are alkaline solutions, organic solvents, or emulsifiers. Alkaline cleaners must penetrate contaminants and wet the surface to be effective. Organic solvents commonly used in the past (naphtha, benzene, methanol, toluene, and carbon tetrachloride) have been largely replaced by chlorinated solvents, such as those used for vapor degreasing. Solvents effectively remove lubricants, cutting oils, and coolants; but are ineffective against oxides or salts. Emulsifiers are solvents combined with surfactants; they disperse contaminants and solids by emulsification. Emulsion cleaners are most effective against heavy oils, greases, sludges, and solids entrained in hydrocarbon films. They are relatively ineffective against adherent solids such as oxide scale.

After wet cleaning, an alkaline rinse is used on casting to prevent short-term rust. This can be followed by treatment with mineral oils, solvents combined with inhibitors and film formers, emulsions of petroleum-base coatings and water, and waxes.

Coating

Castings are coated using plating solutions, molten metal baths, alloys, powdered metals, volatilized metal or metal salt, phosphate coatings, porcelain enamels, and organic coatings.

WASTE DESCRIPTION

Product castings manufactured by foundries generate the following wastes:

- Spent system sand from molding and core making operations and used core sand not returned to the system sand (sweepings, core butts)
- Investment casting shells and waxes
- Cleaning room waste
- Dust collector and scrubber waste
- Slag
- Miscellaneous waste.

Spent Foundry Sand

Most foundries reuse some portion of their core making and molding sand; in many cases most of the sand is reused. Green sand is reused repeatedly. Fines build up as sands are reused, and a certain amount of system sand must be removed regularly to maintain the desired sand properties. The removed sand, combined with the sand lost to spills and shakeout, becomes the waste sand. Figure 3 illustrates the primary sources of waste sand.

Dust and sludge produced from molding sand are often collected as part of an air pollution control system located over the molding and shakeout operations. Waste can also be in the form of large clumps that are screened out of the molding sand recycle system or in the form of sand that has been cleaned from the castings.

Core sand binders either partially or completely degrade when exposed to the heat of the molten metal during the pouring operation. Once loose, sand that has had its binder fully degraded is often mixed with molding sand for recycling or is recycled back into the core sand process. Core butts are partially decomposed core sand removed during shakeout. They contain only partially degraded binder. The core butts can be crushed and recycled into the molding sand process, or may be taken to a landfill along with broken or offspec cores and core room sweepings. Molding sand and core sand waste accounts for 66 to 88 percent of the total waste generated by ferrous foundries.

Brass or bronze foundries may generate hazardous waste sand contaminated with lead, copper, nickel, and zinc, often in high total and extractable concentrations. Some core-making processes use strongly acidic or basic substances for scrubbing the offgases from the core making process. In the free radical cure process, acrylic-epoxy binders are cured using an organic hydroperoxide and SO_2 gas. A wet scrubbing unit absorbs the SO_2 gas. A 5 to 10 percent solution of sodium hydroxide at a pH of 8 to 14 neutralizes the SO_2 and prevents the by-product (sodium sulfite) from precipitating out of solution. Usually, pH controlled sludges are discharged to the sewer system as nonhazardous waste. If not properly treated, the waste may be classified as hazardous corrosive waste.

Investment Casting Waste

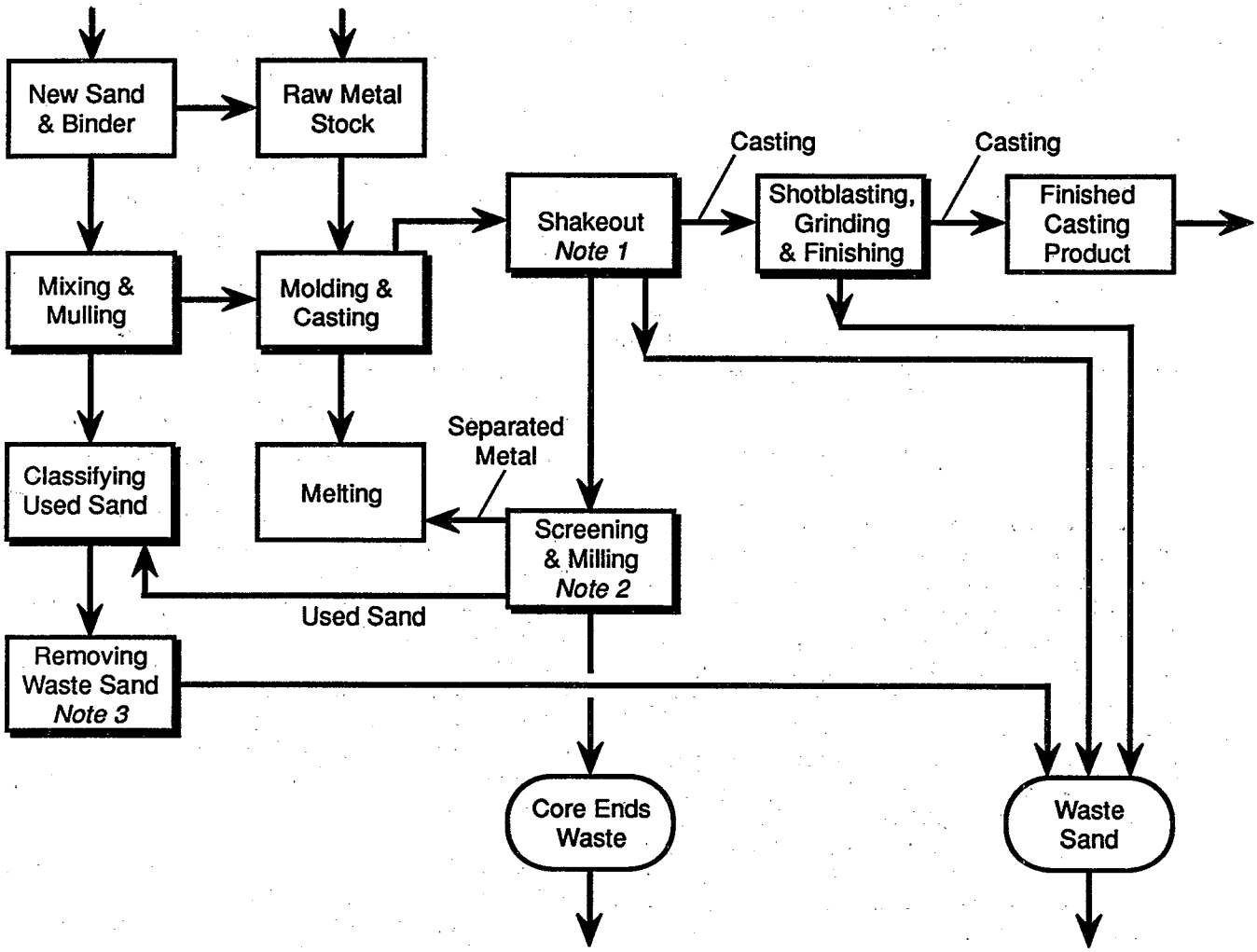
Investment casting shells can be used only once and are disposed in landfills as a nonhazardous waste unless condensates from heavy metal alloy constituents are present in the shells. Waxes that are removed from the casting shells can be recycled back into wax sprues and runners for further reuse or can be sent to a wax recycling operation for recovery.

Cleaning Room Waste

Cleaning room waste that is ultimately disposed in a landfill includes used grinding wheels, spent shot, floor sweepings, and dust from the cleaning room dust collectors. This waste may be hazardous if it contains excessive levels of toxic heavy metals.

Dust Collector and Scrubber Waste

During the melting process, a small percentage of each charge is converted to dust or fumes collected by baghouses or wet scrubbers. In steel foundries, this dust contains varying amounts of zinc, lead, nickel, cadmium, and chromium. Carbon-steel dust tends to be high in zinc and lead as a result of the use of galvanized scrap, while stainless steel dust is high in nickel and chromium. Dust associated with nonferrous metal production may contain copper, aluminum, lead, tin, and zinc. Steel dust may be encapsulated and disposed of in a permitted landfill, while



Note 1 Removing the molding sand from the casting
Note 2 Breaking up large chunks and separating metal pieces
Note 3 Accommodating the new sand and binder

Figure 3. Primary Sources of Waste Sand

nonferrous dust is often sent to a recycler for recovery of metal.

Slag Waste

Slag is a fairly complex, relatively inert glassy mass with a complex chemical structure. It is composed of metal oxides from the melting process, melted refractories, sand, coke ash (if coke is used), and other materials. Slag may be conditioned by fluxes to facilitate removal from the furnace.

Hazardous slag may be produced in melting operations if the charge materials contain significant amounts of toxic metal such as lead, cadmium, and chromium.

To reduce the sulfur content of iron, some foundries use calcium carbide desulfurization in the production of ductile iron. The calcium carbide desulfurization slag generated by this process may be classified as a reactive waste.

Miscellaneous Waste

Most foundries generate miscellaneous waste that varies greatly in composition, but makes up only a small percentage of the total waste. This waste includes welding materials, waste oil from forklifts and hydraulics, empty drums of binder, and scrubber lime.

Heat Treating Industry

Heat treating refers to the heating and cooling operations performed on metal workpieces to change their mechanical properties, their metallurgical structure, or their residual stress state. Heat treating includes stress-relief treating, normalizing, annealing, austenitizing, hardening, quenching, tempering, martempering, austempering, and cold treating. Annealing, as an example, involves heating a metallic material to, and holding it at, a suitable temperature, followed by furnace cooling at an appropriate rate. Steel castings may be annealed to facilitate cold working or machining, to improve mechanical or electrical properties, or to promote dimensional stability. Gray iron castings may be annealed to soften them or to minimize or eliminate massive eutectic carbides, thus improving their machinability.

PROCESS DESCRIPTION

Heating, quenching, descaling, cleaning, and masking operations generate most of the waste in the heat treating industry. Table 2 lists the waste generating processes and waste characteristics.

Heat Treating Other Than Case Hardening

Heat treating is performed in conventional furnaces, salt baths, or fluidized-bed furnaces. The basic conventional furnace consists of an insulated chamber with an external reinforced steel shell, a heating system for the chamber, and one or more access doors to the heated chamber. Heating systems are direct fired or indirect heated. With direct-fired furnace equipment, work being processed is directly exposed to the products of combustion, generally referred to as flue products. Gas- and oil-fired furnaces are the most common types of heat treating equipment. Indirect heating is performed in electrically heated furnaces and radiant-tube-heated furnaces with gas-fired tubes, oil-fired tubes, or electrically heated tubes. The heating operations (e.g., stress-relief, normalizing, annealing, austenitizing, tempering, martempering, and austempering) do not generate hazardous waste. Refractory materials (furnace lining) are the only wastes generated, and they are disposed of as nonhazardous waste.

Table 2. Waste Generating Processes—Heat Treating

Process	Waste
Heat Treating	Refractory material
Case Hardening	Spent salt baths
Quenching	Spent quenchants
Descaling	Spent abrasive media
Cleaning and Masking	Solvents, abrasives Copper plating waste

To obtain better thermal control and more rapid heating rates, salt bath furnaces are commonly used. Salt bath furnaces consist of pots of molten salt heated by direct resistance methods (an electric current is passed through the salt) or by indirect fossil fuel or electric resistance methods (the pot is placed within a furnace-like enclosure).

In the fluidized-bed furnace, gas is passed up through a bed of dry, finely divided particles, typically aluminum oxide. The turbulent motion and rapid circulation of the particles in the furnace provide heat-transfer rates comparable to those of conventional salt-bath equipment. The parts to be treated are submerged in a bed of fine solid particles held in suspension by an upward flow of gas. Heat input to a fluidized bed can be achieved using:

- Internal-resistance-heated beds: the gas and particles are heated by suitably sheathed internal-resistance heated elements

- External-resistance heated beds: a fluidized bed contained in a heat-resisting pot is heated by external resistance elements

- Direct-resistance heated beds: an electrically conducting material such as carbon powder or silicon carbide is employed as the bed material

- External-combustion heated beds: a fluidized bed, contained in a heat-resisting pot, is heated by external gas firing

- Submerged-combustion fluidized beds: the combustion products pass directly through the mass to be heated

- Internal-combustion gas-fired beds: an air/gas mixture is used for fluidization and ignited in the bed, generating heat by internal combustion.

Drag-out loss of the fluidized-bed particles that are removed by agitating, bouncing, and gas blowing can be minimized by water spraying. Recovered particles can then be reused after being dried, sieved, and returned to the bed.

Case Hardening

Case hardening processes supply an adequate quantity of carbon or nitrogen for absorption and diffusion into the steel. These processes are carried out in either gas-phase furnaces or in salt-bath furnaces that are similar to the furnaces used for other heat treating processes. Case hardening performed in liquid media is the major source of waste.

These baths are used in liquid carburizing, liquid cyaniding (carbonitriding), and liquid nitriding processes that are classified as steel case hardening processes. Table 3 shows the operating composition of liquid carburizing baths. Low-temperature cyanide-type carburizing baths (light case baths) usually are operated in the temperature range of 845 to 900C (1550 to 1650F), although for certain effects this operating range sometimes is extended to 790 to 925C (1450 to 1700F). High-temperature cyanide-type carburizing baths (deep case baths) usually are operated in the temperature range of 900 to 955C (1650 to 1750F). Liquid cyaniding (carbonitriding) baths typically are operated at temperatures of 815 to 850C (1500 to 1560F). The composition of both low-temperature and high-temperature baths is provided to satisfy individual requirements for carburizing activity (carbon potential) within the limitations of manual drag-out and replenishment.

Table 4 shows the compositions and properties of sodium cyanide mixtures used in liquid cyaniding processes that produce a file-hard, wear-resistant surface on ferrous parts. A sodium cyanide mixture such as grade 30 in Table 4, is generally used for cyaniding on a production basis. This mixture is preferable to any of the other compositions given in Table 4. The inert salts of sodium chloride and sodium carbonate are added to cyanide to provide fluidity and to control the melting points of all mixtures.

Liquid nitriding is performed in a molten salt bath composed of a typical mixture of sodium and potassium salts. The sodium salts, which comprise 60 to 70 percent (by weight) of the total mixture, consist of 96.5 percent NaCN, 2.5 percent Na_2CO_3, and 0.5 percent NaCNO. The potassium salts, 30 to 40 percent (by weight) of the mixture, consist of 96 percent KCN, 0.6 percent K_2CO_3, 0.75 percent KCNO, and 0.5 percent KCl. The cyanate content in all liquid nitriding baths is responsible for the nitriding action, and the ratio of cyanide to cyanate is critical.

Cyanide-containing baths used in liquid carburizing, liquid cyaniding, and liquid nitriding processes undergo an aging process that generates undesirable products of oxidation. Aging decreases the cyanide content of the bath and increases the cyanate and carbonate content. In a low-temperature cyanide-type bath, several reactions occur simultaneously, depending on bath composition, to produce the following various end products and intermediates: carbon (C), alkali carbonate (Na_2CO_3 or K_2CO_3), nitrogen (N_2 or 2N), carbon monoxide (CO), carbon dioxide (CO_2), cyanamide (Na_2CN_2 or $BaCN_2$), and cyanate (NaNCO). Two of the major reactions believed to occur in the operating bath are the "cyanamide shift" and the formation of cyanate:

$$2\ NaCN \leftrightarrow Na_2CN_2 + C \qquad (1)$$

and either

$$2\ NaCN + O_2 \rightarrow NaNCO \qquad (2)$$

or

$$NaCN + CO_2 \leftrightarrow NaNCO + CO \qquad (3)$$

Table 3. Operating Composition of Liquid Carburizing Baths

Constituent	Composition of Bath, %	
	Light Case, Low Temperature 845 to 900°C (1550 to 1650°F)	Deep Case, High Temperature 900 to 955°C (1650 to 1750°F)
Sodium cyanide	10 to 23	6 to 16
Barium chloride	—	30 to 55[a]
Salts of other alkaline earth metals[b]	0 to 10	0 to 10
Potassium chloride	0 to 25	0 to 20
Sodium chloride	20 to 40	0 to 20
Sodium carbonate	30 max	30 max
Accelerators other than those involving compounds of alkaline earth metals[c]	0 to 5	0 to 2
Sodium cyanate	1.0 max	0.5 max
Density of molten salt	1760 kg/m^3 at 900°C (110 lb/ft^3 at 1650°F)	2000 kg/m^3 at 925°C (125 lb/ft^3 at 1700°F)

(a) Proprietary barium chloride-free deep-case baths are available.
(b) Calcium and strontium chlorides have been employed. Calcium chloride is more effective, but its hygroscopic nature has limited its use.
(c) Among these accelerators are manganese dioxide, boron oxide, sodium fluoride, and sodium pyrophosphate.

Table 4. Compositions and Properties of Sodium Cyanide Mixtures for Cyaniding Baths

Constituent or Property	Grade			
	96-98[a]	75[b]	45[b]	30[b]
Composition, %				
Sodium cyanide	97	75	45.3	30.0
Sodium carbonate	2.3	3.5	37.0	40.0
Sodium chloride	Trace	21.5	17.7	30.0
Melting point, °C (°F)	560 (1040)	590 (1095)	570 (1060)	625 (1155)
Specific gravity				
At 25°C (75°F)	1.50	1.60	1.80	2.09
At 860°C (1580°F)	1.10	1.25	1.40	1.54

(a) Appearance: white crystalline solid. This grade also contains 0.5% sodium cyanate (NaNCO) and 0.2% sodium hydroxide (NaOH); sodium sulfide (Na_2S) content is nil.
(b) Appearance: white granular mixture.

Reactions that influence cyanate content proceed as follows:

$$NaNCO + C \rightarrow NaCN + CO \quad (4)$$

and either

$$4\ NaNCO + 2\ O_2 \rightarrow 2\ Na_2CO_3 + 2\ CO + 4\ N \quad (5)$$

or

$$4\ NaNCO + 4\ CO_2 \rightarrow 2\ Na_2CO_3 + 6\ CO + 4\ N \quad (6)$$

Reactions (5) and (6) deplete the activity of the bath. Oxidation products in the bath media promote unfavorable temperature gradients. In liquid nitriding, the carbonate content is kept below 25 percent. Carbonate content is usually lowered by cooling the bath to 850°F and allowing precipitated salt to settle to the bottom of the salt pot. Another contaminant that forms in the bath is a complex sodium ferrocyanide $Na_4Fe(CN)_6$ that is removed by holding the bath at 649°C for about two hours to settle out the compound in the form of sludge.

The salt baths in liquid carburizing, liquid nitriding, and liquid cyaniding processes are considered hazardous when spent. Typical baths contain molten sodium, potassium cyanide, and cyanate salts. In liquid carburizing, nitriding, and cyaniding, the parts are held at an appropriate high temperature in a molten salt. In carburizing processes, after the workpiece is heat treated, it undergoes quenching for the purpose of hardening. The quenching media becomes contaminated with the cyanide used in case hardening and must be disposed of as hazardous waste. Spent quenching oil or wastewater generated in the cyanide heat treating cycle (liquid carburizing or cyaniding) becomes hazardous waste because cyanide salts are transferred to the oil bath or water bath as a result of drag-out. Gas carburizing burns natural gas in a sealed furnace and produces no hazardous waste. Gas nitriding employs ammonia gas to supply the nitrogen and produces no solid hazardous waste.

Some case hardening processes require source materials from which carbon and nitrogen can be generated. After the case hardening is completed, these spent source materials may be hazardous waste.

Salts that contain barium compounds are sources of hazardous waste. These salts are used in high temperature applications such as hardening high-speed steel, hot work steels, and other air hardening tool steels.

Quenching

Quenching is an integral part of liquid carburizing, liquid cyaniding, and liquid nitriding. When the surface of the steel absorbs a sufficient quantity of carbon or nitrogen from a hot molten salt bath, the part is often quenched in mineral oil, paraffin-base oil, water, or brine to develop a hard surface layer. Tool steels that are liquid nitrided are not normally quenched, but are cooled.

Quenching, a cooling operation in metal heat treating, can be accomplished by immersing a hot workpiece in water, oil, polymer solution, or molten salt, depending on the cooling rate required. In spray quenching, streams of quenching liquid are applied to local areas of a hot workpiece at pressures up to 120 psi. Fog quenching is the application of a fine fog or mist of liquid droplets and the gas carrier as cooling agents. Gas quenching cools faster than still air and slower than oil. Water (3 to 5 percent caustic solutions) and brine (5 to 10 percent sodium chloride) are the quenchants most commonly used for carbon steel. A water soluble polymer is sometimes used to modify the quenching rate of a water quench. Oil quenching is less drastic than water quenching and produces less distortion. Commonly used quenchants are mineral oils fortified with nonsaponifiable additives that increase their quenching characteristics and lengthen their useful lives. Parts should never be transferred directly from a cyanide-containing carburizing bath to a nitrate-nitrite quench bath. This can result in a violent reaction and may cause an explosion.

A complete quenching system consists of a work tank or machines, facilities for handling the parts quenched, quenching medium, equipment for agitation, coolers, heaters, pumps and strainers or filters, quenchant supply tank, equipment for ventilation and for protection against hazards, and equipment for automatic removal of scale from tanks. Quenching is a significant source of waste in the heat treating industry. The waste consists of spent quenching media in the form of spent baths and wastewater generated when quenched workpieces are washed to

remove either salt or oil that remains after the quenching process.

Descaling

The intense heat of air or atmosphere in furnaces may cause an oxide scale to form on the surface of workpieces. Before further processing can take place, this scale must be removed. Descaling can be accomplished by abrasive cleaning (sandblasting) or by pickling. In pickling, the workpiece is immersed in a hot acid bath (usually sulfuric, nitric, or hydrochloric acid) to clean the surface of all impurities. The acid dissolves the metal oxide and ferric oxide rust and scale. The workpiece is then rinsed in water to remove the acid and, in some cases, is bathed in oil or another special coating.

Parts Cleaning and Surface Masking

Supportive operations in heat treating (such as parts cleaning or surface masking) generate hazardous waste. Masking by plating prevents carburizing or nitriding of a metal workpiece or selected parts of a workpiece during the heating cycle. Plated deposits of bronze or copper are the most common coatings. Nickel (including electroless nickel), chrome, and silver are effective also, but their higher cost restricts their use to special applications. When the application does not permit the retention of any protective plate on the finished part after heat treating, selection of the coating is important from the standpoint of subsequent stripping. Copper and silver are the easiest to strip; bronze is more difficult. Nickel is very difficult to remove without detrimentally affecting the part. Therefore, copper plating is most widely used.

Cleaning parts is of great concern in plating and case hardening processes. In liquid nitriding processes, for example, all workpieces placed in the bath should be thoroughly cleaned and free of surface oxide, entrapped sand, oil and grease, and metal particles. Either acid pickling or abrasive cleaning is recommended prior to nitriding. Most parts are successfully nitrided immediately after vapor degreasing. However, some machine finishing processes (such as buffing, finish grinding, lapping, and burnishing) may produce surfaces that retard nitriding and result in uneven case depth and distortion even after cleaning.

There are two ways to condition the surfaces of parts finished by such methods. One method consists of vapor degreasing and abrasive cleaning with aluminum oxide grit immediately prior to liquid nitriding (residual grit must be brushed off before parts are loaded into the furnace). The second is to apply a light phosphate coating.

WASTE DESCRIPTION

Spent cyanide baths, spent quenchants, wastewater generated in parts cleaning operations, spent abrasive media, refractory material, and plating generate the most waste in the heat treating industry. The following sections characterize waste from case hardening baths and pots, quenchant baths, and parts cleaning and masking operations.

Case Hardening Baths and Salt Pots

A significant amount of waste is generated in heat treating operations where cyanide-containing baths are used. In normal bath maintenance routines, sludge collected at the bottom of the pot is removed on a daily basis. It is usually spooned from the bottom with a perforated ladle. This sludge must be disposed of and treated as waste. In liquid carburizing, sludge is removed while the furnace is still at idling temperature. The electrodes of internally heated furnaces are scraped clean. As the bath media is depleted, bath pots corrode. To minimize corrosion of the pot at the air-salt interface, salts are completely changed every three or four months.

Quenching

Cyanide salts on the part contaminate the quenching bath, rendering the bath a hazardous waste when spent.

Salt that adheres after the parts reach room temperature must be washed off, usually in water.

Waste is generated in the following form:

- Residue (salt sludge) from oil baths used for quenching cyanided and liquid carburized and nitrided parts

- Spent water and brine quenchants used for liquid cyanided, liquid carburized, and liquid nitrided parts

- Quenching process drag-out waste from other than case hardening processes.

Another source of waste is the quenchant media washing operation. Drag-out in the form of oil is removed from the part by hot water washing. Oil is one of the most commonly used quenchants in the heat treating industry, therefore the quantity of waste oil that needs to be handled as a hazardous waste is subtantial.

Parts Cleaning and Masking

Additional sources of hazardous waste in the heat treating industry are parts cleaning and masking operations. Solvent cleaning, aqueous cleaning, and abrasive cleaning wastes are generated for disposal or treatment.

The most popular masking operation is copper plating. The hazardous wastes generated in this process are identical to metal finishing industry wastes. For more information on the types of hazardous waste generated in plating operations see USEPA *Guides to Pollution Prevention: The Fabricated Metal Industry* (Appendix B), USEPA *Guides to Pollution Prevention: the Metal Finishing Industry* (Appendix B), and DHS, *Waste Audit Study* (1989, 1990).

References

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SECTION 3
WASTE MINIMIZATION OPTIONS FOR METAL CASTING AND HEAT TREATING FACILITIES

Introduction

Management initiative, commitment, and involvement are key elements in any waste reduction program and include activities such as:

- Employee awareness and participation
- Improved operating procedures
- Employee training
- Improved scheduling of processes.

Employee training, awareness, and participation are critically important and can be problematic aspects of waste minimization programs. Employees are often resistant to broadening their roles beyond the traditional concepts of quantity and quality of products produced. Total commitment and support of management and employees are needed for any waste minimization program to succeed. This includes the evaluation, implementation, and maintenance of techniques and technologies to minimize waste. Companies are advised to use mass balances around their facilities and processes to help identify areas where waste is occurring, perhaps unknowingly. The use of good process control procedures to increase process efficiency is also recommended.

Companies should continually educate themselves to keep abreast of improved waste-reducing, pollution-preventing technology. Information sources to help inform companies about such technology include trade associations and journals, chemical and equipment suppliers, equipment expositions, conferences, and industry newsletters. By implementing better technology, companies can often take advantage of the dual benefits of reduced waste generation and a more cost efficient operation.

Metal Casting Industry

The waste reduction options presented below for the metal casting industry include source reduction and recycling.

SOURCE REDUCTION OPTIONS FOR BAGHOUSE DUST AND SCRUBBER WASTE

Alter Raw Materials

The predominant source of lead, zinc, and cadmium in ferrous foundry baghouse dust or scrubber sludge is galvanized scrap metal used as a charge material. To reduce the level of these contaminants, their source must be identified and charge material containing lower concentrations of the contaminants must be acquired. A charge modification program at a large foundry can successfully reduce the lead and cadmium levels in dust collector waste to below EP-toxicity values (Stephens 1988). Foundries need to work closely with steel scrap suppliers to develop reliable sources of high-grade scrap.

Install Induction Furnaces

Induction furnaces offer advantages over electric arc or cupola furnaces for some applications. An induction furnace emits about 75 percent less dust and fumes because of the absence of combustion gases or excessive metal temperatures. When relatively clean scrap material is used, the need for emission control equipment may be minimized. Of course, production operations and process economics must be considered carefully when planning new or retrofit melting equipment. For more information on induction furnaces, refer to USEPA 1985 and Danielson 1973.

RECYCLING OPTIONS FOR BAGHOUSE DUST AND SCRUBBER WASTE

The dust in electric arc furnaces is typically collected in baghouses. Electric arc furnace dust may contain heavy metals such as lead, cadmium, and zinc, which can make it a hazardous waste. The following options focus on recycling heavy metals from steel foundry electric arc furnace dust.

Recycle to the Original Process

Electric arc furnaces (EAFs) generate 1 to 2 percent of their charge into dust or fumes (Chaubal 1982). If the zinc and lead levels of the metal dust are relatively low, return of the dust to the furnace for recovery of base metals (iron, chromium, or nickel) is often feasible. This method may be employed with dusts generated by the production of stainless or alloy steels. However, this method is usually impractical for handling dust associated with carbon steel production because galvanized metal scrap is used. In the production of carbon steels from galvanized scrap, recovered dust tends to be high in zinc.

Many methods have been proposed for flue-dust recycling, including direct zinc recovery (Morris 1985). Most recovery options require the zinc content of the dust to be at least 15 percent, preferably 20 percent, for the operation to be economical. Zinc content can be increased by returning the dust to the furnace from which it is generated. If the dust is injected into the furnace after the charge of scrap metal is melted, temperatures are high enough for most of the heavy metals to fume off. This results in an increased zinc concentration in the dust collected by the scrubbers, electrostatic precipitation systems, or baghouses.

Recycle Outside the Original Process

Waste can be reused outside the original process by reclaiming the zinc, lead, and cadmium concentrated in emission control residuals. The feasibility of such reclamation depends on the cost of dust treatment and disposal, the concentration of metals within the residual, the cost of recovering the metals, and the market price for the metals. While this approach is useful in the nonferrous foundry industry (i.e., brass foundries), its application within gray iron foundries is extremely limited. Some foundries market furnace dust as input to brick manufacturing and other consumer product applications, but product liability limits this option. Pyrometallurgical, rotary kiln, electrothermic shaft furnace, and zinc oxide enrichment recovery methods are described below. Promising processes for zinc recovery are examined in Morris 1985.

Pyrometallurgical Methods. Pyrometallurgical methods for metals recovery are based on the reduction and volatilization of zinc, lead, cadmium, and other components of EAF dust. The chemistry of these processes is described in Kellogg 1966. A reducing environment favors zinc and cadmium oxide vaporization and removal, while an oxidizing environment favors removal of lead by oxide vaporization. Thus, lead is preferentially removed through roasting in air, while the other metals are removed through roasting under reducing conditions (Dressel 1974).

Rotary Kiln Technology. The rotary (or Waelz) kiln can handle a variety of dusts, as well as other materials containing zinc (Morris 1985). This process can simultaneously reduce ferrous iron oxide to solid iron and lead and zinc oxide to their metallic forms, using a reducing atmosphere such as carbon monoxide and hydrogen (Krishnan 1983). Rotary kilns have been used worldwide on many types of zinc-containing materials, thus their operating conditions and costs are well documented (Krishnan 1982). The biggest disadvantage of the rotary kiln is that it must be fairly large to be economically and thermally efficient. Also, chlorine in the EAF dust must be removed through washing or roasting before metallic zinc can be produced.

Electrothermic Shaft Furnace. The electrothermic shaft furnace can extract zinc from a feed containing at least 40 percent of the metal. Typically, agglomerated EAF dust is mixed with other feed to attain this percentage (Bounds 1983 and Miyashita 1976). Zinc is recovered in its metallic form, from which a very salable Prime Western Grade can be made.

Zinc Oxide Enrichment. To recycle dust by direct reduction of oxides, iron oxide is reduced to iron and water using pure hydrogen at a temperature range of 1000 to 1100°C (AFS 1989). Reducing zinc oxide by reacting it with hydrogen requires recycling hydrogen to the furnace in a second pass.

The reduction of zinc oxide produces zinc vapors and steam at 1000 to 1100°C that are removed from the furnace and subjected to an oxidation step. The zinc reacts with water to produce zinc oxide, and hydrogen is recovered and recycled. The zinc oxide produced is separated in a baghouse. The hydrogen containing the steam is further treated for steam condensation, and then the hydrogen is ready for recycling into the furnace.

In lab scale experiments using dust containing 35 to 40 percent iron, the sponge iron contained 58 percent iron and the separated ZnO contained 56 percent zinc. The cadmium and lead were below EP toxicity criteria. The ZnO produced can be used as a crude zinc oxide product for further upgrading. This method of electric arc dust recycling having proved technically feasible, a preliminary design was developed for a prototype system with a capacity of 2.5 tons of dust charged to the furnace in a single batch. The ZnO recovery cost was estimated at $159 per ton of dust.

Recycle to Cement Manufacturer

Silica-based baghouse dust from sand systems and cupola furnaces may be used as a raw material by cement companies (Kelly 1989, AFS 1989). The dust is sent into a primary crusher and then preblended with other components and transferred to a kiln operation. It is envisioned that baghouse dusts may constitute 5 to 10 percent of the raw material used by cement manufacturers in the near future. The use of higher levels may be limited by the adverse effects of the baghouse dust on the setting characteristics of the cement.

SOURCE REDUCTION OPTIONS FOR HAZARDOUS DESULFURIZING SLAG

In the production of ductile iron, it is often necessary to add a desulfurizing agent in the melt to produce the desired casting microstructure. One desulfurization agent commonly used is solid calcium carbide (CaC_2). Calcium carbide is thought to decompose to calcium and graphite. The calcium carbide desulfurization slag is generally removed from the molten iron in the ladle and placed into a hopper. For adequate sulfur removal, calcium carbide must be added in slight excess. Therefore, the slag contains both CaS and CaC_2. Since an excess of CaC_2 is employed to ensure removal of the sulfur, the resulting slag must be handled as a reactive waste. The slag might also be hazardous due to high concentrations of heavy metals.

Treatment of this material normally consists of converting the carbide to acetylene and calcium hydroxide by reacting with water (Stolzenburg 1985). Problems with this method include handling a potentially explosive waste material; generating a waste stream that contains sulfides (due to calcium sulfide in the slag) and many other toxic compounds; and liberating arsine, phosphine, and other toxic materials in the off gas.

Alter Feed Stock

One way to reduce the need for calcium carbide is to reduce the amount of high sulfur scrap used as furnace charge materials. While this method is effective, the ability to obtain a steady supply of high-grade scrap varies considerably, and the economics usually favor a different solution (Stephens 1988).

Alter Desulfurization Agent

To eliminate the use of calcium carbide, several major foundries have investigated the use of alternative desulfurization agents (Stephens 1988). One proprietary process employs calcium oxide, calcium fluoride, and two other materials. Not only is the quality of the iron satisfactory, but the overall process is economically better than carbide desulfurization.

Alter Product Requirements

Quite often, the specifications for a product are based not on the requirements of that product but on what is achievable in practice. When total sulfur removal is required, it is not uncommon that 20 to 30 percent excess carbide is employed. The excess carbide then ends up as slag and creates a disposal problem. If the iron were desulfurized only to the extent actually needed, much of this waste could be reduced or eliminated (Stephens 1988).

Improve Process Control

In an attempt to reduce calcium carbide usage, and hence waste production, improved process controls are being developed that use different ways of introducing

the material into the molten metal (Stephens 1988). Very fine granules, coated granules, and solid rods of calcium carbide have been investigated as ways of controlling the reaction more closely.

RECYCLING OPTIONS FOR HAZARDOUS DESULFURIZING SLAG

Recycle to Process

Because calcium carbide slag is often removed from the metal by skimming, it is not uncommon to find large amounts of iron mixed in with the slag. Depending on the means of removal, this metal will either be in the form of large blocks or small granules. To reduce metal losses, some foundries crush the slag and remove pieces of metal by hand or with a magnet for remelting.

Other foundries have investigated recharging the entire mass to the remelting furnace (Stephens 1988). Inside the furnace, calcium hydroxide forms in the slag as the recycled calcium carbide either removes additional sulfur or is directly oxidized. While this method has been successful, much work still remains to be done. For example, it is not known to what extent the calcium sulfide stays with the slag or how much sulfur is carried in the flue gas and the scrubber system. Initial tests indicate that the sulfur does not concentrate in the metal, so that product quality is not affected.

Recycle to Other Process Lines

Slag from stainless steel melting operations (where Ni, Mo, and Cr metals are used as alloy additions) is hazardous as a result of high nickel and chromium concentrations. Such slag can be recycled as a feed to cupola furnaces (gray iron production line). The cupola furnace slag scavenges trace metals from the induction furnace slag. The resulting cupola slag may be rendered a nonhazardous waste.

SOURCE REDUCTION OPTIONS FOR SPENT CASTING SAND

In most foundries, casting sands are recycled internally until they can no longer be used. At that time, many of the sands, such as those from iron foundries, are landfilled as nonhazardous waste. Casting sands used in the production of brass castings may be contaminated with lead, zinc, and copper condensates and must be disposed of as hazardous waste.

Waste Segregation

A California DHS study (DHS 1989) concluded that a substantial amount of sand contamination comes from mixing shot blast dust with waste sand in brass foundries. In nonferrous foundries, shot blast dust (a hazardous waste stream) should be kept separate from nonhazardous foundry sand waste streams.

The overall amount of sand being discarded can be significantly reduced by implementing the following waste segregation steps:

- Replumbing the dust collector ducting on the casting metal gate cutoff saws to collect metal chips for easier recycling
- Installing a new baghouse on the sand system to separate the sand system dust from the furnace dust
- Installing a new screening system on the main molding sand system surge hopper to continuously clean metal from the sand system
- Installing a magnetic separation system on the shotblast system to allow the metal dust to be recycled
- Changing the core sand knockout procedure to keep this sand from being mixed in with system sand prior to disposal
- Detoxifying sand that remains unusable as a result of size reclassification after sand reclamation.

RECYCLING OPTIONS FOR SPENT CASTING SAND

Screen and Separate Metal from Sand

Most foundries screen used sand before reusing it. Some employ several different screen types and vibrating mechanisms to break down large masses of sand mixed with metal chips. Coarse screens are used to remove large chunks of metal and core butts. The larger metal pieces collected in the screen are usually

remelted in the furnace or sold to a secondary smelter. Increasingly fine screens remove additional metal particles and help classify the sand before it is molded. Some foundries remelt these smaller metal particles; other foundries sell this portion to metal reclaimers. The metal recovered during the screening process is often mixed with coarser sand components or has sand adhering to it. Therefore, remelting these pieces in the furnace generates large amounts of slag, especially when the smaller particles are remelted.

The Chicago Faucet Co., a red brass foundry, reports (AFS 1989) that the material generated from the sand screening system is recycled in a ball mill. All the furnace skims, floor spills, slags, core butts, and tramp metal from screening are dumped into a vibrator. The vibrator feeds a rotating ball mill that pulverizes all materials into very small particles that are discharged to a vibrating trough. This trough feeds an elevator that discharges into a receiving hopper. Pulverized sand and slag pass through a vibrating screen and come out the bottom into a hopper. The material to be recycled goes through an impactor and back across the vibrating screen. More than 95 percent of the remaining clean metallics can be returned to the furnace. The baghouse from the ball mill contains approximately 14 percent copper metallics, which is a waste stream.

Reclaim Metal and Sand

A process for reclaiming metal and sand in brass foundries is shown in Figure 4 (AFS 1989). First the sand is processed to physically remove as much of the brass metal as possible. This material has relatively high value, and constitutes from one-half to two-thirds of the heavy metal in the sand. The physical separation processes include gravity, size, and magnetic separation units (for any iron-based contaminants). The second stage of the process removes the heavy metals found in the fines and the coatings from the sand. The chemical process consists of mineral acid leaching, followed by metal recovery.

According to PMET (Pittsburgh Mineral Environmental Technology), the chemical treatment step decreases the EP or TCLP lead values 50 to 500 times below the present regulatory thresholds. A bleed stream in the chemical process generates spent acid that must be disposed of. However, the end waste stream is reported to be nonhazardous and may have salable value.

Reclaim Sand by Dry Scrubbing/Attrition

This method is widely used, and a large variety of equipment is available with capacities adaptable to most binder systems and foundry operations. Dry scrubbing may be divided into pneumatic, mechanical, and combined thermal-calcining/thermal-dry scrubbing systems.

In pneumatic scrubbing, grains of sand are agitated in streams of air normally confined in vertical steel tubes called cells. The grains of sand are propelled upward and impact each other, thus removing some of the binder. In some systems, grains are impacted against a steel target. Banks of tubes may be used depending on the capacity and degree of cleanliness desired. Retention time can be regulated, and fines are removed through dust collectors. In mechanical scrubbing, available equipment offers foundries a number of options. An impeller may be used to accelerate the sand grains at a controlled velocity in a horizontal or vertical plane against a metal plate. The sand grains impact each other and metal targets, thereby removing some of the binder. The speed of rotation has some control over impact energy. The binder and fines are removed by exhaust systems, and screen analysis is controlled by air gates or air wash separators. Additional equipment options include:

- A variety of drum types with internal baffles, impactors, and disintegrators that reduce lumps to grains and remove binder
- Vibrating screens with a series of decks for reducing lumps to grains, with recirculating features and removal of dust and fines
- Shot-blast cleaning equipment that may be incorporated into other specially designed units to form a complete casting cleaning/sand reclamation unit
- Vibro-energy systems that use synchronous and diametric vibration. Frictional and compressive forces separate binder from the sand grains.

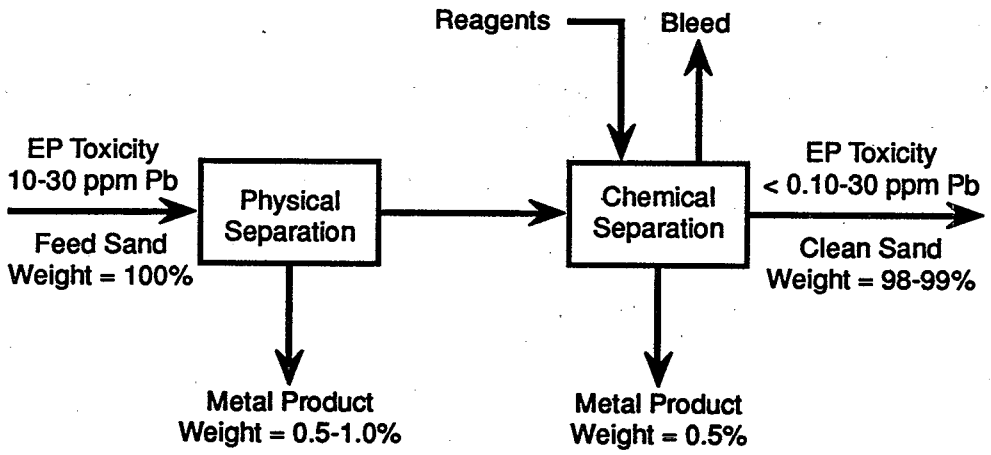

Figure 4. Simplified Process Flow Diagram for Sand Treatment in Brass Foundries (from AFS, 1989)

Reclaim Sand with Thermal Systems

Most foundries recycle core and mold sands; however, these materials eventually lose their basic characteristics, and the portions no longer suitable for use are disposed of in a landfill. In the reclamation of chemically or resin bonded sands, the system employed must be able to break the bond between the resin and sand and remove the fines that are generated. The systems most commonly employed are wet washing and scrubbing for silicate-bonded sands, or dry scrubbing/attrition and thermal (rotary reclamation) systems for resin-bonded sands.

Reclamation of clay-bonded molding sand (green sand) has been practiced on a limited basis in Japan for the past 20 years and is currently being reevaluated in the United States (ASM 1988). Wet reclamation systems employed in the 1950s for handling clay bonded sands are no longer used. Specific thermal reclamation case studies are summarized in AFS 1989. A typical system to reclaim chemically bonded sand for reuse in coreroom and molding operations consists of a lump reduction and metal removal system, a particle classifier, a sand cooler, a dust collection system, and a thermal scrubber (two-bed reactor).

Thermal Calcining/Thermal Dry Scrubbing. These systems are useful for reclamation of organic and clay-bonded systems. Sand grain surfaces are not smooth; they have numerous crevices and indentations. The application of heat with sufficient oxygen calcines the binders or burns off organic binders. Separate mechanical attrition units may be required to remove calcined inorganic binders. Heat offers a simple method of reducing the encrusted grains of molding sand to pure grains. Both horizontal and vertical rotary kiln and fluidized bed systems are available.

Rotary Drum. This system has been used since the 1950s for reclaiming shell and chemically bonded sands. The direct-fired rotary drum is a refractory-lined steel drum that is mounted on casters. The feed end is elevated to allow the sand to flow freely through the unit. The burners can be at either end of the unit with direct flame impingement on the cascading sand; flow can be either with the flow of solids or counter to it.

In indirect-fired units, the drum is mounted on casters in the horizontal position and is surrounded by refractory insulation. Burners line the side of the

drum, with the flames in direct contact with the metal drum. The feed end is elevated to allow the sand to flow freely through the unit, and in some cases flights (paddles connected by chains) are welded to the inside to assist material flow.

Multiple-Hearth Vertical Shaft Furnace. This furnace consists of circular refractory hearths placed one above the other and enclosed in a refractory-lined steel shell. A vertical rotating shaft through the center of the furnace is equipped with air-cooled alloy arms containing rabble blades (plows) that stir the sand and move it in a spiral path across each hearth.

Sand is repeatedly moved outward from the center of a given hearth to the periphery, where it drops through holes to the next hearth. This action gives excellent contact between sand grains and the heated gases. Material is fed into the top of the furnace. It makes its way to the bottom in a zigzag fashion, while the hot gases rise counter-currently, burning the organic material and calcining clay, if one or both are present. Discharge of reclaimed sand can be directly from the bottom hearth into a tube cooler, or other cooling methods may be used. The units are best suited to large tonnages (five tons or more).

New approaches and equipment designed for sand reclamation units are continuing to evolve, and foundries must evaluate each system carefully with regard to the suitability for a particular foundry operation.

Use Sand as a Construction Material

Nonhazardous foundry waste has been used in municipal waste landfills as a supplement for daily earth cover (Smith 1982). This practice has received scrutiny recently because of concerns about mixing industrial and municipal waste and resulting pollution problems. An alternative is using selected foundry wastes for both final cover and as a topsoil substitute for foundry landfills. Another option is to use foundry sand and other waste for construction fill (Smith 1982).

The suitability of these options depends on the physical and chemical nature of the waste; its intended use; the amount of waste to be handled; local market conditions for the waste; and federal, state, and local regulations regarding its handling, storage, and disposal. In addition, some foundries have explored using foundry sand in road beds or to manufacture asphalt and cement, making certain that these options are not considered "use in a manner constituting disposal."

The University of Wisconsin-Madison has performed a substantial amount of research on the suitability of using spent foundry sand as a substitute cover and fill raw material (Engroff et al. 1989, Costello et al. 1983, Stephens et al. 1986, Traeger 1987, and Wellander 1988). TCLP and AFS leaching potential for inorganics and nonvolatile organics were examined, as well as overall physical properties of the samples for use as construction fill. The wastes chosen were from three foundries and included spent system sand and core butts. The binder systems used at these foundries included clay/water, shell, phenolic urethane, sodium silicate, oil, phenol-formaldehyde, and urea-formaldehyde. This research showed that:

- None of the samples leached would be defined as hazardous by RCRA identification criteria.
- The leaching tests showed generally low release of all parameters tested, most at concentrations below drinking water standards
- On the average, only Fe, Mn, and TDS (total dissolved solids) exceeded drinking water standards
- Low levels of TOC (total organic carbon), cyanides, and phenols in leachates suggest there will be little or no problem with organics
- Natural soils leached for comparison released comparable and sometimes higher levels of substances
- Foundry sand leaching characteristics varied little over time and among different waste streams within a given foundry
- Physical properties of foundry sand are appropriate for use as road fill material.

Additional investigations on a wider range of the most commonly used organic binder systems identified by AFS confirmed that no leaching of volatile organics occurred at concentrations above TCLP regulatory levels.

In light of these and other similar findings, a number of states are reexamining their existing solid waste regulations to create special waste categories that will allow nonhazardous materials such as spent foundry sand to be reused beneficially for landfill construction, daily cover, road fill, and construction fill.

Bituminous concrete, commonly called asphalt, is another potential reuse market for foundry waste. Asphalt consists of varying proportions of coarse and fine aggregate and bitumen, a tar-like petroleum-based bonding agent. AFS research (1991) has verified that asphalt made using foundry sand as a partial aggregate replacement will meet standard ASTM specifications. Japanese research (Fujii and Imamura 1980, 1984) has yielded similar findings. In Canada, the Ministry of Transport for the Province of Ontario has been using spent foundry sand in asphalt mixes for nearly 15 years with no deleterious effects, other than a slightly altered surface appearance.

Portland cements are hydraulic cements that react chemically with water to form the bonding agent between the aggregate particles in the production of concrete. Type I (general) cement contains approximately 20 percent silica, 5 percent alumina, and 60 percent quicklime. Raw materials, such as limestone, shale, clay, or sand, are crushed, milled, and mixed. The mixture is then calcined in a high-temperature kiln and pulverized into a fine powder.

Most portions of foundry waste streams could serve as substitute raw materials. Spent sand would provide silica, green sand fines would provide alumina and silica, and slag would provide quicklime and silica. In addition, any organic impurities present would be oxidized during calcination. Foundry wastes have been successfully used as raw material at a cement plan in Davenport, Iowa, where a local foundry sends over 100 cubic yards of waste daily (AFS 1989).

AFS research (1991) has found that use of spent foundry sand in cement manufacturing results in increased compressive strengths over control mixes. This effect increases with the addition of foundry sand. These findings concur with those of Borovskaya (1984) and Mchedlov-Petrosyasn et al. (1983).

AFS research (1991) has also found that using spent foundry sand as a substitute fine aggregate material in the manufacturing of concrete results in decreased compressive strengths when green molding sands are used. This is probably a result of the fines and clay particles, which inhibit bond strength. Nevertheless, many applications for low-strength concrete exist, such as flowable fill, grouts, and sub-bases. Finally, AFS found that using chemically bonded shell sands in concrete mixes slightly increased observed compressive strengths. Additional research is necessary to determine how sands using other types of chemical bonding systems will perform as a concrete fine aggregate.

Heat Treating Industry

SOURCE REDUCTION OPTIONS FOR CASE HARDENING BATHS AND SALT POTS

Oxidation products in cyanide-containing bath media, which is continuously used in case hardening processes (liquid carburizing, cyaniding, and nitriding), deplete the activity of the bath which then becomes hazardous waste. Oxidation products form a hazardous sludge that is removed frequently (in some operations on a daily basis) from the bottom of the pot while the furnace is still at idling temperature. Pots or work-holding fixtures that are in contact with case hardening media undergo corrosion and must be disposed of as hazardous waste every few months to every few years depending upon service. The following options are available to reduce bath and salt pot waste.

Alter Raw Materials (Bath Composition)

In typical liquid carburizing and nitriding processes, molten salts of sodium or potassium cyanides at concentrations of 30% wt and higher are commonly used. Liquid carburizing can be accomplished in a noncyanide bath containing a special grade of carbon instead of cyanide. In such a bath, carbon particles are dispersed in the molten salt of carbonates by mechanical agitation, which is achieved with one or more propeller stirrers that occupy a small fraction of the bath. The chemical reaction is not fully understood, but is thought to involve adsorption of carbon monoxide or carbon particles. Carbon

monoxide is generated by the reaction between the carbon and carbonates, which are major ingredients of the molten salt (ASM 1981).

The adsorbed carbon monoxide is presumed to react with steel surfaces much as in gas or pack carburizing. Case depths and carbon gradients are in the same range as high-temperature cyanide baths, but there is no nitrogen in the case. Temperatures above 954°C produce more rapid carbon penetration and do not adversely affect noncyanide salts because no cyanide is present to break down and cause carbon scum or frothing. Operating temperature is limited primarily by equipment deterioration. Parts that are slowly cooled following noncyanide carburization are more easily machined than parts slowly cooled following cyanide carburization because of the absence of nitrogen in noncyanide-carburized cases.

The increased cost of detoxifying cyanide-containing effluents has led to development of a low-cyanide salt bath for nitrocarburizing treatments. One patented process confers sulfur, nitrogen, and presumably carbon and oxygen to the surfaces of ferrous materials. The process is unique in that lithium salts are incorporated in the bath composition. Cyanide is held at very low levels: 0.1 to 0.5 percent. Sulfur species present in the bath at concentrations of 2 to 10 ppm cause sulfidation to occur simultaneously with nitriding.

Another low-cyanide alternative is using organic polymers for bath regeneration. When water quenching is employed, the low level of cyanide permits easier detoxification. Alternatively, quenching into a caustic-nitrate salt bath at 260 to 424°C may be used for cyanide/cyanate destruction.

Clean All Work Placed in the Bath

To protect the bath from external contamination and to obtain satisfactory case hardening, all work placed in the bath should be thoroughly cleaned and free of scale, oxide, entrapped sand, core material, metal particles, and oil and grease. Acid pickling, abrasive cleaning with aluminum oxide grit, light phosphate coating, or simple vapor degreasing can be used to clean workpieces.

Use Graphite Cover on a Cyanide Bath

To help maintain bath composition and to prolong its lifetime, a graphite cover should be employed on the surface of a cyanide bath. Uncovered baths are exposed to carbonate, which adversely affects bath life and pot life (enhanced corrosion). Artificial graphite covers, free of impurities and sulfur, are best. The higher ash content of natural graphite introduces impurities into the bath. Furthermore, natural graphite that contains sulfur causes corrosion of parts.

Dry Work Completely Prior to Liquid Case Hardening

Loss of bath by spattering during contact with workpieces is avoided if the workpiece is completely dry. Even the slight amount of moisture that may be deposited on parts and fixtures as a result of atmospheric humidity will cause spatter at contact with molten salt.

Remove Impurities

Periodic cleaning increases the longevity of molten baths. Carbonates, the main oxidation products, are readily removed by cooling the bath to 454°C and allowing the precipitated salt to settle to the bottom of the salt pot. Perforated ladles can be used to spoon sludge from the bottom.

Minimize Drag-Out

Drag-out refers to the excess bath media that adheres to the workpiece surface and is carried out of the media upon withdrawal of the workpiece from the bath. Drag-out can be minimized by implementing the following techniques:

- Substituting racks for trays. Tray-type fixtures carry more bath media upon withdrawal from the bath than a rack, and drainage of the drag-out is more difficult.

- Reducing the speed of withdrawal of workpieces from the bath and allowing ample drain time. The faster the workpiece is removed from the bath, the higher the drag-out will be; the

workpiece should be removed as slowly and as smoothly as possible; ample time should be allowed for draining the media back to the tank.

- Proper positioning of the workpiece on the plating rack. The optimal position to minimize drag-out is best determined experimentally, although the following guidelines are effective:
  - — Orient the surface as close to vertical as possible
  - — Position the rack so that the longer dimension of the workpiece is horizontal
  - — Position the rack so that the lower edge is tilted from the horizontal, ensuring that the runoff is from a corner rather than an entire edge.

Replace Pot Lining

Submerged-electrode furnaces will give many years of service in both cyanide and noncyanide operation when ceramic pots are replaced by a modified basic brick.

Alternate Technologies

A number of alternate technologies can be utilized to minimize or totally eliminate hazardous waste in the heat treating industry. These include ion (plasma) nitriding, ion carburizing, and induction heat treatment.

Ion Nitriding and Carburizing. The ion nitriding process uses an electrically charged gas of ions to alloy metal surfaces with nitrogen. The process requires a vacuum vessel in which the workpiece becomes the cathode in a dc circuit. The vessel wall becomes the anode. The vessel is evacuated to remove oxygen and other contaminants, and backfilled with a reactive gas such as an atmosphere containing nitrogen. When the electric power is turned on, the gas becomes ionized. Positive ions strike the workpiece surface and electrons are emitted to the anode producing a glow discharge around the workpiece.

In steel, this process forms a solid solution of nitrogen in the surface or develops a compound layer containing either a gamma prime (Fe_4N) or an epsilon ($Fe_{2-3}N$) crystal structure. The hardness, thickness, and composition of the cases formed can be controlled by varying the temperature, time, gas composition, pressure, voltage, and current.

Frequently the vessel is initially filled with an inert gas. When power is applied, sputtering occurs and the workpiece is cleaned. Since parts can be sputter cleaned in the ion nitriding vessel itself, the need for separate cleaning equipment is eliminated.

Ion nitriding offers numerous advantages over conventional nitriding and carburizing processes.

- Increased Control and Improved Properties. In a conventional nitriding process the furnace is set at 524°C and the operator controls the length of time the workpiece is in the furnace. Dissociation rates for white layer control may also be adjusted by modifying the gas flow rate or by using an external dissociator. The compound layer formed often contains a mixture of the gamma prime and epsilon crystals. It is brittle and tends to spall or chip off during service.

  By contrast, in ion nitriding other parameters such as temperature, time, gas composition, pressure, voltage, and current can be controlled. The process can be used to create a diffusion zone of nitrogen dissolved in the surface layers of the workpiece. The result is surface toughness. By varying the parameters, a diffusion zone and a compound layer of either gamma prime or epsilon crystal structures can be achieved resulting in a surface that is both tough and resistant to wear.

- More Uniform Cases. The glow discharge surrounds the part, forming a more uniform case and making the process ideal for complex parts such as gears, splines, and shafts.

- Negligible Thermal Shock and Distortion. Parts are heated to the desired temperature at a preset rate, thus avoiding the thermal shock and distortion prevalent in a salt bath process. Since ion nitrided parts do not require quench hardening as in carburizing, another source of distortion and cracking is eliminated, as is the waste associated with the quenching operation.

- Broader Treatment Range. The treatment range is 371 to 649°C. The workpiece is heated to the desired temperature using the glow discharge and, in some cases, auxiliary electric-resistance heating elements. Lower temperatures help maintain workpiece dimensions during heat treatment. Keeping the temperatures 24°C or more below the tempering temperature of the steel maintains the core hardness of the parts and eliminates the need for any final heat treatment.

- Faster Cycle Times. Heat treatment cycle times can be 20 to 50 percent shorter and can favorably affect productivity.

- Lower Energy Consumption. Lower temperatures and faster cycle times reduce energy consumption.

- Easier Masking. Mechanical masks are used to leave chosen areas untreated. This avoids masking by electroplating and subsequent stripping procedures.

- Increased Safety. Safety problems associated with the toxic, flammable, or explosive salts or gases used in conventional processes are eliminated.

Ion carburizing is a process similar to ion nitriding in which the surface layers of a part are alloyed with carbon by treating the part in a reaction vessel containing an atmosphere with a high carbon potential. Unlike ion nitriding, which is an accepted commercial process, ion carburizing is still in the development stage.

Induction Hardening. Induction hardening is an attractive and economic alternative to "neutral" hardening in electric or gas furnaces as well as surface hardening operations such as gas, pack, or salt bath carburizing and nitriding. Because no additional carbon (or nitrogen) is introduced during induction hardening, steels used in the process must be selected to have sufficiently high carbon to achieve the desired hardness levels.

Induction heating relies on electrical currents that are induced internally in the workpiece material. These so-called eddy currents dissipate energy and bring about heating. The basic components of an induction heating system are an induction coil, an alternating current (ac) power supply, and the workpiece itself. The coil, which may take different shapes depending on the required heating pattern, is connected to the power supply. The flow of ac current through the coil generates an alternating magnetic field, which cuts through the workpiece. This alternating magnetic field induces eddy currents and heats the workpiece. Moreover, because the magnitude of the eddy currents decreases with distance from the workpiece surface, surface heating and heat treating are possible. In contrast, by allowing sufficient time for heat conduction, relatively uniform heating patterns can be obtained for through heat treating and heating prior to metalworking. Careful attention to coil design and selection of the power supply frequency and rating ensure close control of the heating rate and pattern.

There are several differences between induction and traditional heating techniques. The most significant difference is that induction heat is generated within the workpiece. In furnaces, on the other hand, heat produced by a burning fuel is transported through the furnace atmosphere via convection and radiation. Because heat is generated internally, induction processes do not require a furnace enclosure or a large working area.

By judicious choice of coil design, induction heating can be used to selectively surface harden steel parts, thereby avoiding masking altogether, as well as to carry out uniform surface hardening or through hardening. In addition, dual-frequency induction surface hardening processes have been developed to effect so-called contour hardening for parts such as gears. This type of hardness pattern replicates the uniform case depth pattern obtained from carburizing, nitriding, etc. By contrast, the case depths obtained by this and other induction hardening processes are substantially greater (≈ 0.05 to 0.25 in.) compared to those obtained by carburizing and nitriding (≈ 0.002 to 0.020 in.).

SOURCE REDUCTION OPTIONS FOR QUENCHANT WASTES

Quenching media used in heat treating processes become hazardous waste when exposed to metal

workpieces contaminated with hazardous residues. Cyanide-containing heat treating bath contents are introduced to the quenching media in the form of drag-out residue left on a workpiece after nitriding, carburizing, or cyaniding. Sodium or potassium cyanide salts form insoluble residue while in contact with a mineral oil quenchant or dissolve in an aqueous base quenchant.

Minimize Drag-Out of Molten Salts

Liquid carburizing, liquid cyaniding, and liquid nitriding salts do not dissolve in, or combine with, mineral quenching oils. Salt sludge must be removed periodically either by mechanical means or by filtering through screens.

Salt quench baths also require desludging of contaminants. Carryover of molten salts into brine quench tanks needs to be controlled so that it does not exceed 10 percent of salt concentration.

Minimize Drag-Out of Quenchant

The same waste reduction measures identified for molten salt drag-out apply to the reduction of quenchant drag-out. When quenching oil is used, mechanical removal of surface oil from the workpiece by applying forced air is efficient.

Control Temperature of Oil Quenchant System

As quenching proceeds, heat is removed from the workpieces and the temperature of the quenching oil rises. At high uncontrolled temperatures, oil degradation or oxidation occurs. Carbonaceous deposits on quenched parts (sludging) are symptoms of oil breakdown. This effect might change the cooling rate of the media, causing rejection of treated workpieces. In addition, carbonaceous deposits are difficult and costly to remove. A cooling system should be installed as protection from undesired oil transformations caused by high temperatures.

Use Modified Materials

To minimize degradation of oil quenchant at high temperatures (up to 177°C), mineral oil is fortified with nonsaponifiable additives that increase its quenching effectiveness and lengthen its useful life.

RECYCLING OPTIONS FOR QUENCHANT WASTES

Desludge Quenchant Oil

The lifetime of quenching oil can be prolonged by filtering the oil and recycling it to the original process. The following contaminants should be removed frequently:

- Carbonaceous materials that may be products of oil oxidation or carbon fallout encountered in protective-atmosphere installation
- Scale (metal oxides)
- Sand and other insoluble solids
- Precipitated salts from case hardening baths.

The solids can be best removed by appropriate bypass filters. The most commonly used filtering media are mineral wool and cellulose, which must be replaced and disposed of as hazardous waste once their filtering ability has been exhausted.

Clay filtering media are more expensive, but can be reused after exhaustion by suitable regeneration. The regeneration will not remove scale or sand. Clay media should be carefully selected when fast quenching oils are to be filtered because it is possible to remove the additives along with the undesirable carbonaceous materials. Sintered metal filters that can be cleaned (backwashed) and reused also can be reused.

Magnetic filters or traps and strainers are useful in removing scale and other foreign materials. These types of filters can be easily cleaned and returned to service. They are especially helpful for preventing premature filter clogging and for protecting pumps.

In continuous oil quenching, oil is recycled in a system consisting of the following components:

- Quenchant storage-supply tanks and pumps
- Coolers and heaters to maintain the desired temperature of the quenchant
- Filters to minimize free carbon and other foreign elements

- Agitation equipment to obtain uniform quenching and minimize distortion. Oil is usually agitated by propellers or impeller-type pumps; compressed air is never used for agitation because it creates oil foaming problems.

When molten salts precipitate in the oil bath, periodic desludging is necessary. Screens are usually placed in front of the lines leading to pumps to prevent entry of sludge. The buildup of chlorides carried over from cyanide containing baths into nitrate-nitrite quenchants is undesirable. When chloride is allowed to settle to the bottom of the quench area provided for gravity separation, the chlorides can be collected in sludge pans. Periodically, either the pans are removed or the bottoms of the pans are manually desludged.

Some designs employ continuous filtration of chlorides as the suspended crystals pass through filter baskets. The operator removes the baskets periodically to dump the collected chlorides and then returns them to the furnace. Another technique involves continuous filtering of higher-melting-point salts by pumping the contaminated quench salt through a filter maintained at a lower temperature. The contaminants are deposited on a wire-mesh basket, and the usable salts are returned to the quench tank.

Dewater Quenching Oil

Water in quenching oils results in nonuniform or insufficient hardness of the workpieces. It also creates heavy foaming and increases the fire hazard. Water can be removed from an oil bath by:

- Raising the temperature above the boiling point of water (evaporation)
- Allowing the water to settle and draining it off
- Passing the bath through a centrifuge.

Used quenching oils sometimes emulsify the water content. Such water-containing oils cannot be treated by draining.

Ultrafilter Water-Polymer Quenchants

Water is commonly used for carbon steel quenching. A water soluble polymer is sometimes used to modify the quenching rate of a water quench. If water quenchant is used with a liquid carburizing line, ultrafiltration can be used for continuous salt removal (ASM 1981). The polymers may be precipitated by salt carried into the quench if ultrafiltration is not used.

Economics

The savings associated with many waste reduction measures are strong incentives for their implementation. Less waste means

- Decreased waste management costs. This includes on-site and off-site treatment, storage, disposal, and recycling facility (TSDR) fees; state fees and taxes on generators; transportation costs; and permitting, reporting, and recordkeeping costs.
- Raw material cost savings. Minimizing waste translates into fewer raw materials required per unit of product.
- Insurance and liability savings. This includes reduced liability for eventual remedial cleanup of TSDR facilities. There is also less liability when work place safety is improved.
- Operating cost savings from product quality control. This results from the reduced cost of scrap, rework, rejects, and quality control inspections.

Utilities and overhead costs also can be reduced through waste reduction, although at times, implementation of waste minimization measures can increase costs. Converting from a cyanide to a noncyanide bath in liquid carburizing, for instance, eliminates the cost of cyanide treatment including chemicals, labor, and utilities. Installing a magnetic separation system on the shotblast system to recycle metal dust, however, can increase the cost of electricity.

Many waste reduction measures involve little or no capital cost. Improved operating practices can result in reduced waste management and reduced raw materials costs. While substantial economic benefits can often be realized from waste reduction measures that require no capital expenditures, many measures do

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WORKSHEET
2

WASTE SOURCES

	Significance		
Waste Source: Casting	Low	Medium	High
Baghouse dust			
Slags			
Spent sands			
Combustion emissions			
Waste Source: Heat Treating			
Process baths			
Spills and leaks			
Quenching fluids			
Emission control dust and vapor			
Waste Source: Metal Parts Cleaning and Stripping			
Solvents			
Alkaline wastes			
Acid wastes			
Abrasives			
Waste water			
Air emissions			
Other			
Waste Source: Surface Treatment and Plating			
Spent bath solutions			
Filter waste			
Rinse water			
Spills and leaks			
Solid waste			
Air emissions			
Other			
Waste Source: Other Processes			
Leftover raw materials			
Other process wastes			
Types			
Pollution control residues			
Waste management residues			
Other			

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WORKSHEET
3

WASTE MINIMIZATION: CASTING OPERATIONS

Complete for each furnace

Description of furnace and operation performed: _____

Identification number: _____

Type of metals melted: _____

Additives used: _____

Feed batch or continuous: _____

Size or rate of feed: _____

Method of feed: _____

Method of slag removal: _____

Type of refractory: _____

Replacement frequency of refractory: _____

Type of emission controls: _____

Complete for each type of sand used

Type and amount of sand used per year: _____

Type and amount of binder used per year: _____

Number of castings per year: _____

Of the sand used, what percent is recycled?: _____

What percent ends up as dust?: _____

What type of emission control devices are employed?: _____

For heat-cured or reactive binders, are emissions other than dust produced? _____

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OPTION GENERATION: CASTING OPERATIONS

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Source Reduction Techniques		
Alter Raw Material		
Convert to Induction Furnace		
Use Alternate Desulfurization Agent		
Alter Product Specification		
Improve Process Control		
Keep Waste Segregated		
B. Recycling Techniques		
Charge Dust to Furnace		
Employ Pyrometallurgical Recovery		
Employ Rotary Kiln Technology		
Employ Electrothermic Shaft Process		
Enrich Zinc Oxide		
Sell Dust to Cement Plant		
Screen Metal from Sand		
Reclaim Metal and Sand		
Employ Wet Washing/Scrubbing		
Employ Dry Scrubbing/Attrition		
Employ Thermal Reclamation		
Reuse Treated Sand		
Sell Sand as Fill Material		

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WORKSHEET
5

WASTE MINIMIZATION: HEAT TREATING OPERATIONS

For each heat treatment system provide

Type of system: _____

Size of system: _____

Amount of waste material present: _____

Replacement frequency of material: _____

Type of hazardous material used: _____

Emission controls employed: _____

Method of waste disposal: _____

Type of quenching fluid/method: _____

Replacement frequency of quench bath: _____

How disposed/handled: _____

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OPTION GENERATION: HEAT TREATING OPERATIONS

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Source Reduction Techniques		
Alter Raw Materials		
Clean Parts Before Treatment		
Use Graphite Covers on Cyanide Bath		
Dry Work Before Case Hardening		
Periodically Clean Baths		
Minimize Drag-Out		
Replace Pot Linings		
Control Temperature of Quench Baths		
B. Recycling Techniques		
Desludge Quenchant Oil Baths		
Dewater Quenchant Oil Baths		
Ultrafilter Water Polymer Baths		

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WORKSHEET
7A

WASTE MINIMIZATION: METAL PARTS CLEANING AND STRIPPING

Solvent Cleaning

Are solvents used for cleaning purposes? _____

If so, which of the following are employed?

- ☐ Vapor Degreaser
- ☐ Spray Chamber
- ☐ Covered Solvent Cold Cleaning Tank
- ☐ Uncovered Solvent Cold Cleaning Tank
- ☐ Rag Wipedown
- ☐ Brush Scrubbing
- ☐ Other _____

Spent Chemical	Technique (include number & size)	Annual Usage

How are spent solvents managed?

- ☐ Biodegradable; disposed of in sewer
- ☐ Recycled On Site
- ☐ Recycled Off Site
- ☐ Treated or Incinerated On Site
- ☐ Treated or Incinerated Off Site
- ☐ Other _____

Annual Costs: _____

For on-site recycling, is residue hazardous? _____

How are used rags disposed of? _____

Annual Costs: _____

Aqueous Chemical Cleaning

Are cleaners, strippers, surfactants, and detergents used in the plant?

Types of aqueous cleaners used: _____

Chemical Description	Active Ingredient
☐ Alkaline Surfactant Cleaner	
☐ Alkaline Detergent Cleaner	
☐ Alkaline Stripper	
☐ Acid Cleanser	
☐ Acid Stripper	

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WORKSHEET
7B

WASTE MINIMIZATION: METAL PARTS CLEANING AND STRIPPING

Process Techniques:

Spray Chamber

Air-sparged Bath

Agitated Bath

Sink

Rag Wiping

Brush

Type of Aqueous Cleaner	Technique (include number & size)	Annual Usage
_____	_____	_____
_____	_____	_____
_____	_____	_____

How are spent cleaners managed?

Biodegradable; disposed of in sewer

Transported Off Site

Transported On Site

Annual Costs: _____

Abrasive Cleaning and Stripping

Annual Costs: _____

Describe abrasive cleaning and stripping techniques used (e.g., blasting boxes, buffing machines, etc.):

_____

_____

_____

_____

How are wastes from abrasives techniques managed (e.g., dust, worm discs, etc.): _____

_____

Annual Costs: _____

Water Cleaning

Annual Costs: _____

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WORKSHEET
7C

WASTE MINIMIZATION: METAL PARTS CLEANING AND STRIPPING

Size of Rinse Bath	Application	Continuous or Still Rinse	Temperature	Annual Usage

Are spray rinse techniques used within the plant? _____

Describe spray operations: _____

Is the spray rinsing done in combination with or instead of immersion rinsing? _____

Are spent still rinses used as makeups for the process baths? _____

Is counter-current rinsing employed at the plant? _____

Describe how it is used. (Give the number of tanks in each counter-current series, the flow rates and the process chemicals rinsed from the workpieces.): _____

Water use rate for entire plant rinsing operations: _____

Is deionized water or reverse-osmosis filtered water used for rinsing/cleaning? Where? _____

Is air sparging or mechanical agitation used in the rinse baths? _____

List which technique is used in which bath: _____

Is the spent water recycled or reclaimed? _____

☐ Settled
☐ Filtered
☐ Chemically Classified

Is the spent water treated on site? _____

Is the recycling or treatment residue hazardous? _____

If yes, how is it managed? _____

Waste minimization opportunities in metal parts cleaning and stripping: _____

Potential waste minimization savings of process materials and waste management costs: _____

Comments: _____

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OPTION GENERATION: METAL PARTS CLEANING AND STRIPPING

Meeting format (e.g., brainstorming, nominal group technique) _____
Meeting Coordinator _____
Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Source Reduction Techniques		
General Operating Procedures		
Improve Process Controls		
Provide Operator Training		
Improve Drainage Techniques		
Implement Better Storage and Distribution Measures		
Other		
Solvents		
Use Vapor Degreasers		
Cover Immersion Tanks		
Install Drainboards		
Employ Material Substitution		
Other		
Aqueous Cleaners		
Remove Sludge		
Use Tank Lids		
Other		
Abrasives		
Use Water-Based Binders		
Use Liquid Spray Abrasives		
Preclean Workpieces		
Other		
B. Recycling Techniques		
Solvents		
Filter Solvents		
Distill Solvents		
Abrasives		
Reuse Blasting Media		
Other		

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WASTE MINIMIZATION: METAL SURFACE TREATING AND PLATING

Complete a worksheet for each process tank

Description of tank function: _____

Identification number: _____

Size: _____

Composition of process solution: _____

Temperature: _____

Work volume (square feet of workpiece surface per week): _____

Quantity of make-up chemicals added per week: _____

What chemicals are added?: _____

_____

How much of the make-up volume is due to replenishing drag-out?: _____

Replenishing evaporative losses?: _____

Is deionized or reverse-osmosis filtered water used in the process baths?: _____

Are drag-out reduction techniques employed? _____

Which ones? _____

_____

What is the dump schedule for the process tank? _____

Is the process line manual or automatic? _____

Is rack or barrel plating employed in the tank? _____

What is the production rate of the tank (workpiece surface area per week)? _____

Are baths air sparged or mechanically agitated? _____

Are personnel trained to thoroughly drain workpieces above baths before moving them to another bath? _____

_____

Are they periodically retrained? _____

Are there spaces between process baths and their rinse tanks that allow chemicals to drip on the floor?

_____

Are process baths filtered to remove particulates? _____

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OPTION GENERATION: METAL SURFACE TREATING AND PLATING

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Source Reduction Techniques		
Bath Solution Waste Reduction		
Reduce Drag-Out, Spills, and Leaks		
Provide Efficient Drainage		
Control Viscosity and Surface Tension		
Filter Bath Solutions		
Monitor and Control Bath Solution		
Other		
Rinse System Design		
Incorporate Still Rinse Design		
Employ Counter-Current Rinsing		
Assure Efficient Drainage		
Use No-Rinse Coating		
Other		
Product Substitution		
Substitute Cadmium Plating Alternatives		
Substitute Chromium Plating Alternatives		
Substitute Cyanide Bath Alternatives		
Use Immiscible Rinse		
Other		
B. Recycling Techniques		
Recycle Process Baths		
Recycle Rinsewater		
Other		

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WASTE MINIMIZATION: OTHER PROCESSES

Are any metal oxide wastes generated in welding or soldering operations in your plant? _____

_____ Note: If so, they must be managed as hazardous waste.

Are any hazardous fluxes used in welding or soldering operations?

How are the above wastes managed?

ADDITIONAL PROCESSES THAT GENERATE WASTE

Process	Type of Waste	Annual Amount	Management Method	Annual Cost of Management

Potential source reduction and recycling opportunities: _____

_____

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OPTION GENERATION: OTHER PROCESSES

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Source Reduction Techniques		
B. Recycling Techniques		

Appendix A
METAL CASTING AND HEAT TREATING FACILITY ASSESSMENTS: CASE STUDIES OF PLANTS

In 1990, the California Department of Health Services commissioned a waste minimization study, *Waste Audit Study: Thermal Metal Working Industry*, that included assessments of a nonferrous foundry, a heat treating plant, and a ferrous metal foundry. The objectives of the study were to:

- Investigate current waste reduction methods
- Identify further opportunities to reduce waste.

Results of these waste reduction assessments provide valuable information about the potential for incorporating waste reduction technologies into metal casting and heat treating operations. This appendix presents summaries of the results of the assessments performed by California DHS at three such operations. The summaries presented are largely unedited and should not be taken as recommendations of the USEPA; they are provided as examples only. In addition, the California focus included more than waste reduction alternatives; it also addressed treatment alternatives that would lead to sludge and waste water volume reduction. These recommendations are also included in the following summaries.

The original assessments may be obtained from:

Mr. Benjamin Fries
California Department of Toxic Substances Control
714/744 P Street
Sacramento, CA 94234-7320
(916) 324-1807.

PLANT A WASTE MINIMIZATION ASSESSMENT

Plant A is a brass foundry (SIC 3432) that manufactures cast brass plumbing fixtures. The foundry was built in 1971. Input copper, lead, tin, and zinc for brass manufacturing operations come mainly from recycled automobile radiators.

Process Description

The foundry manufactures 10 to 12 million pounds per year of brass plumbing fixtures. A "semi-red leaded brass" alloy is used, consisting of 79 percent copper, 12 percent zinc, 7 percent lead, and 2 percent tin. Eighty percent of the new feed materials comes from used radiators; the remainder is from Mexican-made ingots. The ingots are frequently out of spec, but are bought in order to keep a second source of materials available.

Channel-type induction furnaces are used in the foundry. Each furnace is heated to 1149°C. There are two furnace lines, only one of which is in use at present. Each line consists of three 450 kW, 10,000 lb capacity melting furnaces arranged in parallel, which feed into a 450 kW, 30,000 lb holding furnace. The holding furnace's function, besides storing the melted metal until it is ready to be poured, is to help homogenize the melt. Output from the holding furnace goes into a 17,000 lb pouring furnace, which is equipped with 50 kW and 200 kW inductors. The pouring furnace is a sealed vessel with a positive air pressure that is used to propel molten metal from furnace to mold. Molten metal is poured into silica sand molds on a moving mold car conveyor. The pour ranges from 15 to 25 lb, depending on the type of castings made. Cooling time is 18 minutes.

The molds use fine (#130) silica sands. The sands are shipped from quarries in Nevada by railroad. The sand is initially white, but develops a black color due to high temperature operations. Clay, cornflour, and wood flour are added during mold making.

Coarse (#55 and #100) sands are used for the mold core. Coarse sand is required to allow gas to escape. Linseed oil is added as a binder, kerosene is added to prevent the core from sticking to the metal, and cornflour is added to give the core strength before it is baked.

Foundry Waste Streams

Hazardous waste streams from foundry operations include:

- Raw slag
- Foundry sand
- Waste casting metal
- Floor sweepings
- Furnace fumes
- Nonfurnace baghouse wastes
- Airborne dust from molding operations

Current Waste Reduction Practices

Most present waste reduction efforts center around reclaiming metal and sand. While many foundries do this to some extent, Plant A's multistage efforts far surpass those of the norm. Plant A is a high-production foundry that must generate as little metal waste as possible to remain profitable. Because of the land ban, and the waste management costs that result from it, Plant A has also been making increased efforts in recent years to reduce the size of its waste streams. Its practices in this regard are documented below.

RAW SLAG

Raw slag from the furnaces is hazardous because of the metals it contains. It is sent to a ball mill after solidifying, which uses cascading steel balls to crush the chunks of slag. It is then sent through an 8 mesh (8 wires per inch) screen. Oversized metal grains caught by the screen are returned to the furnaces for remelting. The undersized stream, consisting of metal and slag, goes to a 20 mesh screen. Again, the oversized metal caught is remelted, while the undersized stream is routed to a 40 mesh screen. Oversized metal caught by this screen is not easily remelted. Fine metal particles with oxide layers on their surfaces

tend to float on the molten slag in the furnace and not melt. Because of this, the 40 mesh metal stream is sent to an off-site metal reclaimer.

The undersized stream that passed through the 40 mesh screen is termed "slag dust," and is sent to an off-site smelter. Metal extracted during smelting is made into ingots, which are bought back by the foundry.

FOUNDRY SAND

Foundry sands are subjected to a series of separation operations for reclaiming both sand and metal. A series of screens passes only the fine sands that are suitable for recycling to molding operations. The oversized stream is termed "raw core butt," and consists of chunks and grains of coarse core sand, as well as metal. This stream is sent through vibrating screens. The oversized stream goes to a ball mill which crushes the core sand chunks, and then through an 8 mesh screen. The oversized "ball mill metal" stream is then sent to a magnetic separator. Any ferrous metals present are removed and sent to an off-site reclaimer. The nonferrous stream is remelted in the furnace.

The undersized stream that passes through the 8 mesh screen goes to a 20 mesh screen. Oversized ball mill metal is remelted. Undersized "dust," until recently, was categorized as hazardous or nonhazardous according to its metal content. Because of the new land disposal restrictions, all of the dust is treated as hazardous. It is presently sent to a TSD facility for stabilization and landfilling. This service costs $300 per ton of waste. Plant A generates 3,000 tons per year of foundry sand dust.

WASTE CASTING METAL

Over half the metal poured into a mold is not a useful part of the casting and needs to be separated from the casting and remelted. For instance, the channel made in the sand that allows metal to pour into the mold fills up with metal that is not in itself a part of the casting. The top of this filled channel is conical and is called a sprue head. Underneath is a filled cylindrical channel called a riser. Underneath the riser are more extraneous pieces of metal, called runners and gates. The term "gates" is also used generically to refer to all of the nonuseful parts of the casting.

Most of the gate material breaks off from the casting during shakeout, is separated on the "sorting and breakoff conveyor" by plant personnel, and is sent back to the furnace. Castings are sent to the wheelabrator, which is a blasting cabinet using steel shot to clean the casting surface. After this, the castings are inspected. Rejects not meeting plant standards are sent for a secondary inspection to determine the reason for substandard casting. This data is communicated to the line foremen, so that methods can be found to reduce rejects in the future. This second level of inspection is not typical of most plants and is an important part of Plant A's waste minimization program. Although most of the metal in a reject casting can be recycled, some metal and sand finds its way into the waste stream.

Good castings are sent to the cutoff and grinding room, where superfluous metal is removed and sent to the furnace. Next the castings go through a wheelabrator and then to the polishing shop for additional cleaning. Operators inspect the castings as they are working on them. Rejects that were missed in the previous inspections are sent to the furnace. The machine shop operators also examine castings and send rejects, plus borings and fines, to the furnace. Castings that pass these inspections go to the plating shop for a surface coating. The castings receive another inspection by the operators handling them. Castings rejected because of bad plating are stripped and replated. If the defect is in the casting itself, it is sent to the furnace. Finally, the castings are sent to the assembly department. Even at this stage, some rejects are identified and sent back to the furnace or plating department.

FLOOR SWEEPINGS

Metallic floor sweepings from the furnace area are sent back to the furnaces for remelting. The metal reclamation methods described above significantly reduce the plant's waste and its operating costs. The financial benefit of internal metal recycling has been shown to be roughly three times that of sending metal to an off-site reclaimer.

FURNACE FUMES

Fumes rich in zinc oxide from the metal melted in the furnaces are collected by baghouses. The foundry has two 63,000 CFM baghouses (one for each furnace line), although only one has been in use in recent years. While sales volume has gone up, the amount of metal feed to the furnaces has been reduced as a result of greater process efficiency. Each baghouse contains 6 sections of bags, which are periodically shaken. The baghouse dust is collected in fiberglass sacks and sold to a fertilizer manufacturer. This company reacts the zinc fraction in the dust with sulfuric acid to produce zinc sulfate. The zinc sulfate is used as an additive for almond tree fertilizer.

NONFURNACE BAGHOUSE WASTES

Plant A has several other baghouse waste streams besides furnace fumes. Airborne dust from the wheelabrator blast cleaning machines is trapped in a 20,000 CFM baghouse and then sent to the TSD to be disposed of as a hazardous waste. Dust from cutoff and grinding operations is very high in metal content and is remelted. As was noted earlier, small particles do not remelt easily if their surfaces are oxidized. The dust from the cutoff and grinding department is not oxidized, however, and thus can be sent to the furnaces.

Airborne dust from coremaking is collected in a 3,500 CFM baghouse, while dust from the sand storage silos is trapped in a small 600 CFM baghouse. These dusts, which were originally clean sand, are sent to sanitary landfills to be disposed of as nonhazardous waste.

AIRBORNE DUST FROM MOLDING OPERATIONS

The airborne dust from sand molding operations is potentially hazardous because of its metal content and because of total suspended particulate (TSP) regulations under the Clean Air Act. Airborne dust from the sand molds is collected by another air emission control system—a "hydrofilter," that includes a wet scrubber and cyclone separators. Dust laden air is passed through venturi rods and into the scrubber. Clean air is vented, after going through de-mist vanes. Liquids are fed into a settling tank, and "mud" settles out (with the aid of polyelectrolytes) onto a conveyer system called a "sludge drag" at the bottom of the tank. The sludge drag conveyer transports mud up an incline and out of the tank, then dumps the mud in a hopper. The mud is reused for making molds. Clean water from the settling tank goes back to the scrubber.

FEED MATERIALS CONTROL

Stringent measures are taken to prevent aluminum from getting into the process streams. Soda cans for instance, are prohibited in the foundry area. This is because a 0.001 percent aluminum content will "poison" the brass and cause leaks in the fixtures manufactured from it.

Future Waste Reduction Alternatives

Plant A has been paying high waste management costs for its spent sands, especially since hazardous waste land disposal restrictions (land ban) have taken effect. Plant A generates 3,000 tons per year of sand wastes. Until the land ban took effect, 1,000 tons were considered hazardous and disposed of at the TSD at a cost of $200 per ton, or $200,000 per year. The remainder was disposed of in a sanitary landfill at a cost of $50 per ton, or $100,000. These costs cover transportation, disposal, and taxes.

Since the land ban has taken effect, the entire 3,000 ton annual waste stream is treated as hazardous and sent to the TSD. Fixation of the metal content is required before landfilling, bringing the total cost of waste management to $300 per ton, or $900,000 annually.

To reduce these costs, Plant A is examining sand reclamation and detoxifying options that it hopes to implement within one year. The options are described below.

THERMAL SAND RECLAMATION

Plant A is planning to install a 927°C thermocalcining reclaimer furnace, to which all waste sands generated in the plant will be added. The furnace will burn off the organic contaminants on the sands over a two-hour cycle. The sand will then be transferred to a pneumatic scrubber that uses a high velocity air stream to smash the sand against a plate. This

operation helps to separate the fines that cannot be recycled from the reusable portion of the sands. The separation process will be completed in a cyclone scrubber. Eighty percent of the sand wastes are expected to be reclaimed and reused for mold and coremaking. The fines, made up of shattered pieces of sand and clay, as well as a metal fraction, will comprise the other 20 percent of the stream.

The cost of this option is $600,000. Plant A has already applied for an operating permit.

DETOXIFICATION OF FINES

Plant A is examining two systems as candidates for detoxifying fines. The first is a thermal process developed by Ceramic Bonding, Inc., of Mountain View, California. It involves mixing the fines with an alumina-silicate clay material and firing the mixture at approximately 1093°C. A ceramic material is produced in which the hazardous metals are physically and chemically bonded to the alumina-silicate matrix. The material has shown excellent resistance to acid leaching, even under extreme pH conditions. The ceramic material can either be disposed of as nonhazardous in a sanitary landfill, or can possibly be marketed as a light-weight construction aggregate. The suitability of this material for construction should be properly researched. As fill, it may be resistant to leaching, according to the tests mentioned. However, as aggregate for concrete, the abrasion during ready-mix preparation may rupture the ceramic particle surface that hinders leaching. There may be other unknowns.

Plant A is also examining an ambient temperature fixation process that employs a cement and silicates mixture. This process also has performed well in acid leaching resistance tests. Both systems are exceptional in that they appear to reliably fixate copper in the sands, which many other methods are not able to do. The payback period for the combination thermal sand reclamation system and detoxification system appears to be approximately one year.

PLANT B WASTE MINIMIZATION ASSESSMENT

Plant B is a commercial heat treating plant (SIC 3398) designed for handling ferrous and nonferrous metal workpieces. The plant employs 140 workers and was established in 1940. Stainless steel, carbon steel, aluminum, and titanium alloys are heat treated at the plant. Machined parts ranging in weight from a few pounds up to 20 tons are delivered for heat treating from numerous suppliers.

This waste minimization assessment focuses on ferrous metal heat treating, which comprises the major share of the plant's business. Heat treating ferrous metals includes the following operations:

- Austenitizing
- Quenching
- Tempering
- Sandblasting
- Aqueous parts cleaning
- Electroplating
- Stripping
- Testing
- Air cooling

Waste minimization measures are included in the following descriptions of these processes.

Austenitizing

Austenitizing is performed in vertical gas-fired gantry type furnaces in a batch mode. The largest parts (missile parts) weigh up to 20 tons and are treated in a special furnace. The furnace has a walking-beam construction consisting of two sets of support rails: one stationary and the other movable. The austenitizing process is performed by heating the part to 885°C for approximately 2.5 hours and subsequently holding the part at this temperature for another 2.5 hours. The temperature is controlled with a thermocouple sensor. The temperature and holding time are the most critical parameters in the austenitizing process. Excessively high austenitizing temperatures or abnormally long holding times may result in distortion, abnormal grain growth, loss of ductility, and low strength. Underheating may result in low hardness and low wear resistance. Gas-fired radiant-tube-heating is used in this process. This method of heating protects the work chamber from the products of natural gas combustion.

Gas-fired furnaces generate a flue gas that is emitted directly to the atmosphere. City water is used to cool the pit that gives access to the walking-beam construction furnace. Because a workpiece is processed without direct contact with the furnace refractory material, no metal oxides or other contaminants are transferred to the water that evaporates from the pit. Thus, the water does not become hazardous waste. The refractory linings of the furnaces were changed once in the past 40 years from asbestos to a fiberglass type of material. No hazardous waste is generated on a continuous basis from this process. Substitution of a nonhazardous lining in furnaces was the only waste minimization measure employed so far in this process. Smaller workpieces are treated in stationary gas-fired Gantry type furnaces that generate the same type of nonhazardous wastes described above.

Quenching

Workpieces can be quenched in one of three separate sumps filled with oil, water, or molten salt media. The largest metal workpieces from walking-beam furnaces are quenched in a sump filled with molten salts of potassium and sodium nitrates. Metal parts are transferred to the sump with an overhead crane. After quenching is completed, the workpieces with their salt residues are returned to the furnace for tempering.

Most carbon steel workpieces are quenched in oil at temperatures from 24 to 60°C. Some stainless steel parts are quenched in the water at ambient temperature. If the same operation was performed with a carbon steel part, it would break as a result of the very drastic quenching environment. Other ferrous alloys are quenched in a molten salt bath at approximately 204°C. All parts quenched in oil are transported by crane to a hot water wash station located in the

INPUT MATERIALS AND WASTE STREAMS

The molten salt quenchant consists of potassium nitrate and sodium nitrate mixed in the proportion of 1:1. Make-up salts are periodically added to the bath to maintain the required volume of quenching media. Since 1971, the molten salt media has not been changed or disposed of. There has been no need to remove solids that have settled since then.

Mineral oil is used as another quenchant. The waste oil is collected in an underground clarifier at a water wash station and removed periodically by a contractor for off-site recycling. An average truckload contains approximately 5 percent oil and 95 percent wastewater. Plant B generates about 4,300 gallons of waste oil every 6 to 7 months.

Water is used as the quenchant where drastic quenching does not result in excessive distortion or cracking of the workpiece. The water quenching sump is very rarely used, and no need for cleaning this sump has been experienced in the last several years.

WASTE REDUCTION ALTERNATIVES

Source reduction measures for quenchant waste could include:

- Substitution of conventional quenching oil for less viscous "fast" quenching oil (a mineral oil blend containing proprietary additives), resulting in decreased drag-out of oil on workpieces and, consequently, lowering oil consumption
- Addition of antioxidants to retard oxidation of the quench oil
- Use of an air blower for mechanical removal of quenchant from the surface of a workpiece
- Increasing drain time of workpieces

Recycling quench oil baths could also minimize waste oil generation and could be achieved by mechanical or thermal conditioning to remove the following contaminants:

- Scale
- Carbonaceous sludges that are products of oil oxidation
- Other insoluble solids, such as sand
- Water
- Soluble compounds, such as carbon dioxide removed in thermal conditioning

Contaminants can be removed by filtering, evaporating, or draining. Solids can best be removed by appropriate bypass filters. The choice of filtering medium for removing solids is important. The most commonly used filtering media are mineral wool and cellulose, which must be replaced after their filtering ability has been exhausted. Clay filtering media are more expensive than the above types, but can be regenerated and reused after exhaustion. However, regeneration will not remove scale or sand. Clay media should be carefully selected when fast quenching oils are to be filtered, because it is possible to remove necessary additives in the oil along with undesirable carbonaceous materials. Sintered metal filters also can be used; these filters can be cleaned and reused.

Magnetic filters, traps, and strainers are useful in removing scale and other foreign materials. These types of filters can be easily cleaned and returned to service. They are especially helpful for preventing premature filter clogging and for protecting pumps.

Water can be removed by filtering or centrifuging, but these methods are expensive and are rarely used. Usually, bulk water is removed by draining and suspended water is removed by heating. Carbon dioxide is also removed by heating.

The waste oil collected in underground clarifiers is sent for off-site recycling. On-site recycling such as gravity oil/water separation and subsequent mechanical/thermal conditioning might be considered for future quench oil recovery.

Tempering

Steel is tempered by reheating the workpiece after quenching to obtain specific values of mechanical properties (e.g., ductility and toughness) and to relieve quenching stresses and ensure dimensional stability. Metal parts, after being quenched, undergo tempering in gas-fired furnaces with forced air atmospheres and temperatures from 371 to 704°C. The flue gas is vented to the atmosphere. No hazardous waste is generated in this process.

Sandblasting

Sandblasting at Plant B is performed indoors in four sandblasting booths. One baghouse collects particulates from all these systems. Twenty-five tons a month of sand is supplied to the location. Spent sand is disposed of off site by the sand supplier.

Future measures for reducing the quantity of spent sand might include:

- Recycling silica-based dust
- Detoxifying hazardous sand with sodium silicate and calcium oxide technology by means of stabilization
- Reducing the use of raw sand by optimizing feed control system

Plating and Stripping

Plating is employed for some parts that must be protected by a coating that is impervious to the carburizing atmosphere in the furnace. Copper plating is widely used for this purpose because it is relatively easy to apply, machinable, noncontaminating to furnace atmospheres, and amenable to stripping by immersing a part in a stripping solution. Most, if not all, of the copper plate may be removed in the course of subsequent machining operations.

Copper electrostriking operations are performed on some steel and other ferrous alloy workpieces to optimize the copper electroplating process, which is performed prior to austenitizing. After this, a metal part typically undergoes austenitizing, molten salt quenching, tempering, air cooling, stripping, sandblasting, and testing.

The following unit operations are performed in sequence at the electroplating/stripping site:

- Alkaline cleaning
- Rinsing with tap water
- Acid cleaning
- Rinsing with tap water
- Striking
- Electroplating
- Stripping

INPUT MATERIALS AND WASTE STREAMS

Input materials include alkaline cleaner, weak acid solution, copper cyanide baths for striking and plating, and copper stripping solution. Alkaline cleaner is employed to remove soil from metal parts, and acidic cleaner is used to remove dust and scale.

All except acidic wastes are collected for batch treatment in a 6,500 gallon tank. One strip tank (1,200 gallons) is emptied every 1 to 1.5 months. The total quantity of hazardous waste generated at this site is equal to approximately 6,500 gallons every three months.

WASTE REDUCTION ALTERNATIVES

On a volume basis, contaminated rinsewater accounts for the majority of plating process waste. Rinsewater is used to wash off the drag-out from a workpiece after it is removed from a bath. By minimizing the amount of drag-out carried from a plating or cleaning bath to a rinsing bath, a smaller amount of water is needed to rinse off the workpiece. As a result, less of the plating solution constituents leave the process, which ultimately produces savings in raw materials and treatment/disposal costs.

Drag-out minimization techniques that can be employed include:

- Reducing the speed of withdrawal of the workpiece from solution and allowing ample drainage time. Usually, 30 seconds allows most of the drag-out to drain back to the tank.

- Using wetting agents to lower the surface tension of plating solutions. Applied in only small amounts, wetting agents can lower solution surface tension enough to reduce drag-out by up to 50 percent. Only nonionic wetting agents, which will not be degraded by electrolysis in the plating bath, should be employed.

- Proper positioning of the workpiece on a plating rack facilitates dripping of drag-out into the bath. The position of any object that will minimize carryover of drag-out is best determined experimentally, although the following guidelines are found to be effective:

  — Orient the surface as close to vertical as possible

  — Position the rack so that the longer dimension of the workpiece is horizontal

  — Position the rack so that the lower edge is tilted from the horizontal to assure that runoff is from a corner rather than an entire edge

For regularly shaped parts that do not contain oddly shaped objects, fog or spray nozzles can be employed to rinse contaminants from the surface. A fog nozzle uses water and air pressure to produce a fine mist. Less water is used than with a conventional spray nozzle. It is possible to use a fog nozzle directly over a heated plating bath to rinse the workpiece. This permits simultaneous rinsing and replenishment of the evaporated losses from the tank.

Spent cleaning solutions might be disposable as nonhazardous wastes if they are kept segregated from plating wastes and neutralized. Another promising waste minimization measure is replacing cyanide plating solutions with cyanide-free pyrophosphate copper plating solutions.

WASTEWATER TREATMENT

Sodium hypochlorite solution is used for batch treatment of wastewater to oxidize the cyanides at alkaline conditions. Treated water is sampled and analyzed for cyanide concentration. Wastewater with a high copper content is then pH-adjusted for optimum $Cu(OH)_2$ precipitation, and pumped to a plate and frame type filter press. Filtrate is discharged to the sewer system. Six to seven drums (500 lbs each) of sludge are disposed of off site as hazardous waste every 2 to 3 months.

Plant B is currently investigating the possibility of off-site copper recovery from the sludge. One option would be to contract these sludges with copper recyclers. Some recyclers specify minimum metal contents in the sludge cake and a minimum tonnage per year for the waste to be accepted for reclamation.

PLANT C WASTE MINIMIZATION ASSESSMENT

Plant C is an iron foundry (SIC 3321) established in 1946. It manufactures gray, ductile, and alloy iron castings from scrap iron including scrap engines. Plant C typically employs 155 workers, although this number can fluctuate up to 320 employees. Daily consumption of scrap metal is estimated at approximately 100 tons per day. Eight hundred tons of waste are generated a month for off-site disposal, including approximately 400 tons of foundry sand and at least 300 tons of refractory material that are disposed of as nonhazardous waste. The balance consists of hazardous waste generated in form of dust and sludge from air emission control systems.

The iron casting process at Plant C consists of the following operations:

- Scrap metal melting
- Core making
- Molding and core setting
- Pouring molten metal
- Shakeout
- Surface cleaning

Some ductile iron castings undergo annealing, a heat treating operation. The foundry produces castings by pouring molten metal into molds consisting of molding sand and core sand. Once the casting has cooled and hardened, it is separated from the mold and core materials in the shakeout process. The castings are cleaned, inspected, and shipped for delivery.

Melting

The foundry employs two types of furnaces for melting scrap metal: five induction furnaces and one cupola furnace.

System No. 1 consists of two "Ni-resist" electric induction furnaces for production of heat resistant alloy. In these, low carbon steel charge is carburized to increase its carbon content; and nickel, molybdenum, and chromium are added. The product castings from these furnaces are classified as heat-resistant iron-based alloys. Total charge to the system is equal to 100 tons per year.

System No. 2 consists of three large induction furnaces with holding capacities of 9, 3.5, and 3.5 tons for production of ductile iron. The feed to this system consists of scrap steel, pig iron returns, granular carbon, silica, and magnesium alloy. The charge is heated electrically to 1593°C.

The cupola furnace at Plant C is used to melt motor blocks. The furnace operates 3 to 4 days a week, 9 hours a day, and has been in operation since 1947 (one of the oldest pieces of equipment at the foundry). It is used for production of gray iron castings. Materials used in the melting operation include scrap metal (such as engine blocks), fluxes, coke, and refractory material.

Fluxes include limestone, fluorspar and soda ash. These are used as conditioners for slag formed in the melted charge to facilitate its removal from the furnace.

The coke is used as a source of fuel for the cupola. Refractory material that can withstand high temperatures is used to line the furnace. The refractory material is subject to deterioration during the foundry process and therefore must be replaced periodically.

WASTE STREAMS

The off gases from the induction furnaces in System No. 2 (ductile iron production) are vented to the atmosphere. Furnace refractory material is disposed of off site as nonhazardous waste. Furnace slag is also disposed of as nonhazardous material.

The off gases from two Ni-resist induction furnaces in System No. 1 (heat resistant alloy production) are vented to the atmosphere. The slag generated in the melting process in these furnaces is classified as hazardous waste because of its heavy metal toxicity characteristics (high nickel and chromium concentrations). An estimated 1 to 2 tons of hazardous slag waste are generated annually. Furnace refractory material from

the Ni-resist furnaces is disposed of as nonhazardous waste.

Wastes generated in cupola melting operations include:

- Dust and sludge from emissions control system
- Slag
- Bottom drop and sweepings
- Spent refractories

The major waste stream from the melting operation is refractory lining. Quantities of more than 300 tons a month are generated. All the waste except refractory linings generated in this process are classified as hazardous.

Emission control residuals are generated at the rate of 1,000 to 1,500 lbs per week. They exceed toxicity characteristics for lead and zinc primarily. Gray iron is melted at approximately 1482°C. The melting points for toxic metals in the furnace is much lower. Lead, for example, melts at 327°C. As the metal feed is melted, the lead, zinc, and cadmium tend to volatilize and are collected by the emission control system. Emissions from cupola furnaces are controlled by a cyclone scrubber, which removes large particulates, and the baghouse, which separates fines.

WASTE REDUCTION ALTERNATIVES

Plant C has implemented two successful waste minimization measures that include:

- On-site recycling of slag from two Ni-resist induction furnaces
- Detoxification of residuals in the cupola furnace emission control system

As of July 1988, Plant C has been recycling the slag from two Ni-resist electric induction furnaces by charging the slag to the cupola furnace.

This slag from Ni-resist furnaces plays the role of scavenger of trace metal elements from the cupola furnace charge. The cupola slag has become a nonhazardous waste since most toxic metals are scavenged from the slag. Forty cubic yards (3-4 tons) of slag a month are sent for application at equestrian trails.

Full-scale experiments on detoxification of residuals from the cyclone scrubber are in progress. Silicate treatment technology is being employed to immobilize heavy metals (Pb, Zn, Cd, and other elements) carried over with flue gases and particulates from the stack of the cupola furnace. A 12.5 percent sodium silicate solution is injected at the rate of 1.5 GPM into the treatment spray nozzle section of the quench zone in the stack, where the temperature exceeds 704°C. Hydrated lime is also added. The chemical costs for this process are estimated at $200 a day.

The total concentration ranges of heavy metals in the wet scrubber residuals before treatment are:

Zn: 500 - 1,595 mg/kg
Pb: 605 - 6,085 mg/kg
Cd: 0.8 - 7.5 mg/kg

Waste extraction test (WET) results after 48 hours of extraction varied as follows on silicate treated materials:

Zn: 0.3 - 44 mg/l
Pb: 20.1 - 230 mg/l
Cd: < 0.1 mg/l

Soluble threshold limit concentrations for metals are as follows:

Zn: 250 mg/l
Pb: 5 mg/l
Cd: 1.0 mg/l

Stack temperature is a critical parameter in the silicate treatment process. Efficiency of treatment increases when temperatures are above 704°C. The cupola furnace stack temperature is unfortunately not stable throughout the process. This results in variance in the efficiency of particulate treatment. The plant is currently attempting to improve this system.

Other possible waste reduction measures under consideration for potential implementation are as follows:

- Off-site recycling to a smelter of lead-containing wastes. The smelter would pick up the material for the cost of $250 per ton.

- Internal recycling by a combination of furnace dust with sand for reuse in the mold making process. Detoxification of sand with sodium silicate and calcium oxide technology followed by formation of a mold with detoxified sand as backing and new sand facing of the mold-metal interface.

Core Making

Core making involves coating a refractory material (silica sand) with binder, compacting the coated sand into the desired shape, and then curing (hardening) the compacted mass so that it can be handled.

Cores are used to produce internal cavities within a casting. The cores are composed of silica sands with small percentages of organic binders. Oil binders and synthetic resin types are used at Plant C. Oil binders are vegetable oils. Resin binders include phenolics and phenol-formaldehydes. Cores must possess the characteristics of strength, hardness, and collapsibility. Often the cores are removed within a casting through a small orifice and, therefore, sand must collapse after the casting solidifies.

The following processes of core making are employed at Plant C:

- Shell core process (heat cured process)
- SO_2 core process (cold box process)
- Core oil process (oven bake heat-cured process)

In the shell core process, precoated shell sand is used. The precoated binder is a synthetic phenol-formaldehyde type of resin. A gas-fired shell core machine is used to form cores at 232°C. This process requires the core box to be heated (177 to 288°C) prior to introduction of the prepared sand.

In the SO_2 core process, the sand is mixed with binder and catalyst. The SO_2 gas activates the catalyst to bind the sand. This cold-cured process utilizes sulfur dioxide gas that is forced through the compacted sand mixture to cure the core.

In the oven bake core process, the sand is mixed with vegetable oil and ferrous oxide. The core box is filled normally with the material, and cores are baked in an oven at 232°C.

WASTE STREAMS

The excess of sulfur dioxide used in the SO_2 core-making process is controlled by the caustic soda scrubber. Fifty percent makeup solution of NaOH is used to replenish the scrubber. Approximately 155 gallons of scrubber waste are generated daily and are discharged to the sanitary sewer system at controlled pH range.

Additional waste streams are handled as follows:

- Shell core machine off gases are vented to the atmosphere
- The core oven gases are combusted in an afterburner
- Solid core wastes are blended with foundry sand and disposed of off site as nonhazardous waste

Mold Making

Molding sand is compacted around a pattern of the casting that is to be produced. Green sand is used at Plant C to form molds.

Green sand is prepared from:

- Green sand mixture (85-95%) - inert silica
- Bentonite clay (4-10%)
- Carbonaceous material (2-10%)
- Water (2-5%)

Sand, clay, water, and carbonaceous materials are charged into the mixing device. These devices are called either mullers or mixers. Three mullers at Plant C prepare the feed for mold making and core setting equipment. Coping/dragging, squeezing, and automatic mold making are used to make molds.

WASTE STREAMS

Waste streams generated in the molding process are in the form of dusts and sludges that have been collected in the air pollution control system. Large sand clumps are also formed that are screened out of the molding sand recycle systems or that are cleaned from the castings.

WASTE REDUCTION ALTERNATIVES

No hazardous waste is generated in the mold making operation. Foundry spent sand is disposed of off site as nonhazardous waste.

Pouring

The molten metal is transported to the pouring area in a transfer ladle, where it is poured into the pouring ladle and into the molds. The poured molds are allowed to cool and the solidified castings are removed from the mold, rough cleaned of mold material, and allowed to cool until the cast metal is cold enough to handle. The smoke emitted is exhausted to the atmosphere. The "sweepings" generated in the pouring process are mixed with foundry sand and disposed off site as nonhazardous waste.

Shakeout

The shakeout process is performed to separate sand from the casting. Sand that has had its binder fully degraded in the pouring process is mixed with molding sand for recycling. The core butts (partially decomposed core sands) are crushed and recycled back into the molding sand process or they are taken directly to the landfill for disposal along with broken or off-spec cores and core recovery sweepings. The molding and core sand wastes account for about 50 percent of the total waste generated by the foundry. The company pays $100,000 a year for sand disposal. The air emission control system consists of four baghouses to collect the foundry sand. The majority of foundry sand is classified and disposed of off site as nonhazardous waste. The sand from System No. 2, with three large induction furnaces, is classified as a hazardous material due to high zinc concentrations. Two hundred pounds per week of hazardous foundry sand are generated in System No. 2 particulate collection equipment.

WASTE REDUCTION ALTERNATIVES

Since 1988, the hazardous sand from System No. 2 has been segregated from other foundry spent sand and recycled as a feed component to the cupola furnace in the quantity of 1,500 lbs per week. This sand becomes a component of the cupola furnace slag and is sold for filling equestrian trails. The company would need to spend $250 per ton for hauling this sand to a smelter if the waste minimization measure was not employed.

Surface Cleaning

Polishing wheels are used to clean castings. The baghouse dust wastes are mixed with foundry sand and disposed of off site as nonhazardous wastes.

Heat Treating

Some ductile iron workpieces undergo an annealing process. Annealing is a heat treating operation. Workpieces are heated to 843°C for six hours and held at this temperature followed by cooling at an appropriate rate, primarily to soften metallic materials. The entire annealing cycle takes from 18 to 24 hours.

Three direct-fired (natural gas fired) box type furnaces operate in batch mode. No hazardous waste is generated in this process. Refractory furnace lining is the only waste generated periodically at this location and is disposed of as nonhazardous waste.

Appendix B
WHERE TO GET HELP: FURTHER INFORMATION ON POLLUTION PREVENTION

Additional information on source reduction, reuse and recycling approaches to pollution prevention is available in EPA reports listed in this section, and through state programs and regional EPA offices (listed below) that offer technical and/or financial assistance in the areas of pollution prevention and treatment.

Waste exchanges have been established in some areas of the U.S. to put waste generators in contact with potential users of the waste. Twenty-four exchanges operating in the U.S. and Canada are listed. Finally, relevant industry associations are listed.

U.S. EPA Reports on Waste Minimization

Facility Pollution Prevention Guide. EPA/600/R-92/088.*

Waste Minimization Opportunity Assessment Manual. EPA/625/7-88/003.*

Waste Minimization Audit Report: Case Studies of Corrosive and Heavy Metal Waste Minimization Audit at a Specialty Steel Manufacturing Complex. Executive Summary. EPA No. PB88-107180.**

Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste for Parts Cleaning and from Electronic Capacitor Manufacturing Operation. Executive Summary. EPA NO. PB87-227013.**

Waste Minimization Audit Report: Case Studies of Minimization of Cyanide Wastes from Electroplating Operations. Executive Summary. EPA No. PB87-229662.**

Report to Congress: Waste Minimization, Vols. I and II. EPA/530-SW-86-033 and -034 (Washington, D.C.: U.S. EPA, 1986).***

Waste Minimization—Issues and Options, Vols. I-III. EPA/530-SW-86-041 through -043. (Washington, D.C.: U.S. EPA, 1986.)***

The Guides to Pollution Prevention manuals* describe waste minimization options for specific industries. This is a continuing series which currently includes the following titles:

Guides to Pollution Prevention: Paint Manufacturing Industry. EPA/625/7-90/005.

Guides to Pollution Prevention: The Pesticide Formulating Industry. EPA/625/7-90/004.

Guides to Pollution Prevention: The Commercial Printing Industry. EPA/625/7-90/008.

Guides to Pollution Prevention: The Fabricated Metal Industry. EPA/625/7-90/006.

Guides to Pollution Prevention for Selected Hospital Waste Streams. EPA/625/7-90/009.

Guides to Pollution Prevention: Research and Educational Institutions. EPA/625/7-90/010.

Guides to Pollution Prevention: The Printed Circuit Board Manufacturing Industry. EPA/625/7-90/007.

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* Available from EPA CERI Publications Unit (513) 569-7562, 26 West Martin Luther King Drive, Cincinnati, OH, 45268.

** Executive Summary available from EPA, CERI Publications Unit, (513) 569-7562, 26 West Martin Luther King Drive, Cincinnati, OH, 45268; full report available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA, 22161.

*** Available from the National Technical Information Service as a five-volume set, NTIS No. PB-87-114-328.

Guides to Pollution Prevention: The Pharmaceutical Industry. EPA/625/7-91/017.

Guides to Pollution Prevention: The Photoprocessing Industry. EPA/625/7-91/012.

Guides to Pollution Prevention: The Fiberglass Reinforced and Composite Plastic Industry. EPA/625/7-91/014.

Guides to Pollution Prevention: The Automotive Repair Industry. EPA/625/7-91/013.

Guides to Pollution Prevention: The Automotive Refinishing Industry. EPA/625/7-91/016.

Guides to Pollution Prevention: The Marine Maintenance and Repair Industry. EPA/625/7-91/015.

Guides to Pollution Prevention: Mechanical Equipment Repair Shops.

Guides to Pollution Prevention: The Metal Finishing Industry.

U.S. EPA Pollution Prevention Information Clearing House (PPIC): *Electronic Information Exchange System (EIES)—User Guide, Version 1.1.* EPA/600/9-89/086.

Waste Reduction Technical/ Financial Assistance Programs

The EPA Pollution Prevention Information Clearinghouse (PPIC) was established to encourage waste reduction through technology transfer, education, and public awareness. PPIC collects and disseminates technical and other information about pollution prevention through a telephone hotline and an electronic information exchange network. Indexed bibliographies and abstracts of reports, publications, and case studies about pollution prevention are available. PPIC also lists a calendar of pertinent conferences and seminars, information about activities abroad, and a directory of waste exchanges. Its Pollution Prevention Information Exchange System (PIES) can be accessed electronically 24 hours a day without fees.

For more information contact:

PIES Technical Assistance
Science Applications International Corp.
8400 Westpark Drive
McLean, VA 22102
(703) 821-4800

or

U.S. Environmental Protection Agency
401 M Street S.W.
Washington, D.C. 20460

Myles E. Morse
Office of Environmental Engineering and Technology Demonstration
(202) 475-7161

Priscilla Flattery
Pollution Prevention Office
(202) 245-3557

The EPA's Office of Solid Waste and Emergency Response has a telephone call-in service to answer questions regarding RCRA and Superfund (CERCLA). The telephone numbers are:

(800) 242-9346 (outside the District of Columbia)

(202) 382-3000 (in the District of Columbia)

The following programs offer technical and/or financial assistance for waste minimization and treatment.

Alabama

Hazardous Material Management and Resource Recovery Program
University of Alabama
P.O. Box 6373
Tuscaloosa, AL 35487-6373
(205) 348-8401

Department of Environmental Management
1751 Federal Drive
Montgomery, AL 36130
(205) 271-7914

Alaska
Alaska Health Project
Waste Reduction Assistance Program
431 West Seventh Avenue, Suite 101
Anchorage, AK 99501
(907) 276-2864

Arizona
Arizona Department of Economic Planning and Development
1645 West Jefferson Street
Phoenix, AZ 85007
(602) 255-5705

Arkansas
Arkansas Industrial Development Commission
One State Capitol Mall
Little Rock, AR 72201
(501) 371-1370

California
Alternative Technology Section
Toxic Substances Control Division
California State Department of Health Services
714/744 P Street
Sacramento, CA 94234-7320
(916) 324-1807

Pollution Prevention Program
San Diego County Department of Health Services
Hazardous Materials Management Division
P.O. Box 85261
San Diego, CA 92186-5261
(619) 338-2215

Colorado
Division of Commerce and Development Commission
500 State Centennial Building
Denver, CO 80203
(303) 866-2205

Connecticut
Connecticut Hazardous Waste Management Service
Suite 360
900 Asylum Avenue
Hartford, CT 06105
(203) 244-2007

Connecticut Department of Economic Development
210 Washington Street
Hartford, CT 06106
(203) 566-7196

Delaware
Delaware Department of Community Affairs & Economic Development
630 State College Road
Dover, DE 19901
(302) 736-4201

District of Columbia
U.S. Department of Energy
Conservation and Renewable Energy
Office of Industrial Technologies
Office of Waste Reduction, Waste Material Management Division
Bruce Cranford CE-222
Washington, DC 20585
(202) 586-9496

Pollution Control Financing Staff
Small Business Administration
1441 "L" Street, N.W., Room 808
Washington, DC 20416
(202) 653-2548

Florida
Waste Reduction Assistance Program
Florida Department of Environmental Regulation
2600 Blair Stone Road
Tallahassee, FL 32399-2400
(904) 488-0300

Georgia
Hazardous Waste Technical Assistance Program
Georgia Institute of Technology
Georgia Technical Research Institute
Environmental Health and Safety Division
O'Keefe Building, Room 027
Atlanta, GA 30332
(404) 894-3806

Environmental Protection Division
Georgia Department of Natural Resources
205 Butler Street, S.E., Suite 1154
Atlanta, GA 30334
(404) 656-2833

Guam
Solid and Hazardous Waste Management Program
Guam Environmental Protection Agency
IT&E Harmon Plaza, Complex Unit D-107
130 Rojas Street
Harmon, Guam 96911
(671) 646-8863-5

Hawaii
Department of Planning & Economic Development
Financial Management and Assistance Branch
P.O. Box 2359
Honolulu, HI 96813
(808) 548-4617

Idaho
IDHW-DEQ
Hazardous Materials Bureau
450 West State Street, 3rd Floor
Boise, ID 83720
(208) 334-5879

Illinois
Hazardous Waste Research and Information Center
Illinois Department of Energy and Natural Resources
One East Hazelwood Drive
Champaign, IL 61820
(217) 333-8940

Illinois Waste Elimination Research Center
Pritzker Department of Environmental Engineering
Alumni Memorial Hall, Room 103
Illinois Institute of Technology
3201 South Dearborn
Chicago, IL 60616
(312) 567-3535

Indiana
Environmental Management and Education Program
School of Civil Engineering
Purdue University
2129 Civil Engineering Building
West Lafayette, IN 47907
(317) 494-5036

Indiana Department of Environmental Management
Office of Technical Assistance
P.O. Box 6015
105 South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-8172

Iowa
Center for Industrial Research and Service
Iowa State University
Suite 500, Building 1
2501 North Loop Drive
Ames, IA 50010-8286
(515) 294-3420

Iowa Department of Natural Resources
Air Quality and Solid Waste Protection Bureau
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319-0034
(515) 281-8690

Waste Management Authority
Iowa Department of Natural Resources
Henry A. Wallace Building
900 East Grand
Des Moines, IA 50319
(515) 281-8489

Iowa Waste Reduction Center
University of Northern Iowa
75 Biology Research Complex
Cedar Falls, IA 50614
(319) 273-2079

Kansas
Bureau of Waste Management
Department of Health and Environment
Forbes Field, Building 730
Topeka, KS 66620
(913) 269-1607

Kentucky
Division of Waste Management
Natural Resources and Environmental Protection Cabinet
18 Reilly Road
Frankfort, KY 40601
(502) 564-6716

Kentucky Partners
Room 312 Ernst Hall
University of Louisville
Speed Scientific School
Louisville, KY 40292
(502) 588-7260

Louisiana
Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 44307
Baton Rouge, LA 70804
(504) 342-1354

Maine
State Planning Office
184 State Street
Augusta, ME 04333
(207) 289-3261

Maryland
Maryland Hazardous Waste Facilities Siting Board
60 West Street, Suite 200 A
Annapolis, MD 21401
(301) 974-3432

Massachusetts
Office of Technical Assistance
Executive Office of Environmental Affairs
100 Cambridge Street, Room 1904
Boston, MA 02202
(617) 727-3260

Source Reduction Program
Massachusetts Department of Environmental Quality Engineering
1 Winter Street
Boston, MA 02108
(617) 292-5982

Michigan
Resource Recovery Section
Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909
(517) 373-0540

Minnesota
Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road
St. Paul, MN 55155
(612) 296-6300

Minnesota Technical Assistance Program
1313 5th Street, S.E., Suite 207
Minneapolis, MN 55414
(612) 627-4646
(800) 247-0015 (in Minnesota)

Mississippi
Waste Reduction & Minimization Program
Bureau of Pollution Control
Department of Environmental Quality
P.O. Box 10385
Jackson, MS 39289-0385
(601) 961-5190

Missouri
State Environmental Improvement and Energy Resources Agency
P.O. Box 744
Jefferson City, MO 65102
(314) 751-4919

Waste Management Program
Missouri Department of Natural Resources
Jefferson Building, 13th Floor
P.O. Box 176
Jefferson City, MO 65102
(314) 751-3176

Nebraska
Land Quality Division
Nebraska Department of Environmental Control
Box 98922
State House Station
Lincoln, NE 68509-8922
(402) 471-2186

Hazardous Waste Section
Nebraska Department of Environmental Control
P.O. Box 98922
Lincoln, NE 68509-8922
(402) 471-2186

New Jersey
New Jersey Hazardous Waste Facilities Siting Commission
Room 514
28 West State Street
Trenton, NJ 08625
(609) 292-1459
(609) 292-1026

Hazardous Waste Advisement Program
Bureau of Regulation and Classification
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625
(609) 292-8341

Risk Reduction Unit
Office of Science and Research
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625
(609) 292-8341

New Mexico
Economic Development Department
Bataan Memorial Building
State Capitol Complex
Santa Fe, NM 87503
(505) 827-6207

New York
New York Environmental Facilities Corporation
50 Wolf Road
Albany, NY 12205
(518) 457-4222

North Carolina
Pollution Prevention Pays Program
Department of Natural Resources and Community Development
P.O. Box 27687
512 North Salisbury Street
Raleigh, NC 27611-7687
(919) 733-7015

Governor's Waste Management Board
P.O. Box 27687
325 North Salisbury Street
Raleigh, NC 27611-7687
(919) 733-9020

Technical Assistance Unit
Solid and Hazardous Waste Management Branch
North Carolina Department of Human Resources
P.O. Box 2091
306 North Wilmington Street
Raleigh, NC 27602
(919) 733-2178

North Dakota
North Dakota Economic Development Commission
Liberty Memorial Building
State Capitol Grounds
Bismarck, ND 58505
(701) 224-2810

Ohio
Division of Hazardous Waste Management
Division of Solid and Infectious Waste Management
Ohio Environmental Protection Agency
P.O. Box 0149
1800 Watermark Drive
Columbus, OH 43266-0149
(614) 644-2917

Oklahoma
Industrial Waste Elimination Program
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
(405) 271-7353

Oregon
Oregon Hazardous Waste Reduction Program
Department of Environmental Quality
811 Southwest Sixth Avenue
Portland, OR 97204
(503) 229-5913
(800) 452-4011 (in Oregon)

Pennsylvania
Pennsylvania Technical Assistance Program
501 F. Orvis Keller Building
University Park, PA 16802
(814) 865-0427

Center of Hazardous Material Research
Subsidiary of the University of Pittsburgh Trust
320 William Pitt Way
Pittsburgh, PA 15238
(412) 826-5320
(800) 334-2467

Puerto Rico
Government of Puerto Rico
Economic Development Administration
Box 2350
San Juan, PR 00936
(809) 758-4747

Rhode Island
Hazardous Waste Reduction Section
Office of Environmental Management
83 Park Street
Providence, RI 02903
(401) 277-3434
(800) 253-2674 (in Rhode Island)

South Carolina
Center for Waste Minimization
Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
(803) 734-4715

South Dakota
Department of State Development
P.O. Box 6000
Pierre, SD 57501
(800) 843-8000

Tennessee
Center for Industrial Services
University of Tennessee
Building #401
226 Capitol Boulevard
Nashville, TN 37219-1804
(615) 242-2456

Bureau of Environment
Tennessee Department of Health and Environment
150 9th Avenue North
Nashville, TN 37219-5404
(615) 741-3657

Tennessee Hazardous Waste Minimization Program
Tennessee Department of Economic and Community Development
Division of Existing Industry Services
7th Floor, 320 6th Avenue, North
Nashville, TN 37219
(615) 741-1888

Texas
Texas Economic Development Authority
410 East Fifth Street
Austin, TX 78701
(512) 472-5059

Utah
Utah Division of Economic Development
6150 State Office Building
Salt Lake City, UT 84114
(801) 533-5325

Vermont
Economic Development Department
Pavilion Office Building
Montpelier, VT 05602
(802) 828-3221

Virginia
Office of Policy and Planning
Virginia Department of Waste Management
11th Floor, Monroe Building
101 North 14th Street
Richmond, VA 23219
(804) 225-2667

Washington
Hazardous Waste Section
Mail Stop PV-11
Washington Department of Ecology
Olympia, WA 98504-8711
(206) 459-6322

West Virginia
Governor's Office of Economics and Community Development
Building G, Room B-517
Capitol Complex
Charleston, WV 25305
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Wisconsin
Bureau of Solid Waste Management
Wisconsin Department of Natural Resources
P.O. Box 7921
101 South Webster Street
Madison, WI 53707
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Wyoming
Solid Waste Management Program
Wyoming Department of Environmental Quality
Herschler Building, 4th Floor, West Wing
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Waste Exchanges

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Mr. William C. Kay
Alberta Research Council
P.O. Box 8330
Postal Station F
Edmonton, Alberta
CANADA T6H 5X2
(403) 450-5408

British Columbia Waste Exchange
Ms. Judy Toth
2150 Maple Street
Vancouver, B.C.
CANADA V6J 3T3
(604) 731-7222

California Waste Exchange
Mr. Robert McCormick
Department of Health Services
Toxic Substances Control Program
Alternative Technology Division
P.O. Box 942732
Sacramento, CA 94234-7320
(916) 324-1807

Canadian Chemical Exchange*
Mr. Philippe LaRoche
P.O. Box 1135
Ste-Adele, Quebec
CANADA J0R 1L0
(514) 229-6511

Canadian Waste Materials Exchange
ORTECH International
Dr. Robert Laughlin
2395 Speakman Drive
Mississauga, Ontario
CANADA L5K 1B3
(416) 822-4111 (Ext. 265)
FAX: (416) 823-1446

Enstar Corporation*
Mr. J. T. Engster
P.O. Box 189
Latham, NY 12110
(518) 785-0470

Great Lakes Regional Waste Exchange
400 Ann Street, N.W., Suite 204
Grand Rapids, MI 49504
(616) 363-3262

Indiana Waste Exchange
Dr. Lynn A. Corson
Purdue University
School of Civil Engineering
Civil Engineering Building
West Lafayette, IN 47907
(317) 494-5036

Industrial Materials Exchange
Mr. Jerry Henderson
172 20th Avenue
Seattle, WA 98122
(206) 296-4633
FAX: (206) 296-0188

Industrial Materials Exchange Service
Ms. Diane Shockey
P.O. Box 19276
Springfield, IL 62794-9276
(217) 782-0450
FAX: (217) 524-4193

Industrial Waste Information Exchange
Mr. William E. Payne
New Jersey Chamber of Commerce
5 Commerce Street
Newark, NJ 07102
(201) 623-7070

Manitoba Waste Exchange
Mr. James Ferguson
c/o Biomass Energy Institute, Inc.
1329 Niakwa Road
Winnipeg, Manitoba
CANADA R2J 3T4
(204) 257-3891

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Mr. Don Ingles
Montana Chamber of Commerce
P.O. Box 1730
Helena, MT 59624
(406) 442-2405

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Mr. Gary J. Olson
c/o NHRRA
P.O. Box 721
Concord, NH 03301
(603) 224-6996

Northeast Industrial Waste Exchange, Inc.
Mr. Lewis Cutler
90 Presidential Plaza, Suite 122
Syracuse, NY 13202
(315) 422-6572
FAX: (315) 422-9051

Ontario Waste Exchange
ORTECH International
Ms. Linda Varangu
2395 Speakman Drive
Mississauga, Ontario
CANADA L5K 1B3
(416) 822-4111 (Ext. 512)
FAX: (416) 823-1446

Pacific Materials Exchange
Mr. Bob Smee
South 3707 Godfrey Boulevard
Spokane, WA 99204
(509) 623-4244

Peel Regional Waste Exchange
Mr. Glen Milbury
Regional Municipality of Peel
10 Peel Center Drive
Brampton, Ontario
CANADA L6T 4B9
(416) 791-9400

RENEW
Ms. Hope Castillo
Texas Water Commission
P.O. Box 13087
Austin, TX 78711-3087
(512) 463-7773
FAX: (512) 463-8317

San Francisco Waste Exchange
Ms. Portia Sinnott
2524 Benvenue #35
Berkeley, CA 94704
(415) 548-6659

Southeast Waste Exchange
Ms. Maxie L. May
Urban Institute
UNCC Station
Charlotte, NC 28223
(704) 547-2307

Southern Waste Information Exchange
Mr. Eugene B. Jones
P.O. Box 960
Tallahassee, FL 32302
(800) 441-SWIX (7949)
(904) 644-5516
FAX: (904) 574-6704

Tennessee Waste Exchange
Ms. Patti Christian
226 Capital Boulevard, Suite 800
Nashville, TN 37202
(615) 256-5141
FAX: (615) 256-6726

Wastelink, Division of Tencon, Inc.
Ms. Mary E. Malotke
140 Wooster Pike
Milford, OH 45150
(513) 248-0012
FAX: (513) 248-1094.

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San Francisco, CA 94105
(415) 744-1305

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Seattle, WA 98101
(206) 442-5810

Industry & Trade Associations

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Des Plaines, IL 60016-8399
(708) 824-0181

ASM International
Materials Park, OH 44073
(216) 338-5151

Ductile Iron Society
28938 Lorain Road
North Olmstead, OH 44070
(216) 734-8040

Investment Casting Institute
8350 North Central Expressway
Suite M-1110
Dallas, TX 75206-1602
(214) 368-8896

Metal Treating Institute
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Jacksonville Beach, FL 32250
(904) 249-0448

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455 State Street, Suite 100
Des Plaines, IL 60016
(708) 299-0950

North American Die Casting Association
2000 North Fifth Avenue
River Grove, IL 60171-1992
(708) 452-0700

Steel Founder's Society of America
Cast Metals Federation Building
455 State Street
Des Plaines, IL 60016
(708) 299-9160

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